DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
SPORT SCIENCES
2018

Stig Haugsbø Andersson

Injury prevention in elite handball

NORWEGIAN SCHOOL
OF SPORT SCIENCES

nih.no

Oslo Sports Trauma
RESEARCH CENTER

Stig Haugsbø Andersson

Injury prevention in elite handball

DISSERTATION FROM THE NORWEGIAN SCHOOL OF SPORT SCIENCES • 2018

ISBN 978-82-502-0553-6

In loving memory of my dad

Lars Gunnar Andersson

(23.12.1957 – 01.07.2014)

Table of contents

Acknowledgements

Two separate research projects constitute the foundation of this dissertation. The first project (Paper I, II and III) was carried out at the Oslo Sports Trauma Research Center (OSTRC), Norwegian School of Sport Sciences, Oslo, Norway, and the second project (Paper IV) was the result of a collaboration between the OSTRC and the Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar. These projects and the four papers arising from them would be impossible to complete without the efforts and contribution of many people, of whom I am deeply grateful. First and foremost, I would like to express my sincere gratitude to my supervisors, Professor Grethe Myklebust, PT PhD, and Professor Roald Bahr, MD PhD.

Grethe, thank you for extensive support and guidance over the past four years. I cannot state strongly enough how important your understanding and support was when my dad passed away, nor how privileged I feel to have had you as my main supervisor. Thank you for involving me in your work with the Norwegian Handball Federation and for all the opportunities you have provided me. Your enthusiasm and efforts to change the culture of injury prevention in handball have truly inspired me, and I hope we will continue this work together.

Roald, your steady guidance and immense knowledge have been invaluable for me as a PhD student. Thank you for motivating me to aim high, for pushing me through constructive feedback and for always providing precise responses to my manuscripts. Thank you for believing in me and providing me with knowledge to develop as a researcher. It has been a true privilege to work with you.

I would also like to express my sincere gratitude to my mentor, Dr Ben Clarsen, PT PhD. Thank you for always finding time to share your expertise on research methods, data management and statistical analysis. I am truly grateful for your thorough input on manuscripts and presentations, and you have truly inspired and motivated me during my time as a PhD student.

I have had the privilege of working with several co-authors and would like to thank them for their prompt and constructive feedback: Magnus Johnsen Olsen, Nebojsa Popovic, and Rod Whiteley. Special thanks to Ben Clarsen, who has been extensively involved in all phases of Paper I and II, to Tone Bere, who lead the consensus meeting and contributed to the data management in Paper IV, and to Marco Cardinale, Clint Hansen and Fernando Sanz Lopez, who were responsible for preparation of the video material in Paper IV.

To the people sharing their clinical expertise to develop the exercise programme in Paper I, my sincere thanks for providing essential input and willingness to contribute: Marte Fagerheim, Hilde Fredriksen, Jan Henning Løken, Harald Markussen, and Tom Morten Svendsen.

To the people who constituted the expert panels in Paper IV, thank you for contributing with your experience and evaluating the video material: Marco Cardinale, Grethe Myklebust, Øistein Pettersen, Nebojsa Popovic, Tom Morten Svendsen, Per Morten Sødal, and Øyvind Togstad.

Thank you to all who assisted in the data collection, without your efforts and persistent work the projects would be impossible to complete: Arnulf Aune, Even Eide Eriksen, Marte Fagerheim, Daniel Høgli Major, Magnus Johnsen Olsen, Rikke Munk Kristensen, Runa Nesje, Kirsty Arbuthnott Røed, Arnhild Skjølberg, Camilla Skovly, Karin Söderström, Helene Kværne Vileid, and Ola Tveitan Østvold.

Professors Ingar Morten Holme and Morten Wang Fagerland, thank you for sharing your expertise on statistics during my PhD period.

I would also like to express my gratitude to all players and coaches who participated in the projects, as well as the team medical staff. Particular thank you to the Norwegian Handball Federation for being positive and willing to support our work.

I am honoured to be a member of the Oslo Sports Trauma Research Center and have truly enjoyed working at the Department of Sports Medicine at the Norwegian School of Sport Sciences. Special thanks to Sigmund Alfred Anderssen, Solveig Sunde and Tone Øritsland for great leadership and administration. You make SIM a great place to work. To all my previous and present colleagues at SIM, thank you for creating a positive and stimulating research culture. Special thanks to Merete Møller, who has shared her research experience on handball players, to Nils Fredrik Holm Moseid, who has been my supportive "office roomie", and to Joar Harøy, for insightful discussions on injury prevention research.

To my friends and family, I am sincerely grateful for your patience and support over the past four years. I would particularly like to thank my dad, Lars, for always believing in me and motivating me to continue this PhD period, even when he was at his weakest. Your enthusiasm for handball has been a great inspiration for me and I wish you could have witnessed me finishing my work. I dedicate this dissertation to you.

Dear Marte, my beloved wife and mother of our lovely Thelma, words cannot describe how grateful I am for your patience, support and care during these intense years. From the moment we met, you have showed a genuine interest in my work and I have benefitted greatly from your experience as a sports physiotherapist working with handball players. Thank you for sharing your expertise when we developed the exercise programme in Paper I and for assisting in the data collection in Paper II. But most importantly, thank you for being my safe haven, for reminding me to enjoy life, for always making me laugh, and for all the fantastic (and therapeutic) travels we have experienced together. You and Thelma mean the world to me – IFLY!

Stig Haugsbø Andersson

Oslo, February 2018

The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic Committee & Confederation of Sport, and Norsk Tipping AS.

List of papers

This dissertation is based on the following papers, which are referred to in the text by their Roman numerals:

I. Andersson SH, Bahr R, Clarsen B, Myklebust G. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. Br J Sports Med 2017;51:1073-1080

II. Andersson SH, Bahr R, Clarsen B, Myklebust G. Risk factors for overuse shoulder injuries in a mixed-sex cohort of 329 elite handball players: previous findings could not be confirmed. Br J Sports Med. Published Online First: 07 August 2017. doi: 10.1136/bjsports-2017-097648

III. Andersson SH, Bahr R, Olsen MJ, Myklebust G. Attitudes, beliefs and behaviour towards shoulder injury prevention in elite handball: fertile ground for implementation. Submitted Br J Sports Med, 27 February 2018.

IV. Andersson SH, Cardinale M, Whiteley R, Popovic N, Hansen C, Sanz Lopez F, Bere T, Bahr R, Myklebust G. Video analysis of acute injuries and referee decisions during the 24th Men´s handball world championship 2015 in Qatar. Submitted Scand J Med Sci Sports, 16 June 2017. Revision submitted, 01 December 2017. Second revision submitted, 19 February 2018.

Summary

Introduction

Handball is a team throwing sport characterised by frequent and rapid changes of movement, high intensity running efforts, cutting and jumping, frequent physical contact between opponents and repeated overhead throwing at high velocity. Considering injury risk, the shoulder region has been highlighted as an area warranting preventative efforts, especially in regard to overuse injuries, with reduced glenohumeral rotation, external rotation weakness and obvious scapular dyskinesis suggested as modifiable risk factors. Furthermore, players have been reported to be at high risk of acute injuries, especially during matches, with a lack of knowledge on their mechanisms.

The main aim of this dissertation was to inform injury prevention efforts in elite handball, with an emphasis on overuse shoulder injuries specifically and acute injury mechanisms in general.

Methods

This dissertation is based on two separate research projects. In the first project (Paper I, II and III), we evaluated the effect of an exercise programme developed to prevent overuse shoulder injuries in a cluster-randomised controlled trial including elite handball players (Paper I) and assessed whether previously identified risk factors could be confirmed in a prospective risk factor study including the players in the control group (Paper II). The exercise programme was designed to increase glenohumeral internal rotation, external rotation strength and scapular muscle strength, as well as improve kinetic chain and thoracic mobility. Towards the end of the intervention period, we also examined the end-user perspective on prevention of shoulder injuries, as well as key issues related to the application of the exercise programme (Paper III).
In the second project (Paper IV), we described acute injury mechanisms and evaluated referee performance based on prospective video analysis of acute injury situations during the 24th Men´s Handball Wold Championship in 2015.

Main results

In Paper I, the exercise programme was found to reduce the risk of shoulder problems by 28% in the intervention group compared with the control group (OR 0.72, 95% CI 0.52 to 0.98). In Paper II, no significant associations were found between total rotation (OR 1.05 per 5° change, 95% CI 0.98 to 1.13), external rotation strength (OR 1.05 per 10 N change, 95% CI 0.92 to 1.20) or obvious scapular dyskinesis (OR 1.23, 95% CI 0.25 to 5.99) and overuse shoulder injury. A

significant positive association was found between greater internal rotation (OR 1.16 per 5° change, 95% CI 1.00 to 1.34) and overuse shoulder injury. In Paper III, we found that the majority of coaches (84%) and captains (89%) believed that handball players are at high risk for shoulder injuries. All delivery agents in the trial were familiar with the exercise programme and the majority believed in a preventative effect (coaches 90%, captains 81%). Only a minority reported full compliance with the recommended frequency (coaches 29%, captains 14%), with the programme being too time consuming (coaches 67%, captains 81%) and lack of player motivation (coaches 76%, captains 62%) as the main barriers. In Paper IV, we found acute injuries (n=55) to be evenly distributed among attackers (n=29) and defenders (n=26). At the time of injury, attackers were most frequently performing a jump shot (n=9), while defenders were completing a tackle (n=10). Agreement between the referees and the expert panel was weak (kappa: 0.22, 95% CI 0.07 to 0.36), with substantially more lenient rule interpretation by the referees.

Conclusions

The exercise programme reduced the risk of shoulder problems in elite handball and should be included as a part of the warm-up routine, with programme length and lack of player motivation as the main barriers to overcome. We could not confirm any of the risk factors previously reported to be associated with shoulder injuries in elite handball. Stricter refereeing and rule amendments should be considered to prevent acute injuries in elite handball, especially in relation to tackling episodes where an attacker is performing a jump shot.

Sammendrag (Summary in Norwegian)

Introduksjon

Flere undersøkelser har vist høy forekomst av skulderproblemer i håndball, i hovedsak overbelastningsskader. En undersøkelse blant mannlige elitehåndballspillere viste at redusert total rotasjonsbevegelighet og lav utadrotasjonsstyrke i glenohumeralleddet, samt tydelig scapula dyskinesi, økte risikoen for skulderproblemer, og forfatterne konkluderte med at fremtidige studier burde undersøke den forebyggende effekten av et treningsprogram rettet mot disse faktorene. Videre er det rapporter at håndballspillere er utsatt for en høy andel av akutte skader, spesielt i kampsituasjon. Til tross for dette finnes det lite kunnskap om hvordan disse skadene oppstår.

Formålet med denne avhandlingen var å øke kunnskapsgrunnlaget omhandlende forebygging av skader i elitehåndball med hovedvekt på skulderproblemer. Videre ønsket vi å undersøke hvordan, og i hvilke spillsituasjoner, akutte skader oppstår under kamper.

Metode

Denne avhandlingen er basert på to forskningsprosjekt. I det første prosjektet (Undersøkelse I, II og III) gjennomførte vi en randomisert kontrollert studie for å undersøke effekten av et forebyggende treningsprogram rettet mot å redusere risikoen for skulderproblemer i elitehåndball (Undersøkelse I). Treningsprogrammet inneholdt øvelser for økt innadrotasjonsbevegelighet og utadrotasjonsstyrke i glenohumeralleddet, øvelser rettet mot økt styrke i scapulamuskulatur, samt øvelser rettet mot den kinetiske kjede og økt thorakal mobilitet. Samtidig gjennomførte vi en prospektiv undersøkelse i kontrollgruppen for å utforske om vi kunne bekrefte risikofaktorene som tidligere er rapportert å øke risikoen for skulderproblemer (Undersøkelse II). Mot slutten av intervensjonsperioden undersøkte vi også erfaringer, holdninger og nåværende praksis til forebygging av skulderproblemer blant trenere og kapteiner, samt gransket hvordan intervensjonslagene opplevde å gjennomføre treningsprogrammet (Undersøkelse III). I det andre prosjektet (Undersøkelse IV) undersøkte vi hvordan, og i hvilke spillsituasjoner, akutte skader oppstod under håndball-VM for menn i 2015. I tillegg undersøkte vi hvilke avgjørelser dommerne tok i forbindelse med skadesituasjoner og sammenlignet disse med vurderingene til et eksternt dommerpanel bestående av tre eksperter.

Hovedresultat

Treningsprogrammet som ble evaluert i Undersøkelse I viste en 28% lavere risiko for skulderproblemer i intervensjonsgruppen sammenlignet med kontrollgruppen (OR 0.72, 95% CI 0.52 til 0.98). Vi observerte ingen signifikant assosiasjon mellom de tidligere rapporterte risikofaktorene og skulderproblemer (Undersøkelse II): total rotasjonsbevegelighet (OR 1.05 per 5° endring, 95% CI 0.98 til 1.13), utadrotasjonsstyrke (OR 1.05 per 10 N endring, 95% CI 0.92 til 1.20), tydelig scapula dyskinesi (OR 1.23, 95% CI 0.25 til 5.99). En signifikant positiv assosiasjon ble observert mellom økt bevegelighet i innadrotasjon (OR 1.16 per 5° endring, 95% CI 1.00 til 1.34) og skulderproblemer. Flertallet av trenere (84%) og kapteiner (89%) som var inkludert i Undersøkelse III rapporterte at håndballspillere har høy risiko for skulderproblemer. Alle trenerne og kapteinene i intervensjonslagene var kjent med treningsprogrammet de skulle gjennomføre og flertallet hadde tro på at programmet ville ha en forebyggende effekt på skulderproblemer (trenere 90%, kapteiner 81%). Kun et mindretall rapporterte å gjennomføre programmet med den anbefalte hyppigheten (trenere 29%, kapteiner 14%). For tidskrevende program (trenere 67%, kapteiner 81%) og mangel på motivasjon blant spillerne (trenere 76%, kapteiner 62%) ble fremhevet som de viktigste barrierene for å lykkes med implementering. I den siste undersøkelsen (Undersøkelse IV) observerte vi at de akutte skadene (n=55) var likt fordelt mellom angripende (n=29) og forsvarende spillere (n=26). Mesteparten av skadene blant angripende spillere oppstod idet de gjennomførte et hoppskudd (n=9). Mens flertallet av forsvarende spillere pådrog seg skader idet de gjennomførte en takling (n=10). Det ble avdekket at dommernes avgjørelser samsvarte dårlig med ekspertpanelets vurderinger av skadesituasjoner (kappa: 0.22, 95% CI 0.07 til 0.36). Sammenlignet med ekspertpanelet vurderte dommerne færre situasjoner som brudd på reglementet og benyttet betydelig færre sanksjoner.

Konklusjon

Treningsprogrammet reduserte risikoen for skulderproblemer i elitehåndball og bør inkluderes som en del av oppvarmingsrutinene. Trenere og kapteiner er enige om at spillere har høy risiko for skulderproblemer og har tro på at programmet kan ha en forebyggende effekt, men for å lykkes med utbredt implementering bør lengden på programmet reduseres og tiltak for å øke spillernes motivasjon for å gjennomføre programmet bør utforskes. Ingen av de tidligere identifiserte risikofaktorene for skulderproblemer ble bekreftet. Strengere dømming og regelendringer bør vurderes for å redusere risikoen for akutte skader. Disse initiativene bør spesielt rettes mot spillsituasjoner der angripende spillere gjennomfører et hoppskudd.

Abbreviations

CI	Confidence Interval
F-MARC	Fédération Internationale de Football Association Medical Assessment and Research Centre
GEE	Generalised estimating equation
ICC	Intraclass correlation coefficient
IHF	International Handball Federation
MVIC	Maximal voluntary isometric contraction
N	Newton
NHF	Norwegian Handball Federation
OR	Odds Ratio
OSTRC	Oslo Sports Trauma Research Center
RE-AIM	Reach Efficacy Adoption Implementation Maintenance
RM	Repetition maximum
SD	Standard deviation

Introduction

The characteristics of handball

Handball, also referred to as team handball in the literature, is a worldwide team throwing sport played by both sexes across different age levels. The International Handball Federation (IHF) has 190 official member federations comprising 1 952 000 teams and more than 27 million players (IHF, 2013). Modern indoor handball arose towards the end of the 19th century with Denmark, Germany and Sweden considered as the main pioneering countries. In 1938, the first World Handball Championship was hosted in Germany, and in 1946 Denmark, Finland, France, the Netherlands, Norway, Poland, Sweden and Switzerland founded the IHF on the initiative of Denmark and Sweden. In 1972, men´s handball was introduced as an Olympic team sport, followed by women´s handball in 1976 (IHF, 2013).

In Norway, handball was first introduced in 1936 by a Swedish sports club visiting Oslo and in 1937 the Norwegian Handball Federation (NHF) was founded with the first national championships arranged in 1938 for women and in 1939 for men (NHF, 1997). Today, there are more than 127 000 registered players in the NHF, which ranks handball as the third most popular organised sport in Norway (Idrettsforbund, 2017; NHF, 2017b). Of the 7 900 teams registered in the NHF, 144 compete in the national league system, ranked according to their skill level in three divisions (~ 2 300 players). For each gender, 12 teams play in the elite division, 12 teams in the 1st division and 12 teams in each of the four 2nd division conferences. Each division and conference competes in a double round-robin system from mid September through March, with play-offs and qualifications in April and May. In addition, a single-elimination tournament for the Norwegian Cup Championships is completed during the season, and high ranked teams from the previous season also compete in European tournaments organised by the European Handball Federation (NHF, 2017a). Typically, teams in the elite division practice five to ten times per week (each session lasting ± 1.5 h) and play 60 to 80 matches during the season, including league, tournament, cup and training matches. Teams in the 1st and 2nd division practice between two to five times per week and play 30 to 60 matches.

Match play

A handball match involves two teams consisting of 14 players each, with the objective of scoring more goals than the opposing team. No more than seven players from each team may be present on court at the same time, with unlimited number of substitutions permitted throughout the match. The playing court is 40 m long and 20 m wide, with three back players, two wing players, one line player and one goalkeeper as the standard distribution of court player positions.
An official match is divided into two 30-minute (age >16), 25-minute (age 12-16) or 20-minute (age 8-12) halves with a half-time break of 10 minutes. During official matches, two referees with equal authority ensure that players comply with the IHF Rules of the game (IHF, 2016).

The two main playing phases during a match are attack and defence. The team in possession of the ball is considered as the attacking team, whereas the opposing team is the defending team. The defensive phase is further divided into return and organised defence, whereas the attacking phase is divided into counter-attack (fast break) and organised attack. The counter-attack is featured by the attacking team´s effort to overtake the defending team during their return phase, typically immediately after winning ball possession (e.g. after successful defence or goalkeeper save). Organised attack occurs when the counter-attack is unsuccessful and the opposing team is able to organise their defence. Based on the average number of ball possessions during matches at the elite level, it is estimated that defence and attack phases alternate every 22 to 36 s (Karcher & Buchheit, 2014).

Physical demands

The physical demands during matches encompass running, jumping, pushing, change of direction and handball specific movements of passing, catching, throwing, cutting, tackling and blocking (Povoas et al., 2012; Michalsik et al., 2013; Michalsik et al., 2014). In elite handball, the mean total distance covered per match is reported to be 3 627 m with an average speed of 6.4 km/h among male players and 4 002 m with an average speed of 5.3 km/h among female players (Michalsik et al., 2013; Michalsik et al., 2014). High-intensity running is demonstrated to constitute about 8% of the total distance covered by males and 3% by females, and in both sexes, more than 70% of the playing time is reported to consist of low intensity activities (standing still, walking), 22% to 26% is moderate (backwards running, jogging, running, sideways movement) and 1% to 2% is high intensity activities (fast running, sprinting) (Michalsik et al., 2013; Michalsik et al., 2014). However, based on heart rate analysis, players are reported to spend more than half of the effective match time above 80% of their maximal heart rate and less than 7% below 60% of their maximal heart rate (Povoas et al., 2012). On average, male players perform 1 482 activity changes during a match, whereas female players perform 663 (Michalsik et al., 2013; Michalsik et al., 2014). One-on-one situations, i.e. duels between players, is reported to be common with an average frequency of 20 per player per match (Povoas et al., 2012). Hard and light tackles by the defending players have been reported with an average frequency of 6 to 15 per player per match (Michalsik et al., 2015).

Throwing performance

Fast and accurate throwing is an important skill for handball players, and training to enhance throwing performance is a key activity in the sport (Van Den Tillaar & Cabri, 2012). At the elite level, players are reported to perform an average of 101 passes and 18 shots per training hour (~ 1 200 throws per week), and between 18 to 94 passes and 7 to 8 shots per match, with the majority of shots performed as overhead throws (88%) (Povoas et al., 2012; Prestkvern, 2013; Karcher & Buchheit, 2014; Michalsik et al., 2015).

The overhead throwing motion is described as a complex activity that involves the whole body to achieve optimal throwing performance, i.e. high velocity and accuracy (Weber et al., 2014). It has been suggested that throwing with maximum velocity is best performed with a temporal progression of the segmental and joint movements involved in a proximal-to-distal sequence, allowing optimal transfer of energy and momentum from the ground through the lower extremities, pelvis and trunk to the throwing arm (Herring & Chapman, 1992; Marshall & Elliott, 2000). The linkage that allows for this sequential transfer of energy is described as the kinetic chain, which optimally maximises the ground reaction force and creates a stable proximal base for distal arm mobility (Sciascia et al., 2012; Chu et al., 2016).

Although details of the throwing motion vary among different sports, the general kinematics, originally described for baseball pitching, are considered comparable and traditionally divided into six phases: wind-up, stride, arm cocking, acceleration, deceleration and follow-through (Dillman et al., 1993; Van den Tillaar & Ettema, 2007). During the wind-up, the thrower rotates the pelvis and trunk towards the throwing arm while transferring weight onto the stance leg (same side as throwing arm), followed by the stride phase, where the stride leg (opposite of throwing arm) is extended towards the target while external rotation and abduction is initiated in the throwing shoulder (Weber et al., 2014). Subsequently, when the stride foot contacts the ground, the shoulder progresses towards maximal external rotation in an abducted position with the elbow flexed (arm cocking), followed by the acceleration phase, where the trunk and pelvis is rotated and flexed towards the throwing direction, with a rapid extension of the elbow and internal rotation of the shoulder (Weber et al., 2014). Immediately after ball release, the deceleration phase initiates, with the elbow continuing into extension and the shoulder being further internally rotated and adducted across the body, before moving into the follow-through phase, where the trunk decelerates by flexing over the braced stride leg (Weber et al., 2014).

Due to the nature of handball, with defending players constantly seeking to obstruct or tackle attackers, jump throws (75%) and standing throws with a run-up (15%) are most commonly used to overcome the defence (Wagner et al., 2008). In addition, players tend to use two different wind-up techniques, each with its own advantage. The circular wind-up, reported to produce higher ball velocities, characterised by players reaching the cocking position by moving the shoulder backwards in a circular motion, starting with extension, similar to baseball (Van den Tillaar et al., 2013). And the whip-like wind-up, demonstrated to reduced the total throwing time, where the cocking position is reached by moving the ball straight upward in front of the body and then backwards, reported to reduce the total throwing time (Van den Tillaar et al., 2013).

Irrespective of throwing technique, kinematic studies in handball report consistent results of maximum angular velocities occurring in a specific proximal-to-distal order, starting with pelvis internal rotation and followed by trunk internal rotation, trunk flexion, elbow extension, shoulder internal rotation and shoulder flexion (Van den Tillaar & Ettema, 2009; Wagner et al., 2010; Wagner et al., 2012; Wagner et al., 2014). The main parameters reported to be correlated with throwing velocity are pelvis, trunk and shoulder internal rotation (Van den Tillaar & Ettema, 2007; Wagner et al., 2010; Wagner et al., 2011), reported to be 450°/s, 756°/s and 5 039°/s on average among elite males (Wagner et al., 2010; Wagner et al., 2014). When comparing different throwing techniques, players attain greater ball velocities using the standing throw with run-up (Wagner et al., 2011), reported to be up to 25.2 m/s in elite males and 22.5 m/s in elite females (Vila et al., 2012; Kruger et al., 2014). During standing throws, the stride leg braces the body in the acceleration phase, allowing players to take better advantage of the energy transfer from the lower extremities, which may explain the higher ball velocities. In contrast during jump throws, opposing movements of the legs are used during the flight phase to rotate the pelvis and enable transfer of momentum through the trunk to the throwing arm (Wagner et al., 2011). In a study investigating the relationship between ground reaction forces and throwing performance specifically, elite players were found to produce greater vertical force with shorter contact time during jump throws compared to novice players, illustrating the importance of energy transfer from the most proximal parts of the kinetic chain (Rousanoglou et al., 2014).

Literature search

To obtain information to be included in this dissertation, three PubMed searches were performed. First, a broad literature search was completed to identify studies reporting on injuries in handball, including epidemiological studies, prospective risk factor studies and intervention studies. The information from these studies is used to describe the injury characteristics in handball, the causes of injuries in handball and prevention of injuries in handball. Second, an additional search was performed to obtain knowledge on modifiable risk factors reported to be associated with shoulder injuries in overhead sport in general, with the results used to expand on the description of causes of injuries in handball. Only cohort studies investigating glenohumeral range of motion, shoulder strength, scapular dyskinesis and external load as potential risk factors were included. As no standardised definition was identified for overhead sport, the following was applied: *"a sport in which athletes or players, with the hand lifted above the head, repetitively throws, hits or shuttles a ball towards an opponent or teammate"*, encompassing: badminton, baseball, cricket, handball, lacrosse, softball, tennis, volleyball and water polo. And finally, a literature search was completed to obtain information on exercises reported to alter glenohumeral internal rotation, shoulder external rotation strength and scapular dyskinesis, including experimental studies reporting on the effectiveness of such exercises. However, due to an expectancy of a low number of hits, studies using electromyography to investigate activation of the shoulder and scapular muscles during commonly used exercises were also included. This search was performed during the planning of this PhD and is limited to studies published prior to 01.06.2014. Detailed information on the search strategy and its results is presented in Appendix I.

Injuries in handball

It is well documented that results of sports injury research are highly influenced by the definitions and methods used to register and report injuries, with discrepancy between studies challenging the ability to interpret and compare data (Van Mechelen et al., 1992; Finch, 1997; Junge & Dvorak, 2000; Brooks & Fuller, 2006; Clarsen et al., 2013). In 2006, the Fédération Internationale de Football Association Medical Assessment and Research Centre (F-MARC) hosted a consensus meeting to address these issues within prevention research in football. This resulted in a consensus statement aiming to determine injury definitions, methodology, implementation and reporting standards for studies on football injures (Fuller et al., 2006), with several sports-specific adaptions published subsequently, including the injury surveillance approach in multi-sports events by the International Olympic Committee (IOC) (Fuller et al., 2007; Junge et al., 2008; King et al., 2009; Pluim et al., 2009).

According to the F-MARC consensus statement, prospective cohort studies employing the following injury definition were preferred: "*Any physical complaint sustained by a player that results from football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a medical attention injury and an injury that results in a player being unable to take full part in future football training or match play as a time-loss injury"* (Fuller et al., 2006). Injuries should further be classified by location, type and mechanism of injury, with an acute injury defined as an injury originating from a specific and identifiable event and an overuse injury as one caused by repeated microtrauma without a single, identifiable event causing the injury. The extent of injuries should be reported as incidence (number of injuries/1000 player-hours), separately for match and training. In case of time loss, the severity should be reported in days with the following distribution: slight (0 days), minimal (1 to 3 days), mild (4 to 7 days), moderate (8-28 days), severe (>28 days) and career ending (Fuller et al., 2006).

Subsequent to its publication, the consensus paper rapidly reached a high number of citations and it seemed that its recommendations were generally accepted (Bahr, 2009). However, as the paper in reality provided three different injury definitions, i.e. any physical complaint, medical attention injury and time-loss injury, Bahr (2009) emphasised that the choice of definition would have substantial influence on the injury rate reported, as players will not always seek medical attention for physical complaints, and even fewer will lead to time loss. Consequently, as the vast majority of the papers referring to the consensus paper only employed the last dimension of the injury definition, i.e. time loss, Bahr (2009) questioned how appropriate this approach was when applied to sports where overuse injuries may be expected. Using beach volleyball as an example, he concluded that new approaches to record overuse injuries in sport were needed, as the time-loss definition failed to record prevalent pain problems in the shoulder, knee and lower back (Bahr, 2009). This may be explained by how athletes handle overuse injuries, which in most cases have a gradual onset of transient or intermittent symptoms, and therefore players are likely to continue to train and compete, at least in the early phase of an overuse condition. In the case of worsening, athletes may try to adapt their training and competition habits by refraining from the most aggravating activities, before finally seeking medical treatment when their participation is affected (Clarsen et al., 2013). In fact, it is reported that athletes often continue to train and compete despite the presence of pain and reduced function related to overuse conditions (Bahr, 2009; Clarsen et al., 2010; Vleck et al., 2010; Myklebust et al., 2013a), implying that a time-loss definition is poorly suited to record overuse injuries in sport.

With these challenges in mind, a new method using a self-reported questionnaire to register overuse injuries in sports was developed, the OSTRC Overuse Injury Questionnaire (Clarsen et al., 2013). The questionnaire consists of four questions, which can be adapted to different body regions, and gathers information on the extent to which overuse injuries affect participation, training volume and performance, as well as pain experienced during the past week. The questionnaire is administered regularly to each participant in prospective cohort studies, allowing researchers to determine the extent of overuse symptoms over time and evaluate severity based on changes in the participant´s function or sports performance limitations, rather than time loss (Clarsen et al., 2013). Compared to the standard time-loss approach, this method has been reported to identify more than ten times as many overuse injury cases over a three-month period, and may therefore be a better alternative in the study of overuse injuries in sport (Clarsen et al., 2013). In addition, as overuse injuries often are chronic or intermittent, it is argued that they are most appropriately reported as prevalence, i.e. the proportion of athletes affected by problems related to an overuse condition at any given time, with multiple measurements allowing calculation of average values throughout a study period (Bahr, 2009).

Incidence of injuries

An overview of studies reporting injury incidence (injuries per 1000 player-hours of match or training, or total incidence including both match and training) in handball is presented in Table 1. Four of the studies have a retrospective design, all using self-reporting to record injuries, with a recall period ranging from 40 weeks to one year (Jørgensen, 1984; Wedderkopp et al., 1997; Wedderkopp et al., 2003; Piry et al., 2011). The remaining ten studies have a prospective design (Nielsen & Yde, 1988; Seil et al., 1998; Wedderkopp et al., 1999; Olsen et al., 2005; Junge et al., 2006; Olsen et al., 2006a; Langevoort et al., 2007; Møller et al., 2012; Bere et al., 2015; Giroto et al., 2017), including two intervention studies where the results from the control group are presented (Wedderkopp et al., 1999; Olsen et al., 2005). Reporting by team medical staff is the most common injury registration method used in the prospective studies (Junge et al., 2006; Langevoort et al., 2007; Bere et al., 2015), followed by reporting by players, coaches and research personnel (Table 1.) Overall, medical attention alone or in combination with time loss is the most common injury definition used (Jørgensen, 1984; Olsen et al., 2005; Junge et al., 2006; Olsen et al., 2006a; Langevoort et al., 2007; Piry et al., 2011; Bere et al., 2015; Giroto et al., 2017). None of the studies have employed a true any physical complaint definition as defined in the F-MARC consensus statement (Fuller et al., 2006). However, in three of the studies by Wedderkopp et al. (1997, 1999; 2003), the injury definition used may have captured injuries in a broader sense, as injuries causing the player to being unable to participate without considerable discomfort were included.

In prospective studies at the senior level, the injury incidence reported during matches varies greatly for both sexes depending on the competition level, with the lowest numbers reported in a study including players from the first division or lower and the highest among players competing at an international level, 13.3 vs. 104.5 for females and 13.8 vs. 145 for males (Nielsen & Yde, 1988; Junge et al., 2006; Bere et al., 2015). For training, the injury incidence are reported to be substantial lower and more consistent, ranging from 0.6 to 3.4 among males and from 0.7 to 4.1 among females (Nielsen & Yde, 1988; Seil et al., 1998; Møller et al., 2012; Giroto et al., 2017).

Table 1 Epidemiological studies reporting incidence for all injuries in handball.

Reference Design, country and period	Population	Number of players / injuries	Injury definition and registration	Injuries / 1000 hours		
				Match	Training	Total
Senior						
Jørgensen (1984) Retrospective cohort Denmark, 1981-82, 40 weeks	Selected players, div. I-III Male players Age 17-37 years	♂ 288 / 282	An injury received in connection with the game or in training in the club, which handicaps you during the game and/or requires special treatment in order to play, or completely prevents you from playing; self-reported retrospectively			♂ 8.3
Nielsen & Yde (1988) Prospective cohort Denmark, Sep. 1985-May 1986	11 teams, div. I-II and lower Male and female players Age >18 years	♂ 69 / 44 ♀ 58 / 24	An incident occurring during games or practice in the club causing the player to miss at least one game or practice session; weekly by research personnel including physical examination	♂ 13.3 ♀ 13.8	♂ 2.4 ♀ 0.7	
Seil et al. (1998) Prospective cohort Germany, July 1995-May 1996	16 teams, div. III-IV Male players Mean age 25.8	♂ 186 / 91	An incident occurring during practice or competition that led to nonparticipation of at least one practice session or game; reported by coaches at the time of injury with regular visits by research personnel to ensure adherence	♂ 14.3	♂ 0.6	♂ 2.5
Junge et al. (2006) Prospective cohort 2004 Olympic games	Participating teams International level Male and female players Age NR	♂ 44* / 49 ♀ 33*/ 65	Any physical complaint incurring during the match that received medical attention from the physician, regardless of consequences with respect to absence from match or training; per match by team physician	♂ 89 ♀ 145		
Langevoort et al. (2007) Prospective cohort Six international tournaments 2001-2004	Participating teams International level Male and female players Age NR	♂+♀ 365* / 478	Any physical complaint incurring during the match that received medical attention from the team physician regardless of the consequences with respect to absence from match or training; per match by team physician	♂+♀ 108		

NR, not reported; ♂, male; ♀, female; *teams

Reference Design, country and period	Population	Number of players / injuries	Injury definition and registration	Injuries / 1000 hours		
				Match	Training	Total
Piry et al. (2011) Retrospective cohort 2008 Asian handball championships, 1 year	Selected players, elite level Male players Age NR	♂ 40 / 63	All the physical injuries happening during the match and training requiring medical aid without considering the consequences such as absence in the following games or training sessions; self-reported retrospectively	♂ 20.7	♂ 0.96	
Møller et al. (2012) Prospective cohort Denmark, Sep. 2010-April 2011, 31 weeks	Selected players, elite level Male and female players Age >18 years	♂ NR / 88 ♀ NR / 95	Any physical complaint sustained by a player that results from a handball match or handball training causing the players to miss part of or rest of the match or training session; self-reported weekly with follow-up interview	♂ 31.7 ♀ 17.9	♂ 3.4 ♀ 2.6	♂ 7.8 ♀ 6.1
Bere et al. (2015) Prospective cohort 2015 Handball World Championship	Participating teams International level Male players Age NR	♂ 384 / 122	Any musculoskeletal complaint and/or concussion incurred in competition and/or training during the tournament that received medical attention, regardless of the consequences with respect to absence from competition or training; daily by team doctor/physiotherapist	♂ 104.5		
Giroto et al. (2017) Prospective cohort, risk factor Brazil, May 2011-Nov. 2011	21 teams, elite level Male and female players Mean age 23.4 (♂ 24.1, ♀ 22.8)	♂ 156 / 136 ♀ 183 / 176	Pain of musculoskeletal origin related to practice of handball that occurred during the study, and which resulted in interruption of at least one training session or match; or the loss of at least one training session or match; or situations in which medical intervention was needed; weekly by an appointed person in each team	♂ 23.5 ♀ 17.9	♂ 3.2 ♀ 4.1	

NR, not reported; ♂, male; ♀, female

Reference Design, country and period	Population	Number of players / injuries	Injury definition and registration	Injuries / 1000 hours		
				Match	Training	Total
Junior						
Nielsen & Yde (1988) Prospective cohort Denmark, Sep. 1985-May 1986	7 teams, youth div. Male and female players Age 7-18 years	♂ 40 / 15 ♀ 54 / 22	An incident occurring during games or practice in the club causing the player to miss at least one game or practice session; weekly by research personnel including physical examination	♂ 8.9 ♀ 11.4	♂ 1.7 ♀ 2.2	
Wedderkopp et al. (1997) Retrospective cohort Denmark, 1994-1995, 1 season	22 teams, youth elite, intermediate and recreational level Female players Age 16-18	♀ 217 / 211	An injury occurring during scheduled games or practices and causing the player to miss the next game, or practice session, or being unable to participate without considerable discomfort; self-reported retrospectively	♀ 40.7	♀ 3.4	
Wedderkopp et al. (1999) Cluster-randomised controlled trial Denmark, Aug. 1995-May 1996, 1 seson	11 control teams, youth elite, intermediate and recreational level Female players Age 16-18	♀ 126 / 66	An injury occurring during scheduled games or practices and causing the player to miss the next game or practice session, or being unable to participate without considerable discomfort; self-reported at time of injury (coach administered)	♀ 23.4	♀ 1.2	
Wedderkopp et al. (2003) Retrospective cohort Denmark, 1997-98, 1 season	16 teams, youth elite, intermediate and recreational level Female players Age 14-16	♀ 163 / NR	Any injury occurring during scheduled games or practice, causing the players to miss the next game, practice session or to participate with considerable discomfort; self-reported at time of injury (coach administered)	♀ 52		
Olsen et al. (2005) Cluster-randomised controlled trial Norway, Sep. 2002-April 2003, 1 season	59 control teams, youth elite, intermediate and recreational level Male and female players Mean age 16.2	♂+♀ 879 / 156	An injury occurred during scheduled matches or training sessions, causing player to require medical attention or miss part of or next match or training session; monthly by research personnel using interview	♂+♀ 10.3	♂+♀ 0.6	♂+♀ 1.8

NR, not reported; ♂, male; ♀, female

Reference Design, country and period	Population	Number of players / injuries	Injury definition and registration	Injuries / 1000 hours		
				Match	Training	Total
Olsen et al. (2006a) Prospective cohort Norway, Sep. 2001-March 2002, 1 season	90 teams, youth amateur level Male and female players Mean age 16.4 (injured players)	♂+♀ 428 / 93	An injury occurring during scheduled matches or training sessions, causing player to require medical attention or miss part of or next match or training session; by coaches within two weeks of the time of injury	♂ 8.3 ♀ 10.4	♂ 0.6 ♀ 1.0	
Møller et al. (2012) Prospective cohort Denmark, Sep. 2010-April 2011, 31 weeks	Selected players, youth elite level Male and female players Age 16-18 years	♂ NR / 67 ♀ NR / 50	Any physical complaint sustained by a player that results from a handball match or handball training causing the players to miss part of or rest of the match or training session; self-reported weekly with follow-up interview	♂ 11.5 ♀ 10.8	♂ 1.7 ♀ 2.9	♂ 4.2 ♀ 6.8
Møller et al. (2012) Prospective cohort Denmark, Sep. 2010-April 2011, 31 weeks	Selected players, youth elite level Male and female players Age <16 years	♂ NR / 31 ♀ NR / 117	Any physical complaint sustained by a player that results from a handball match or handball training causing the players to miss part of or rest of the match or training session; self-reported weekly with follow-up interview	♂ 17.2 ♀ 13.0	♂ 3.2 ♀ 2.1	♂ 6.9 ♀ 4.7

NR, not reported; ♂, male; ♀, female

In comparable studies using a prospective design at the junior level, the injury incidence is reported to range from 8.3 to 17.2 for males and from 10.4 to for 13.0 for females, with the highest numbers among players below 16 years of age for both sexes (Olsen et al., 2006a; Møller et al., 2012). Irrespective of study design, injury definition and registration method, the highest match injury incidence at the junior level is reported among female players, ranging from 40.7 to 52 (Wedderkopp et al., 1997; Wedderkopp et al., 2003). However, due to the retrospective design and broad injury definition employed in these studies, the comparability is low.

In two studies using Swedish insurance records to investigate and compare the total incidence of acute injuries during matches and training (injuries per 1000 player years) between different sports, handball was reported as the team sport with the highest risk of acute injury for both sexes, with slightly higher numbers in females (Aman et al., 2016; Aman et al., 2017).

Based on injury surveillance using similar methods during three consecutive Summer Olympic Games (2008 to 2016), injury incidence proportions (number of players injured divided by number of participating players) have been reported to range from 15% to 22% in handball, with the majority of injuries occurring during matches (Junge et al., 2009; Engebretsen et al., 2013; Soligard et al., 2017). Compared to other team sports, handball was reported to have the third highest risk of injury in 2008 (behind football and field hockey) (Junge et al., 2009), the second highest in 2012 (behind football) (Engebretsen et al., 2013), and the fourth highest in 2016 (behind football, rugby and water polo) (Soligard et al., 2017).

According to studies reporting match injury incidence separately for different player positions, line players had the highest risk of injury (14.6 to 185.6), followed by wing players (18.6 to 93), back players (10.5 to 88.0) and goalkeepers (7.3 to 30.6) (Jørgensen, 1984; Seil et al., 1998; Wedderkopp et al., 1999; Bere et al., 2015). Conflicting results exits regarding the time of injury during matches, with proportion measures ranging from 35% to 44% for the 1st half and from 56% to 65% for the 2nd half (Junge et al., 2006; Piry et al., 2011; Giroto et al., 2017), whereas a report on match injury incidence reveals that the risk was greater in the 1st half (126.7 vs. 63.4) (Bere et al., 2015).

Severity of injuries

Only one study has reported on the severity of time-loss injuries according to the F-MARC consensus statement (Fuller et al., 2006), with 8% categorised as slight (0 days), 22% as minimal (1 to 3 days), 22% as mild (4 to 7 days), 33% as moderate (8 to 28 days) and 16% as severe (>28 days) (Møller et al., 2012). One study based on injury data from six international tournaments used the same distribution to report estimated absence, with 50% to 80% of the injuries categorised as slight, 9% to 38% as minimal, 2% to 13% as mild, 1% to 7% as moderate and 1% to 6% as severe (Langevoort et al., 2007). Three studies have categorised 27% to 57% of the injuries as minor (less than one week), 30% to 53% as moderate (1 to 4 weeks) and 12% to 20% as major (>4 weeks) (Nielsen & Yde, 1988; Wedderkopp et al., 1997, 1999). Two studies have accounted for injury mechanism when reporting severity, with 3% to 22% of the acute injuries categorised as slight (0 days), 25% to 34% as minor (1 to 7 days), 22% to 28% as moderate (8 to 21 days) and 32% to 35% major (>21 days), and with 8% to 20% of the overuse injuries categorised as slight, 16% to 23% as minor, 16% to 31% as moderate and 38% to 48% as major (Olsen et al., 2005; Olsen et al., 2006a). One study reported with the same distribution; however, for all injuries, with 38% categorised as slight, 25% as minor, 20% as moderate and 15% as major (Piry et al., 2011). The latest study reporting on the severity during an international tournament categorised more than half of the time-loss injuries (61%) as less severe injuries, leading to an estimated absence from full participation in training and match play for 1 to 2 days, while 34% were categorised as moderate injuries (3 days to 4 weeks) and 5% as severe (>4 weeks) (Bere et al., 2015).

Location and type of injuries

The majority of injuries in handball are demonstrated to be located in the lower extremities (42% to 63%), followed by upper extremity injuries (15% to 40%), head and face injuries (13% to 34%), head and neck injuries (4% to 26%) and trunk injuries (2% to 14%) (Wedderkopp et al., 1997; Seil et al., 1998; Junge et al., 2006; Langevoort et al., 2007; Bere et al., 2015). Regardless of injury type, the most common injury locations are reported to be the ankle (11% to 40%), head (4% to 33%), fingers (4% to 24%), knee (9% to 19%) and leg (6% to 18%), with sprains (11% to 65%), contusions (3% to 56%), tendinopathies (8% to 12%) and strains (6% to 12%) as the most frequently reported injury types (Jørgensen, 1984; Nielsen & Yde, 1988; Yde & Nielsen, 1990; Wedderkopp et al., 1997; Seil et al., 1998; Wedderkopp et al., 1999; Junge et al., 2006; Langevoort et al., 2007; Møller et al., 2012; Bere et al., 2015). Acute injuries have been demonstrated to represent 63% to 93% of all injuries, while 7% to 37% are overuse injuries (Nielsen & Yde, 1988; Wedderkopp et al., 1997; Olsen et al., 2005; Olsen et al., 2006a; Piry et al., 2011; Møller et al., 2012; Bere et al., 2015; Giroto et al., 2017). However, as these studies recorded injuries based on medical attention alone or in combination with time loss, they are unlikely to have captured the true extent of overuse injuries. In studies accounting for injury type when reporting overall location, the knee (14% to 26%), ankle (19% to 24%), finger (9% to 17%) and thigh (3% to 10%)

are reported as the most frequent acute injury locations, whereas the lower leg (52%), knee (16% to 27%), shoulder (4% to 44%) and back (16%) are reported as the most frequent locations for overuse injuries (Olsen et al., 2006a; Giroto et al., 2017). Also, one of these studies reported injury types separately, with contusions (9%), strains (17%) and sprains (46%) as the most common acute injury types, and bursitis (7%), tendinopathies (22%) and shin splints as the most common types of overuse injuries (Møller et al., 2012).

Shoulder injuries

Eight studies have reported on the proportion of injuries represented by shoulder injuries handball, with percentages ranging from 3% to 22% (Jørgensen, 1984; Nielsen & Yde, 1988; Seil et al., 1998; Olsen et al., 2005; Junge et al., 2006; Langevoort et al., 2007; Møller et al., 2012; Bere et al., 2015). During a 31-week cohort study, using an any physical complaint definition, Møller et al. (2017) reported the total incidence of shoulder injuries (both match and training) to be 1.4 among elite youth players (age 14 to 18), which is 2.5 greater than the results of a previous study reporting on the incidence of shoulder injuries in a similar population using a time-loss definition (Møller et al., 2012; Møller et al., 2017). In a prospective study of amateur male players, the shoulder was reported as the most common anatomical region in which players experienced overuse symptoms (Seil et al., 1998), which is in line with the results by Giroto et al. (2017), showing that overuse shoulder injuries represented the majority of overuse injuries among elite players in a prospective cohort study.

In studies specifically investigating shoulder injuries, several prevalence measures have been used to report on the manifestations of dominant shoulder pain, problems or injuries in relation to handball activity (training and match), irrespective of the need for medical attention or time loss. Retrospectively at the elite senior level, 59% of female players and 44% to 75% of male players have been demonstrated to experience shoulder pain at some point during their career (Mohseni-Bandpei et al., 2012; Myklebust et al., 2013a; Clarsen et al., 2014a), and 41% of male players during the preceding season (Mohseni-Bandpei et al., 2012). At the elite youth level, shoulder pain or problems during the last season have been reported to range from 23% to 38% (Edouard et al., 2013; Østerås et al., 2015; Asker et al., 2018). The point prevalence of shoulder pain has been demonstrated to be 36% in elite female players and ranging from 20% to 44% in elite male players (Mohseni-Bandpei et al., 2012; Myklebust et al., 2013a; Clarsen et al., 2014a), whereas at the amateur level, 49% of adolescent players reported current shoulder pain in a cross-sectional study including a small sample (Oliveira et al., 2017).

In a prospective cohort study with bi-weekly registration of shoulder problems, irrespective of time loss or medical attention, 52% of elite male players were demonstrated to experience shoulder problems at some point during the season, and at any given point in time, 28% of the players were reported to be affected by a shoulder problem (Clarsen et al., 2014a). Using similar methods to register shoulder problems at the elite youth level, Asker et al. (2018) recently demonstrated that 44% of players reported a shoulder problem at some point during the season, and at any given point in time, 25% of the players were affected by a shoulder problem. At the elite female level, 56% of the players have been demonstrated to experience a shoulder injury or pain leading to time loss of at least one day during a season (Edouard et al., 2013).

The causes of injuries in handball

Research aiming to establish the causes of injuries is traditionally guided by an injury aetiology model, such as the original multifactorial model described by Meeuwisse et al. (Meeuwisse, 1994), or one of its subsequent revisions (Bahr & Krosshaug, 2005; Meeuwisse et al., 2007). According to these models, knowledge about how injuries occur (injury mechanisms) as well as why certain players may be at risk of an injury (risk factors) is essential to fully understand the causes of injuries. With respect to injury mechanisms, descriptions should not only include details of the whole body and joint biomechanics at the time of injury, but also needs to account for the events leading up to the injury, i.e. the playing situation, as well as player and opponent behaviour (Bahr & Krosshaug, 2005).

Traditionally, injury aetiology models divide risk factors into two main categories: internal or intrinsic player related risk factors (e.g. sex, age, previous injury and strength) and external or extrinsic environmental risk factors (e.g. rules, refereeing, equipment, weather) (Meeuwisse, 1994; Bahr & Krosshaug, 2005; Meeuwisse et al., 2007). However, it is important to recognise that risk factors can be divided into modifiable (e.g. strength, rules, refereeing, equipment) and non-modifiable risk factors (e.g. sex, age, previous injury, weather),
which probably is more in line with the overall aim of sports injury prevention, as it emphasises factors which possibly can be altered through physical training or behavioural changes (Bahr & Holme, 2003).

A prospective cohort design with measurements of the potential risk factors prior to injury is preferred, as this allows for assessment of associations (Grimes & Schulz, 2002; Bahr & Holme, 2003). In order to establish if an association represents a causal relationship, risk factor studies traditionally exclude all injured players at baseline and only record new injuries occurring during the study period. However, when applying this premise to the study of overuse injuries, challenges arise. To exemplify, if a large proportion of the cohort reports overuse symptoms (e.g. shoulder pain) at baseline, exclusion of these will result in a biased cohort not representative for the target population. Consequently, only players reporting symptoms during the actual testing can be excluded, limiting the study to only assess associations between the risk factors and overuse conditions without assumptions of causality (Clarsen et al., 2014a).

Subsequent to the commencement of this PhD project, several proposals have been made to enhance the study of risk factors in sport. Bittencourt et al. (2016) have emphasised the importance of progressing from analyses of isolated risk factors to investigation of how risk factors may interact. Windt & Gabbet (2017) have argued that none of the existing injury aetiology models account for the effects of training and competition load, resulting in a revised model including workloads and how they contribute to injury risk. Finally Bahr (2016) has argued that identified risk factors should be confirmed in relevant populations using similar methods.

Injury mechanisms

Overall, contact injuries have been reported to represent 35% to 92% of all injuries in handball, with the highest proportions during international championships, while 8% to 47% are non-contact injuries, with the highest proportions demonstrated in junior players (Nielsen & Yde, 1988; Olsen et al., 2005; Langevoort et al., 2007; Bere et al., 2015; Giroto et al., 2017). Direct contact with opponent is reported as the main cause of contact injuries (31% to 53%), followed by contact with the ball (14% to 18%), ground (9%) and teammate (3%) (Nielsen & Yde, 1988; Seil et al., 1998). The majority of injuries are reported to occur while players are running (28% to 33%) or shooting (25% to 31%) (Nielsen & Yde, 1988; Yde & Nielsen, 1990). About half of the injuries is reported among attacking players, about one-third among defending players and the rest occur during warm-up or in unknown situations (Wedderkopp et al., 1997; Seil et al., 1998).

Despite video analysis being highlighted as an important tool to describe how injuries occur (Krosshaug et al., 2005), none of the above mentioned studies have employed this method to describe the playing situations leading to injuries in handball. Therefore, we wanted to describe the mechanisms of acute match injuries in elite handball using video analysis (Paper IV).

Referee performance in relation to injuries

The degree of foul play in relation to contact injuries has been investigated during tournaments at the international level, in which 44% to 77% of the injuries have been reported to be caused by foul play in the view of team physicians, although only 48% to 74% of these were followed by a sanction by the referee (Langevoort et al., 2007). However, as these data are limited and solely based on retrospective reports from team medical staff, knowledge regarding referee performance in relation to injury situations is warranted, and we therefore included this as an objective of Paper IV.

Modifiable risk factors for shoulder injuries in overhead sport

Glenohumeral range of motion

An overview of cohort studies investigating the association between glenohumeral range of motion and shoulder injuries in overhead sport is presented in Table 2. Three studies have demonstrated associations between internal rotation deficits and dominant shoulder and elbow injuries in baseball and softball, with ≥25° and ≥13° as cut-offs (Shanley et al., 2011; Shanley et al., 2015; Shitara et al., 2017). In contrast, Tyler et al. (2014) has reported that a lack of an internal rotation deficit ≥20° represented an increased risk of dominant shoulder and elbow injuries in high school baseball pitchers. In professional baseball pitchers, a total rotational motion deficit >5° has been demonstrated to be associated with dominant shoulder injuries or pain leading to time loss (Wilk et al., 2011), whereas among elite male handball players, absolute rather than relative dominant total rotational motion values were found to be associated with shoulder problems (Clarsen et al., 2014a). Only among professional baseball pitchers has an external rotation deficit exceeding 5° been reported to be associated with shoulder injuries (Wilk et al., 2015). The presence of a deficit ≥15° in horizontal adduction has been reported to be associated with shoulder and elbow injuries among youth and adolescent baseball pitchers (Shanley et al., 2015). Still, three studies have reported no associations between glenohumeral range of motion measures and injury (Forthomme et al., 2013; Camp et al., 2017; Møller et al., 2017).

Table 2 Studies investigating the association between glenohumeral range of motion and shoulder injury in overhead sport. Only significant results reported (p<0.05)

Reference Design and period Level and country	Study group	Injury definition and registration	GH ROM measures and instrumentation	Results
Baseball and softball				
Shanley et al. (2011) * Prospective cohort, 2009-10, 1 season High school, US	103 female softball players 143 male baseball players Mean age 15.7	All shoulder and elbow injuries or pain leading to time loss; daily by coaches and team medical staff, including physical examination	IR, ER, HA; goniometer (°)	Players with dominant IR deficit ≥25° increased risk of an upper extremity injury (RR 3.7, 95% CI 1.6 to 8.9), especially baseball players (RR 4.8, 95% CI 2.11 to 11.3)
Wilk et al. (2011) Case series, 2005-07, 3 seasons Professional, US	122 male baseball pitchers 170 pitcher seasons Mean age 25.6	All shoulder injuries or pain leading to time loss; team medical staff, including physical examination	IR, ER; goniometer (°)	Pitchers with dominant TROM deficit >5° more likely to be injured (OR 2.5, 95% CI 1.1 to 5.3)
Tyler et al. (2014) * Prospective cohort, 4 seasons High school, US	101 male baseball pitchers 166 pitcher seasons Mean age NR	All shoulder and elbow injuries leading to time loss; team medical staff	IR, ER, HA; digital level (°)	Pitchers with no dominant IR deficit ≥20° at increased risk of injury (RR 4.9, 95% CI 1.0 to 23.3)
Shanley et al. (2015) * Prospective cohort, 2009-12, 1 season Youth and adolescent, US	115 baseball pitchers 47 youth; mean age 9.9 68 adolescent; mean age 14.9	Overuse shoulder and elbow injuries leading to time loss; team medical staff and research personnel	IR, ER, HA; inclinometer (°)	Adolescent pitchers more likely to be injured with the presence of a dominant IR deficit >13° (OR 5.82, 95% CI 1.6 to 20.9) or a dominant HA deficit >15° (OR 4.1, 95% CI 1.2 to 13.9)
Wilk et al. (2015) Prospective cohort, 2005-12, 8 seasons Professional, US	296 male baseball pitchers 505 pitcher seasons Mean age 24.7	All shoulder injuries leading to time loss and/or surgery; disabled list	IR, ER, flexion; goniometer (°)	Pitchers with dominant ER deficit >5° more likely to be put on the disabled list (OR 2.2 95% CI 1.2 to 4.1) and require surgery (OR 4.0 95% CI 1.5 to 12.6)
Camp et al. (2017) * Prospective cohort, 2010-15, 6 seasons Professional, US	81 male baseball pitchers 132 pitcher seasons Mean age 27.9	All shoulder and elbow injuries not related to contact and leading to time loss; team medical staff	IR, ER, HA and flexion; goniometer (°)	No association between GH ROM measures and shoulder an elbow injuries

CI, confidence interval; ER, external rotation; GH, glenohumeral; HA, horizontal adduction; IR, internal rotation; NR, not reported; OR, odds ratio; ROM, range of motion, RR, relative risk; TROM, total rotational motion; *combines shoulder and elbow in their outcome

Reference Design and period Level and country	Study group	Injury definition and registration	GH ROM measures and instrumentation	Results
Shitara et al. (2017) * Prospective cohort, 1 season High school, Japan	105 male baseball pitchers Mean age 16.3	All shoulder and elbow injuries leading to time loss ≥8 days; self-reported at medical check-ups and at the end of the season	IR, ER; goniometer (°)	Reduced absolute IR ROM in the dominant shoulder associated with shoulder and elbow injuries (OR 0.95, 95% CI 0.91 to 0.99)
Handball				
Clarsen et al. (2014a) Prospective cohort, 2011-12, 1 season Elite, Norway	206 male players Mean age 24	Shoulder problems affecting player´s participation, training volume and performance, as well as shoulder pain last 7 days; self-reported bi-weekly	IR, ER; inclinometer (°)	Reduced absolute TROM associated with increased probability of injury (OR 0.77 per 5° change, 95% CI 0.56 to 0.99)
Møller et al. (2017) Prospective cohort, 2013-14, 1 season Elite youth, Denmark	679 male and female players Age 14-18	Any handball related shoulder problem irrespective of time loss and medical attention; self-reported weekly	IR, ER, inclinometer (°)	Dominant IR, ER and TROM deficits had no effect on the association between increase in handball load and shoulder injury rate.
Volleyball				
Forthomme et al. (2013) Prospective cohort, 2008-09, 6 months I and II div, Belgium, France, the Netherlands and Luxembourg	66 players Gender distribution NR Mean age 24	Shoulder pain during the season; self-reported weekly	IR, ER; goniometer (°), distance sleepers stretch; tape (cm)	No association between GH ROM measures and shoulder pain during the season

CI, confidence interval; ER, external rotation; GH, glenohumeral; HA, horizontal adduction; IR, internal rotation; NR, not reported; OR, odds ratio; ROM, range of motion, RR, relative risk; TROM, total rotational motion; *combines shoulder and elbow in their outcome

Shoulder strength

A total of seven prospective cohort studies investigating the association between glenohumeral strength measures and shoulder injuries in overhead sport were identified (Table 3). Reduced abduction strength has been reported to be associated with shoulder and elbow injuries among professional and high school baseball pitchers using isometric testing (Byram et al., 2010; Tyler et al., 2014). External rotation weakness (isometric) has been reported to be associated with shoulder and elbow injuries requiring surgery in professional baseball pitchers (Byram et al., 2010), and with increased probability of reporting shoulder problems in elite handball (Clarsen et al., 2014a). Also lower ratios of external to internal rotation strength have been reported to be associated with shoulder injuries leading to time loss in baseball using isometric testing (Byram et al., 2010), and in handball using isokinetic testing (Edouard et al., 2013). In addition, Møller et al. (2017) have reported that a ratio of external to internal rotation strength (isometric) below 75% accentuated the effect of handball load on shoulder injury rate among elite youth players when weekly handball load increased >20%. When comparing external rotation strength (isometric) between sides, Shitara et al. (2017) reported that lower values in the dominant shoulder were associated with shoulder and elbow injuries in baseball pitchers. Similarly, higher values of eccentric external rotation strength (isokinetic) have been reported to be protective in relation to shoulder pain in volleyball (Forthomme et al., 2013).

Scapular dyskinesis

An overview of the cohort studies reporting on the relationship between scapular dyskinesis and shoulder injuries in overhead sport is presented in Table 4. Of the six studies identified, only one, including elite male handball players, reported an association between scapular dyskinesis and shoulder injuries when assessing risk factors independently (Clarsen et al., 2014a). When assessing scapular dyskinesis as an effect modifier, Møller et al. (2017) reported an exacerbating effect on the association between an increase in weekly handball load above 20% and shoulder injury rate in elite youth handball. The two studies carried out in baseball, both at the high school level, reported no association between scapular dyskinesis and shoulder and elbow injuries (Myers et al., 2013; Shitara et al., 2017). In a study including athletes from five different overhead sports, none of the measures of scapular function were found to be associated with shoulder complaints during the last month prior to follow-up at 12 and 24 months (Struyf et al., 2014). However, athletes categorised as developing shoulder pain during the study period demonstrated less scapular upward rotation during abduction at baseline. In the one study found on volleyball players, no associations were reported (Forthomme et al., 2013).

Table 3 Studies investigating the association between shoulder strength and shoulder injury in overhead sport. Only significant results reported ($p<0.05$)

Reference Design and period Level and country	Study group	Injury definition and registration	GH strength measures, instrumentation and procedure	Results
Baseball				
Byram et al. (2010) Prospective cohort, 2001-05, 4 seasons Professional, US	144 male pitchers 207 pitcher seasons Age NR	(1) Any throwing related injury (shoulder or elbow) leading to placement onto the disabled list and/or time loss (2) Injuries requiring surgery	Isometric make (HHD, kg) IR: prone[a] ER: prone[a] and seated[b] ABD: seated[c]	(1) Lower ratios of prone ER:IR strength and ABD weakness associated with shoulder injury (2) Reduced seated and prone ER strength, as well as seated ABD strength associated with throwing related injuries requiring surgery
Tyler et al. (2014) * Prospective cohort, 4 seasons High school, US	101 male pitchers 166 pitcher seasons Age NR	All shoulder and elbow injuries leading to time loss; team medical staff	Isometric break (HHD, N) IR: supine[a] ER: supine[a] ABD: seated[d]	Preseason ABD weakness associated with injuries leading to >3 missed games (RR 4.58, 95% CI 1.40 to 15.01)
Shitara et al. (2017) * Prospective cohort, 1 season High school, Japan	105 male pitchers Mean age 16.3	All shoulder and elbow injuries leading to time loss ≥8 days; self-reported at medical check-ups and at the end of the season	Isometric make (HHD, N) IR: prone[a] ER: prone[a] ABD: seated[c]	Reduced prone ER ratio between sides (dominant vs. non-dominant) associated with shoulder and elbow injuries (OR 0.007, 95% CI 0.0001 to 0.542)
Handball				
Edouard et al. (2013) Prospective cohort, 2009-10, 1 season National elite, Brazil	16 female players Mean age 18	All shoulder injuries leading to time loss; national team physician	Isokinetic torque (Nm/kg) IR: seated[d] ER: seated[d] 60, 120, 240°/sec con 60°/sec ecc	Ratios of ERcon:IRcon at 240°/s <0.69 (RR 2.57, 95% CI 1.60 to 3.54) and ratios of IRecc:ERcon at 60°/s >1.61 (RR 2.08 95% CI 1.18 to 2.98) associated with shoulder injury

ABD, abduction; con, concentric; ecc, eccentric; ER, external rotation; GH, glenohumeral; HHD, handheld dynamometer; IR, internal rotation; NR, not reported; OR, odds ratio; RR, relative risk; [a]90° GH ABD, 0° GH rotation and 90° elbow flexion; [b]Neutral GH position and 90° elbow flexion; [c]90° GH ABD, 45° HA with thumb up; [d]90° GH ABD in the scapular plane with thumb up; [e]90° GH ABD, 30° GH rotation and 90° elbow flexion; *combines shoulder and elbow in their outcome

Reference Design and period Level and country	Study group	Injury definition and registration	GH strength measures, instrumentation and procedure	Results
Clarsen et al. (2014a) Prospective cohort, 2011-12, 1 season Elite, Norway	206 male players Mean age 24	Shoulder problems affecting player´s participation, training volume and performance, as well as shoulder pain last 7 days; self-reported bi-weekly	Isometric make (HHD, N) IR: supine[b] ER supine[b] ABD: standing[d]	Reduced ER strength associated with increased probability of injury (OR 0.71 per 10N change, 95% CI 0.44 to 0.99)
Møller et al. (2017) Prospective cohort, 2013-14, 1 season Elite youth, Denmark	679 male and female Age 14-18	Any handball related shoulder problem irrespective of time loss and medical attention; self-reported weekly	Isometric make (HHD, N) IR: supine[a/e] ER: supine[a/e] ABD: standing[d]	ER:IR ratio <0.75 accentuated the effect of handball load on shoulder injury rate at an increase in weekly handball load between 20% to 60% (HR 4.0, 95% CI 1.1 to 15.2) or above 60% (HR 4.2, 95% CI 1.4 to 12.8)
Volleyball				
Forthomme et al. (2013) Prospective cohort, 2008-09, 6 months I and II div, Belgium, France, the Netherlands and Luxembourg	66 players Gender distribution NR Mean age 24	Shoulder pain during the season; self-reported weekly	Isokinetic torque (Nm) IR: supine? ER: supine? 60 and 240°/ con 60°/ ecc	IRecc and ERecc associated with reduced probability of injury, OR 0.95 per 1N change and OR 0.94 per 1N change respectively

ABD, abduction; con, concentric; ecc, eccentric; ER, external rotation; GH, glenohumeral; HHD, handheld dynamometer; IR, internal rotation; NR, not reported; OR, odds ratio; RR, relative risk; [a]90° GH ABD, 0° GH rotation and 90° elbow flexion; [b]Neutral GH position and 90° elbow flexion; [c]90° GH ABD, 45° HA with thumb up; [d]90° GH ABD in the scapular plane with thumb up; [e]90° GH ABD, 30° GH rotation and 90° elbow flexion

Table 4 Studies investigating the association between scapular dyskinesis and shoulder injury in overhead sport. Only significant results reported ($p<0.05$)

Reference Design and period Level and country	Study group	Injury definition and registration	Measures of scapular function, instrumentation and procedure	Results
Baseball				
Myers et al. (2013) * Prospective cohort, 2010-11, 2 seasons High school, US	246 baseball players Mean age 16.4	All shoulder and elbow injuries leading to time loss or limited exposure; weekly by team medical staff	Subjective evaluation during bilateral ABD and FLX by two testers in standing (video). External load dependent on body weight: < 68.1 kg: 1.4kg, >68.1 kg: 2.3 kg Three categories: normal function, subtle dysfunction or obvious dysfunction In case of disagreement, consensus reached by reviewing videos together with discussion	No differences in injury rates between players with normal scapular function and any degree of dysfunction
Shitara et al. (2017) * Prospective cohort, 1 season High school, Japan	105 male pitchers Mean age 16.3	All shoulder and elbow injuries leading to time loss ≥8 days; self-reported at medical check-ups and at the end of the season	Subjective evaluation during bilateral ABD and FLX by two testers in standing (live) Two categories: Abnormal dyskinesis pattern and normal scapular motion In case of disagreement, consensus reached through discussion	No association between scapular dyskinesis and shoulder or elbow injuries
Handball				
Clarsen et al. (2014a) Prospective cohort, 2011-12, 1 season Elite, Norway	206 male players Mean age 24	Shoulder problems affecting player´s participation, training volume and performance, as well as shoulder pain last 7 days; self-reported bi-weekly	Subjective evaluation during bilateral ABD and FLX by one tester in standing (live and video). External load: 5 kg Three categories: Normal control, slight dyskinesis and obvious dyskinesis Video used if the tester was uncertain during live assessment	Obvious scapular dyskinesis associated with increased probability of reporting shoulder problems (OR 8.41, 95% CI 1.47 to 48.1)

ABD, abduction; FLX, flexion; *combines shoulder and elbow in their outcome

Reference Design and period Level and country	Study group	Injury definition and registration	Measures of scapular function, instrumentation and procedure	Results
Møller et al. (2017) Prospective cohort, 2013-14, 1 season Elite youth, Denmark	679 male and female players Age 14-18	Any handball related shoulder problem irrespective of time loss and medical attention; self-reported weekly	Subjective evaluation during bilateral ABD and FLX by one tester (live). External load: 5 kg for males, 3 kg for females Three categories: Normal control, slight dyskinesis and obvious dyskinesis	Scapular dyskinesis (any) accentuated the effect of handball load on shoulder injury rate at an increase in weekly handball load between 20-60% (HR 4.8, 95% CI 1.3 to 18.3)
Overhead sport				
Struyf et al. (2014) Prospective cohort, 2 years Recreational, Belgium	113 athletes 26 tennis 37 volleyball, 5 baseball 35 badminton 10 handball Mean age 34	Any physical shoulder complaint present during the last month (>1 day) irrespective of time loss and medical attention; self-reported at 12 and 24 months follow-up	Subjective evaluation of (1) resting position and (2) during unloaded bilateral ABD in standing, two categories: impaired (anterior tilt/winging) and normal (3) Distance from acromion to the table in supine (cm) (4) Scapular upward rotation and humeral abduction in standing (inclinometer, °)	None of the scapular assessments predicted development of shoulder pain measured at 12 and 24 months followed up. Athletes developing shoulder pain demonstrated less upward scapular rotation at 45° and 90° of humeral abduction at baseline.
Volleyball				
Forthomme et al. (2013) Prospective cohort, 2008-09, 6 months I and II div, Belgium, France, the Netherlands and Luxembourg	66 players Gender distribution NR Mean age 24	Shoulder pain during the season; self-reported weekly	(1) Distance between the spine and of the scapula proximal border and the corresponding spinous process in standing with arms at the side (cm) (2) Distance from the posterior edge of the acromion to the table in supine position with arms at the side (cm)	None of the measurements associated with shoulder pain

ABD, abduction; FLX, flexion

External load

An overview of cohort studies investigating the association between external load and shoulder injuries in overhead sport is presented in Table 5. Five of the seven studies identified have been carried out in baseball, with the majority using pitch count as a measure of throwing workload. Among youth pitchers, the number of pitches performed per game and per season, as well as innings per years has been reported to be associated with shoulder pain irrespective of time loss, resulting in suggested pitching limits of 75 per game and 600 per season (Lyman et al., 2001; Lyman et al., 2002). In addition, pitching more than 100 innings per year has been found to be associated with serious shoulder and elbow injuries requiring surgery or leading to retirement among youth pitchers (Fleisig et al., 2011). Among adolescent pitchers, the recommendations are to avoid pitching competitively more than eight months per year with a maximum of 80 pitches per game, as these measures are reported to be associated with shoulder and elbow surgery (Olsen et al., 2006b). In a recent study using training hours per week as measure of load in baseball, Matsuura et al. (2017) reported that players exceeding 16 hours per week were more likely to experience shoulder and elbow injuries leading to time loss. Using video recordings and live observation to monitor throwing workload in elite cricket, Saw et al. (2011) reported an association between performing more than 75 throws per week and shoulder or elbow pain. Interestingly, injured players in this study demonstrated to have increased their throwing workload significantly the week prior to injury onset. Recently Møller et al. (2017) were the first to investigate risk factors for shoulder injury in overhead sports using an analysis accounting for interactions as proposed by Bittencourt et al. (2016). With handball participation considered as the primary risk factor in junior elite handball, they reported an association between a weekly increase in handball load exceeding 60% and the rate of shoulder injuries. Furthermore, they demonstrated that the effect of an increase in handball load between 20% and 60% was exacerbated by the presence of external rotation weakness and scapular dyskinesis. Additionally, external rotation weakness was reported to exacerbate the effect of an increase above 60% (Møller et al., 2017).

Based on the evidence available at the commencement of this PhD project (2014), we wanted to design and evaluate the effect of an exercise programme designed to reduce the prevalence of overuse shoulder injuries in elite handball through alteration of suggested risk factors, i.e. reduced glenohumeral range of motion, external rotation weakness and scapular dyskinesis (Paper I). Additionally, we wanted to assess whether the previously identified risk factors could be confirmed in a relevant population using similar methods (Paper II).

Table 5 Studies investigating the association between external load and shoulder injury in overhead sport. Only significant results reported ($p<0.05$)

Reference Design and period Level and country	Study group	Injury definition and registration	Measures of load and procedure	Results
Baseball				
Lyman et al. (2001) Prospective cohort, 2 seasons Youth, US	298 pitchers 398 pitcher seasons Mean age 10.8	Pain or soreness in the elbow or shoulder during or after pitching in a game irrespective of time loss; telephone interview of pitchers after each game and at the end of the season	Number of pitches per game; by coaches using a pitch count book and self-reported during end of season interview	Every 10 pitches thrown in a game increased the odds of shoulder pain (OR 1.15, 95% CI 1.08 to 1.23) Throwing ≥75 pitches in a game increased the odds of shoulder pain (OR 3.22, 95% CI 1.84 to 5.61)
Lyman et al. (2002) Prospective cohort, 1 season Youth, US	476 pitchers Mean age 12	Pain or soreness in the elbow or shoulder during or after pitching in a game irrespective of time loss; telephone interview of pitchers after each game and at the end of the season	Each team kept a pitch count log of game pitches thrown by each pitcher	A steady increase in OR was observed for the associations reported between number of pitches (per game and per season) and shoulder pain, suggesting that there is no optimal pitch limit. However, authors suggested that limits of 75 pitches per game (OR 1.52) and 600 per season (OR 2.90) should be considered
Olsen et al. (2006b) * Retrospective cohort, 1 year Adolescents, US	95 pitchers; mean age 18.6 45 controls; mean age 18.3	Any shoulder or elbow surgery performed by the senior author between Sept 2003 to Sept 2004	Questionnaires completed by telephone to record pitching history and competition habits one year retrospectively	Competitive pitching for more than 8 months per year (OR 5.05, 95% CI 1.39 to 18.32) and more than 80 pitches per game (OR 3.83, 95% CI 1.36 to 10.77) was associated with surgery.
Fleisig et al. (2011) * Prospective cohort, 1999-2008, 10 years Youth, US	481 male pitchers Age 9-14 years	Any elbow or shoulder surgery or retirement due to a throwing injury; self-reported during an annual survey	Number of innings and team affiliation during the past fall, winter, spring and summer was self-reported during an annual survey per telephone	Pitching more than 100 innings in a year was associated with serious injuries (OR 3.5 95% CI 1.2 to 10.4)
Matsuura et al. (2017) * Prospective cohort, 1 year Youth, Japan	900 players Mean age 9.5	Any shoulder or elbow pain leading to time loss; self-reported retrospectively at one year follow-up	Training hours per week; self-reported retrospectively at one year follow-up	Average training load >16 hours per week associated with shoulder or elbow pain (OR 2.00, 95% CI 1.07 to 3.92)

HR, hazard ratio; OR, odds ratio; RR, relative risk; *combines shoulder and elbow in their outcome

Reference Design and period Level and country	Study group	Injury definition and registration	Measures of load and procedure	Results
Cricket				
Saw et al. (2011) * Prospective cohort, 2007-08, 1 season Elite, Australia	28 players, Mean age 24.4	Any throwing related shoulder or elbow pain leading to medical attention; team medical staff	Throwing workload was monitored by either video recordings or live observation, only overhead throws recorded	Players throwing >75 throws per week at increased risk of injury (RR 1.73, 95% CI 1.03 to 2.92). In the week before injury onset, injured players had increased their throwing workload; more throws (≈ 146 vs 107), more throwing days (≈ 4 vs 3) and less rest days (≈ 1 vs 3).
Handball				
Møller et al. (2017) Prospective cohort, 2013-14, 1 season Elite youth, Denmark	679 male and female players Age 14-18	Any handball related shoulder problem irrespective of time loss and medical attention; self-reported weekly	Weekly handball load defined as the amount of hours of handball playing (training and match hours) recorded weekly using an SMS system. Change in handball load calculated by dividing the load in the current week by the average of the preceding four weeks	An increase in weekly handball load >60% associated with greater shoulder injury rate (HR 1.91, 95% CI 1.00 to 3.70)

HR, hazard ratio; OR, odds ratio; RR, relative risk; *combines shoulder and elbow in their outcome

Prevention of injuries in handball

The traditional four-stage approach to prevention of sports injuries introduced by van Mechelen et al. (1992) is completed by development of preventive measures (stage 3) on the basis of epidemiology (stage 1) and aetiology (stage 2), in which the effectiveness ultimately is assessed in randomised controlled trials (stage 4). Existing preventative efforts in handball have mainly targeted acute and severe injuries to the lower extremities, with a particular focus on the knee and ankle (Table 6). The common features of these studies are employment of exercise programmes as a part of the handball warm-up, with players as end-users and coaches as delivery agents. Among youth female players, overall reduction of acute injuries has been reported in two studies using balance board and strength training (Wedderkopp et al., 1999; Wedderkopp et al., 2003), with only ankle and finger sprains reaching statistical significance when comparing location and type (Wedderkopp et al., 1999). In a quasi-experimental study in senior female handball, a reduced risk of anterior cruciate ligament injuries was reported among elite players meeting the compliance criteria (Myklebust et al., 2003). Among youth players a structured warm-up programme designed to improve awareness and control of knees and ankles during landing and cutting movements reduced the risk of acute injuries to the lower limb (Olsen et al., 2005).

No intervention studies targeting shoulder injuries in handball specifically, or overhead sport in general, existed at the initiation of this PhD project, and we therefore included this as the aim of Paper I.

However, during the project period, two studies investigating preventative efforts to reduce shoulder injuries in handball have been published. In a six-month pilot study including three elite youth female teams in the intervention group (53 players), they reported that the prevalence of shoulder complaints decreased during the intervention period among players completing specific shoulder-strengthening exercises (descriptive statistics pre and post). The exercise programme was implemented as a part of the handball warm-up three times per week (compliance 73%) and consisted of three exercises, push-up plus, standing shoulder external rotation and internal rotation with elastic band as resistance (Østerås et al., 2015). Recently, the same research group published a seven-month randomised controlled trial with a similar sample and size (53 players in the intervention group), reporting no effect of a shoulder-strengthening exercise programme on the prevention of shoulder pain among youth female handball players (Sommervold & Østerås, 2017). However, the sample size, injury definition, registration method and statistics used to assess the effect of the programme can be questioned. To exemplify, current self-reported pain in the throwing shoulder was registered seven times during the season using a visual analog scale, with comparison of the mean group values at each time point using independent t-tests, without any efforts to assess changes and differences over time, despite the use of repeated measures.

Table 6 Intervention studies aiming to reduce injuries in handball. Only significant results reported ($p<0.05$)

Reference Design and follow-up Level and country	End users Delivery agents Implementation	Study group	Injury definition and registration	Comparison of intervention	Results
Wedderkopp et al. (1999) Cluster-RCT, 10 months Youth elite, intermediate and recreational Denmark	All players Coaches Part of the warm-up to training sessions	22 female teams IG: 11 teams, 111 players CG: 11 teams, 126 players Age 16-18	All injuries leading to time loss or unable to participate without considerable discomfort; self-reported at time of injury (coach administered)	***IG:*** 10-15 min balance board training and an exercise programme targeting major muscle groups of the upper and lower extremities ***CG:*** Continue as normal	Overall reduction in number of acute and overuse injuries. Only ankle- and finger sprains significantly lower when comparing location and type. Compliance NR
Wedderkopp et al. (2003) Cluster-RCT, 9 months Youth elite, intermediate and recreational Denmark	All players Coaches Part of the warm-up to training sessions	16 female teams IG: 8 teams, 77 players CG: 8 teams, 86 players Age 14-16	All injuries leading to time loss or unable to participate without considerable discomfort; self-reported at time of injury (coach administered)	***IG:*** Functional strength training and 10-15 min balance board training ***CG:*** Functional strength training only	Overall reduction of acute injuries. Compliance NR
Myklebust et al. (2003) Quasi-experimental, 3 seasons Top three divisions Norway	All players Coaches Part of the warm-up to training sessions 3/week in pre-season 1/week in season CC: 15 sessions in pre-season with 75% player participation	60 female teams CS: 60 teams, 942 players 1st IS: 58 teams, 855 players 2nd IS: 52 teams, 850 players Mean age injured players 22	ACL injuries; reported by coaches or team medical staff using telephone interview every 1 to 2 months	***CS:*** Injury registration, continue as normal ***1st IS:*** 15 min balance exercises (floor, mat and board) ***2nd IS:*** Progression and more handball specific	In the elite division, the risk of ACL injuries was reduced from the CS to 2nd IS among players meeting the CC (OR 0.06, 95% CI 0.01 to 0.54) 26% fulfilled the CC in the 1st IS (40% in the elite) and 29% in the 2nd IS (50% in the elite)
Olsen et al. (2005) Cluster-RCT, 1 season Youth elite, intermediate and recreational Norway	All players Coaches Part of the warm-up to training sessions 15 consecutive session followed by once a week	120 clubs IG: 61 clubs, 958 players CG: 59 clubs, 879 players Age 15-17	Main outcome: ACL injuries Secondary: all injuries leading to medical attention or time loss; monthly by research personnel using interview	***IG:*** 15-20 min of running, technique, balance, strength and power exercises to improve awareness and control of knees and ankles ***CG:*** Continue as normal	Reduced risk of acute knee and ankle injuries, relative risk 0.53, rate ratio 0.55. Compliance 87%

ACL, anterior cruciate ligament; CC: compliance criteria; CG, control group; CS, control season; IG, intervention group; IS: intervention season; NR, not reported

Considerations on preventing overuse shoulder injuries in handball

Exercise selection

Glenohumeral internal rotation

Several studies have demonstrated increased glenohumeral internal range of motion as a result of stretching procedures for posterior shoulder tightness (McClure et al., 2007; Laudner et al., 2008; Manske et al., 2010; Maenhout et al., 2012). McClure et al. (2007) compared the cross-body stretch with the sleeper stretch in a four-week randomised controlled trial including asymptomatic individuals with limited internal rotation, and showed that both stretching procedures increased internal range of motion, with the sleeper stretch resulting in the greatest increase (20°). The stretching exercises were performed five times per day, with each stretch lasting 5 s. Similarly, it has been shown that a six-week daily sleeper stretch programme (3 repetitions of 30 s) increased the internal rotation of the dominant shoulder (13.5°) (Maenhout et al., 2012). Furthermore, a single session (3 repetitions of 30 s) of the sleeper stretch has been demonstrated to increase internal rotation (3°) in baseball players (Laudner et al., 2008).

Shoulder external rotation strength

Increased shoulder external rotation strength has been reported in a few studies investigating the efficacy of shoulder strengthening exercise protocols (Moncrief et al., 2002; Carter et al., 2007; Niederbracht et al., 2008). Moncrief et al. (2002) showed increased strength (isokinetic) in both shoulder internal and external rotation in healthy individuals after a four-week period using a shoulder exercise protocol consisting of five isotonic exercises: (1) external rotation in the prone position with the shoulder abducted to 90° and elbow flexed to 90°; (2) side-lying external rotation; (3) standing abduction in the scapular plane (empty can position); (4) prone horizontal abduction with the shoulder externally rotated; and (5) prone extension. The exercise protocol was performed five days per week and each exercise was performed with 15 repetitions to failure and repeated two times at each session. Utilizing a shoulder exercise programme developed for tennis players (Roetert et al., 1997), Niederbracht et al. (2008) demonstrated gains in eccentric external total work (isokinetic) and increase in eccentric external to concentric internal total work ratios in an experimental study over five weeks. The programme was performed four times per week (3 sets of 10 to 15 repetitions) and consisted of five isotonic exercises targeting large muscle groups, as well as six rotator cuff exercises, i.e. (1) side-lying external rotation, (2) prone horizontal abduction with the shoulder externally rotated, (3) prone extension, (4) external rotation at 90° of shoulder abduction, (5) standing abduction in the scapular plane (open can position), and (6) external rotation with shoulder in neutral. Furthermore, a plyometric shoulder exercise programme has been reported to increase the eccentric peak torque of the external rotators (isokinetic), as well as throwing velocity, during an eight-week experimental study including collegiate baseball players (Carter et al., 2007). The exercises required minimal equipment (Thera-Bands and weighted balls) and were performed twice weekly (3 sets of 10 to 20 repetitions), including: (1) external rotation with shoulder in neutral, (2) external rotation at 90° of shoulder abduction, (3) overhead soccer throw, (4) backwards throw at 90° of shoulder abduction, (5) eccentric deceleration at 90° of abduction, and (6) baseball throw.

Several studies have used electromyography to investigate the activation of the shoulder external rotators during common exercises used in rehabilitation (Blackburn et al., 1990; Townsend et al., 1991; Ballantyne et al., 1993; Hintermeister et al., 1998; Reinold et al., 2004; Myers et al., 2005; Dark et al., 2007; Swanik et al., 2011). With the objective of describing the effectiveness of 12 rubber-tubing exercises commonly used by throwers, Myers et al. (2005) demonstrated that throwing deceleration produced the highest maximal voluntary isometric contraction (MVIC) of the supraspinatus (64% MVIC), with the MVIC values for the infraspinatus and teres minor muscle reported to be 45% and 90% respectively. External rotation at 90° of abduction produced the greatest activation of the infraspinatus muscle (51% MVIC), with MVIC values for the supraspinatus and teres minor muscle reported to be 50% and 89% respectively. And finally, shoulder flexion resulted in the greatest activation of the teres minor muscle (112% MVIC), with the MVIC values for the supraspinatus and infraspinatus muscle demonstrated to be 42% and 47%, respectively. Investigating a different set of exercises, Reinold et al. (2004) demonstrated that side-lying external rotation produced the highest activation of both the infraspinatus (62% MVIC) and teres minor muscle (67% MVIC), while the greatest amount of supraspinatus activity was revealed during prone horizontal abduction (82% MVIC).

When utilizing standing shoulder external rotation exercises in the rehabilitation of throwing athletes with shoulder pain, it is initially recommended to perform the exercises at 20° to 30° of abduction, with progression towards 90° of abduction, due to its resemblance with the throwing position (Ellenbecker & Cools, 2010).

Scapular dyskinesis

A clinical reasoning algorithm has been proposed to facilitate clinicians' efforts to alter the presence of scapular dyskinesis in overhead athletes with shoulder pain (Cools et al., 2014b). According to the algorithm, scapular muscle performance may be inhibited by both reduced muscle control (neuromuscular deficits) and reduced muscle strength (scapular strength deficits). In the early stage of scapular muscle rehabilitation, therapeutic guided exercises and home-based exercises to improve muscle control is emphasised, followed by advancement to exercises to improve muscle control and introduction of exercises to restore scapular muscle imbalances, i.e. weakness in the serratus anterior, middle trapezius and lower trapezius muscle, and hyperactivity in the upper trapezius muscle (Ludewig & Cook, 2000; Cools et al., 2003; Cools et al., 2007a). Ultimately (in the final stage), exercises to strengthen scapular muscles are emphasised (Cools et al., 2014b). Thus, it seems reasonable to assume that exercises aiming to strengthen serratus anterior, middle trapezius and lower trapezius, while maintaining scapular muscle balance, are appropriate when aiming to prevent shoulder injuries in an active population.

Several studies have investigated scapular muscle activity during different exercises without considering the simultaneous impact on the upper trapezius muscle (Moseley et al., 1992; Hintermeister et al., 1998; Decker et al., 1999; Ekstrom et al., 2003; Myers et al., 2005). Exercises demonstrated to produce high serratus anterior activity includes the push-up plus, shoulder abduction in the scapular plane, forward punch, and shoulder flexion (Moseley et al., 1992; Hintermeister et al., 1998; Decker et al., 1999; Ekstrom et al., 2003; Myers et al., 2005). Furthermore, shoulder extension, prone flexion (Y-flies) and horizontal abduction with external rotation (standing or prone) have been shown to produce high middle trapezius activity (Moseley et al., 1992; Ekstrom et al., 2003). And finally, exercises reported to produce high activity of the lower trapezius includes shoulder abduction, prone flexion (Y-flies), rowing, horizontal abduction with external rotation, external rotation at 90° of abduction and throwing deceleration (Moseley et al., 1992; Ekstrom et al., 2003; Myers et al., 2005).

However, in order to restore scapular muscle imbalances in patients with shoulder pain, exercises demonstrating high activity in the serratus anterior, middle trapezius and lower trapezius, with simultaneously low activity in the upper trapezius, have been emphasised to be preferable (Ellenbecker & Cools, 2010). According to Ludewig et al. (2004) the push-up plus should be emphasised when aiming to strengthen the serratus anterior in patients with an imbalance of upper trapezius to serratus anterior imbalance. However, both the knee push-up plus and the elbow push-up plus are also applicable, as they both demonstrated low ratios of upper trapezius to serratus anterior ratios. Similarly, Andersen et al. (2012) have recommended the push-up plus to strengthen the serratus anterior when investigating scapular muscle activation during shoulder exercises performed at low and high intensities (Borg scale level 3 and 8), as this exercise was superior in activating the serratus anterior over the upper trapezius at intensities sufficient to strengthen the serratus anterior. To promote middle and lower trapezius activity in the treatment of scapular imbalances, Cools et al. (2007b) have recommended clinicians to use side-lying external rotation, side-lying forward flexion, prone horizontal abduction with external rotation, and prone extension. When investigating exercises during different intensities, Andersen et al. (2012) demonstrated that the favourable shift toward lower trapezius activity during prone exercises disappeared at higher intensities (Borg scale 8), as all three parts of the trapezius showed high activation. Furthermore, they reported that the press-up was preferable with respect to a low upper to lower trapezius ratio at higher intensities. However, as this activation only was found to be moderate, the authors expressed uncertainty regarding the possibility to induce strength gains when performing this exercise.

In a 12-week experimental study aiming to evaluate and compare the effect of two different exercise protocols, aiming to increase either scapular muscular strength or endurance in adolescent swimmers, Van de Velde et al. (2011) demonstrated similar improvements of the protocols with respect to strength. However, none of the protocols resulted in increased muscular endurance. The exercise selection was similar for both protocols and consisted of two exercises targeting the serratus anterior muscle, i.e. dynamic hug and elbow push-up and two exercises targeting the entire trapezius muscle, i.e. side-lying external rotation and prone horizontal abduction with scapular retraction. Both protocols were supervised by a physiotherapist and performed three times per week prior to swimming training sessions. Participants performing the strength protocol completed 3 sets of 10 repetitions to failure, whereas the participants performing the endurance protocol completed 3 sets of 20 repetitions to failure.

Interaction between exercises

It is important to note that exercises described to target scapular muscles also stimulate the shoulder external rotators and vice versa, e.g. reports suggests high activation of the infraspinatus and teres minor muscles during different scapular rowing exercises and prone horizontal abduction (Townsend et al., 1991; Myers et al., 2005), whereas high activation of the serratus anterior and lower trapezius muscle has been reported during shoulder internal and external rotation at 90° of abduction (Ekstrom et al., 2003; Myers et al., 2005). This should be considered as an advantage when planning exercise programmes and underlines the interaction between scapulothoracic and scapulohumeral muscles.

Multifactorial exercise programmes

In a six-week randomised controlled trial aiming to evaluate the effectiveness of a six-week strengthening and stretching exercise programme in collegiate swimmers (n=37), Hibberd et al. (2012) revealed no significant findings with respect to isometric shoulder strength measures or scapular kinematics. No outcome measures were reported for glenohumeral range of motion. The exercise programme was implemented three times per week after swimming practice and consisted of eleven strength exercises (2 sets of 15 repetitions), with no compliance data reported. Elastic bands were utilized to apply resistance during the strength exercises, which included (1) shoulder flexion, (2) shoulder extension, (3) internal and (4) external rotation at 90° of abduction, (5) throwing acceleration and (6) deceleration, (7) low rows, (8) scapular punches, (9) Y-flies, (10) T-flies, and (11) W-flies.

In a 20-week cohort study, Moore et al. (2013) investigated the effect of an exercise programme combining typical field-based exercises (elastic-resisted) with traditional strength exercises (weight-resisted) to increase shoulder musculature endurance. The authors emphasised the elastic-resistance exercises as the core of the programme, and were performed three times per week throughout the study period, including one clinical based session and two field based sessions. Exercise load was either based on time with progression to longer durations, i.e. 3 sets of 30 s repetitions with 15 s progression per week, or sets and repetitions with a stair-step progression, i.e. 3 sets with weekly increase in repetitions (from 10, 12, 15 and finally 20), or simply progression from 1 set of 15 repetitions to 3 sets of 15 repetitions. The elastic resistance exercises consisted of three rowing exercises: (1) low row, (2) mid row, and (3) high row. To evaluate shoulder musculature endurance, they developed a test based on the prone horizontal abduction exercise (Posterior Shoulder Endurance Test), in which participants performed significantly more repetitions at four time points during the study period (4, 8 and 20 weeks) compared to baseline.

Prescribing exercise load

When designing exercise programmes, load is emphasised as an important variable and refers to the amount of weight assigned to an exercise set (McDonagh & Davies, 1984). The load can be determined as either a percentage of one repetition maximum (1 RM), e.g. 60% of 1 RM, or by the RM method, i.e. the greatest amount of weight lifted with optimal technique for a specified number of repetitions, e.g. 15 RM (DeLorme, 1945). Prescribing load using the RM method is thought to be superior to the percentage of 1 RM method, as this eliminates the need for repeated 1 RM testing to secure optimal exercise effectiveness (Hass et al., 2001; Bird et al., 2005), and can be an alternative when 1 RM testing is inappropriate, e.g. when using elastic bands to achieve external resistance. To secure exercise progression, it is recommended to progress the load whenever a subject can perform the current load for one to two repetitions over the desired number (Kraemer et al., 2002). According to a review providing guidelines on how to design exercise programmes to enhance muscular fitness (Bird et al., 2005), the load prescription should be 1 to 3 sets of 15 to 20 RM to enhance muscular endurance, 4 to 6 sets of 8 to 15 RM to achieve hypertrophy and 3 to 5 sets of 3 to 8 RM to increase maximal strength. These recommendations illustrate that a certain RM emphasises different outcomes. However, in reality, the benefits of resistance training are blended at any given RM (Bird et al., 2005).

In addition to these recommendations, knowledge of exercise loads reported to be effective in existing studies can be useful when planning the load prescription of exercise programmes. Previous high quality intervention studies in team sport have demonstrated effect of strength exercises aiming to prevent acute injuries to the lower limb, using load prescriptions of 3 sets, each consisting of 8 to 15 repetitions, without application of the RM method (Olsen et al., 2005; Walden et al., 2012). Furthermore, the studies demonstrating increased shoulder external rotation strength applied different load prescriptions, with the frequency ranging from 2 to 5 days per week, the number of sets from 2 to 3 and the number of repetitions from 10 to 20 (Moncrief et al., 2002; Carter et al., 2007; Niederbracht et al., 2008), with only one study applying the RM method (Moncrief et al., 2002). And finally, the studies aiming to increase scapular muscle strength, prescribed the exercises to be performed 3 times per week, with the number of sets ranging from 2 to 3, and the number of repetitions ranging from 10 to 15 (Van de Velde et al., 2011; Hibberd et al., 2012), with only one of them utilizing the RM method (Van de Velde et al., 2011).

Elastic tubing as resistance in strength exercises

Using electromyography, Andersen et al. (2012) investigated shoulder muscle activation during lateral raise and shoulder external rotation with dumbbells compared to elastic tubing as resistance. Interestingly, their results revealed high levels of muscle activation during both procedures, demonstrating that elastic tubing is well suited as an alternative to achieve resistance. The same research group investigated infraspinatus and trapezius muscle activation during lateral rise using elastic band as resistance, and showed that a plateau of high-level muscle activity was reached at 10 to 12 repetitions of the predetermined 15 RM load. This illustrates that training to complete failure is not necessary to fully recruit the involved muscles and strength gains may be achieved without the unpleasant experience of going to failure (Sundstrup et al., 2012).

Facilitators and barriers to implementation

All intervention studies aiming to evaluate an injury preventive effect of an exercise programme in sport are highly dependent on successful adoption and implementation. According to existing injury prevention studies in team sport, several facilitators and barriers to implementation have been reported (Cumps et al., 2007; Engebretsen et al., 2008; Soligard et al., 2008; Steffen et al., 2008; Kraemer & Knobloch, 2009; Kiani et al., 2010; Soligard et al., 2010; Petersen et al., 2011; Finch et al., 2014), and should be considered when planning exercise programmes. With respect to the implementation setting, the ability to integrate the exercise programme as a part of teams' normal training sessions, e.g. the warm-up, has been reported as an important facilitator (Soligard et al., 2008; Kraemer & Knobloch, 2009; Kiani et al., 2010). Considering the total number of exercises included in the programme, variation and progression have been emphasised (Soligard et al., 2008; Steffen et al., 2008; Finch et al., 2014). Furthermore, the exercises should seek to be sport specific, and if possible, include interaction with a partner (Cumps et al., 2007; Soligard et al., 2008).

However, in order to successfully implement an exercise programme, there are also several barriers to overcome, with the length of the programme most frequently reported as a threat to successful implementation (Cumps et al., 2007; Engebretsen et al., 2008; Soligard et al., 2010; Petersen et al., 2011; Finch et al., 2014). Furthermore, if the programme requires expensive equipment, or if the teams are dependent on their team medical staff to perform the programme, the degree of implementation may be challenged (Cumps et al., 2007).

The evidence presented regarding exercise selection and prescription of exercise load, as well as information on facilitators and barriers to implementation, were used to develop the exercise programme evaluated in Paper I.

The research to practice gap

Despite widespread use of the traditional four-stage approach since its origin in the early 90 s, several papers have emphasised the need for integration of implementation science in sports injury prevention research (Finch, 2006; Finch & Donaldson, 2010; Donaldson & Finch, 2012; Hanson et al., 2014). It is argued that evaluation of injury prevention exercise programmes in randomised controlled studies poorly reflects the final implementation context (Finch, 2006; Finch & Donaldson, 2010). Hence, dissemination and widespread use of evidence based prevention programmes in the real-world sport setting may be inhibited, as the full potential will only be realised if the targeted delivery agents and end-users adopt, implement and maintain the programmes as intended (Finch, 2006; Donaldson & Finch, 2012). To meet these challenges, Finch (2006) outlined the Translating Research into Injury Prevention Practice (TRIPP) framework, an extension to the traditional four-stage approach. Subsequent to evaluating programmes under ideal scientific conditions, researchers should aim to understand how to translate them into actions to be implemented in the real-world sport setting (stage 5). Key elements of this stage are knowledge regarding attitudes, beliefs and current behaviours towards injury causes, predisposing factors and preventative measures, as well as identification of facilitators and barriers to implementation of programmes in the targeted population (Finch, 2006; Finch et al., 2011). Finally, the programme effectiveness should be evaluated in a real-world sport setting by implementing it among the intended end users, while taking into account the knowledge identified in stage 5 (stage 6) (Finch, 2006).

To fully understand the complexities of implementation contexts and gain knowledge to improve study designs and dissemination efforts, integration of a five-dimensioned framework from implementation science is recommended in sports injury prevention research: the Reach Efficacy Adoption Implementation Maintenance (RE-AIM) framework (Finch & Donaldson, 2010; O'Brien & Finch, 2014). However, when applying the framework originally developed to enhance the impact of public health research (Glasgow et al., 1999), adjustments are necessary to meet the specific features of a sport setting. To meet these challenges, Finch & Donaldson (2010) proposed an extension to the original framework: the RE-AIM Sports Setting Matrix, which accounts for the fact that preventive measures in sport, such as coach delivered programmes, can be targeted at multiple levels of delivery, e.g. at an organisational level and/or at a club, team and participant level.

To date, studies expanding on the traditional four-stage approach and efforts to report on the dimensions in the RE-AIM framework are lacking in handball, with only one study reporting on the maintenance of preventive measures aimed at anterior cruciate ligament injuries.(Myklebust et al., 2013b) Therefore, in paper III, we wanted to examine attitudes, beliefs and current behaviour towards risk factors and prevention of shoulder injuries, and to investigate the application of the exercise programme in Paper I.

Aims of the dissertation

The overall research aim of this dissertation was to inform injury prevention efforts in elite handball. Three studies encompassed overuse shoulder injuries specifically (Paper I to III) and one dealt with mechanisms of acute match injuries in general (Paper IV).

The following aims were addressed in the four papers:

I. To evaluate the effect of an exercise programme designed to reduce the prevalence and risk of overuse shoulder injuries in elite handball (Paper I).

II. To assess whether previously identified risk factors are associated with overuse shoulder injuries in a mixed-sex cohort of elite handball players (Paper II)

III. To examine attitudes, beliefs and current behaviour towards risk factors and prevention of shoulder injuries, and to investigate the application of the OSTRC Shoulder Injury Prevention Programme during a randomised controlled trial aiming to prevent overuse shoulder injuries in elite handball (Paper III).

IV. To describe the mechanisms of acute match injuries in elite male handball, with emphasis on the events leading up to injures, and to evaluate referee performance in injury situations (Paper IV).

Methods

Study designs and approach

The four papers included in this dissertation were the result of two separate research projects. In the first project, a seven-month cluster-randomised controlled trial to evaluate the preventive effect of an injury prevention exercise programme on overuse shoulder injuries among 660 elite handball players was completed (Paper I), with an embedded prospective cohort study of risk factors for overuse shoulder injuries in the control group (Paper II). Towards the end of the intervention period, we also invited all team captains and coaches in both study arms to take part in a survey addressing end-user perspective on prevention of shoulder injuries, as well as key issues related to the application of the OSTRC Shoulder Injury Prevention Programme in the intervention group (Paper III). In the second project, using prospective video analysis of acute injury situations during the 24th Men´s Handball World Championship in 2015, we described acute injury mechanisms and evaluated referee performance (Paper IV).

Material and participants

In the first project (Paper I, II and III) we aimed to include every male and female handball team in the two top divisions in Norway (n=48). During the off-season in 2014 we contacted coaches for each team, of whom 46 agreed to participate. After recruitment of the final team, a neutral, blinded person who had no further involvement in the study randomised teams stratified by gender and competition level into an intervention or control group, with all players from the same team assigned to the same group. We visited each team during preseason handball training sessions and invited players present to participate on an individual basis, irrespective of their baseline injury status or history. A total of 660 of the 677 players (45 of 46 teams) in the two top divisions were in attendance, agreed to participate and constituted the intervention (331 players, 22 teams) and control arm (329 players, 23 teams) of the trial (Paper I). In parallel, the control group constituted the cohort in the prospective risk factor study (Paper II). Towards the end of the intervention period, we invited all team captains and coaches of the 44 teams (21 intervention, 23 control) still participating in the trial to take part in a survey (Paper III).

The video material included in the second project (Paper IV) consisted of 55 videos of acute injury situations, in which the referee decisions were visible and recorded in 37. All videos were derived from matches during the 24th Men´s Handball World Championship in 2015 using video analysis software. The specific acute injury situations were identified on the basis of injury reports from a previous publication, which also included approximate timing of match injuries (Bere et al., 2015).

In the first project (Paper I, II and III), all players with a team contract were eligible for participation. Written and verbal information regarding the aims of the project, the procedures involved and any potential risk with participation was provided. The Regional Committee for Medical and Health Research Ethics reviewed the project and concluded that, according to the Act on Medical Health and Research, the project did not require full review. The Norwegian Social Science Data Services approved the project, and all players included completed informed consent forms (Appendix II). The second project (Paper IV) was reviewed and approved by the Aspire Zone Foundation Research Committee (Appendix II).

Prevention and risk factors for overuse shoulder injuries

Baseline testing

We visited each team included in the second project (22 intervention, 23 control) during a training session in the six weeks prior to the season. All players (331 intervention, 329 control) were asked to complete a baseline questionnaire (Paper I and II). In the intervention group, coaches, team captains and team medical staff received specific training on the content and execution of the injury prevention exercise programme evaluated in the trial (Paper I). In the control group, all players took part in a series of shoulder tests completed in random order, including measurements of glenohumeral joint range of motion and isometric rotation strength, as well as assessment of scapular control (Paper II).

Questionnaire

In Paper I and II, Information on baseline shoulder injury status and history was collected using a modified version of the Fahlström questionnaire previously used in studies on elite handball players (Appendix III) (Myklebust et al., 2013a; Clarsen et al., 2014a). Players were also asked whether they had sustained any acute shoulder injuries within the past six months and if they had undergone any shoulder surgery within the past 12 months. This information was crosschecked with the team medical staff. Finally, we recorded any shoulder problems during the previous week using the OSTRC Overuse Injury Questionnaire previously used in a study on elite male handball players (Appendix III) (Clarsen et al., 2014a).

Shoulder tests

In paper II, six different test teams, each of two sports physiotherapists, performed the shoulder testing, with one tester responsible for questionnaire administration and assessment of scapular control, and the other measuring glenohumeral range of motion and isometric strength. Prior to baseline testing, we performed three days of training and assessed the inter- and intrarater reliability of the testers in a pilot study. Three testers, blinded to the results of each other, measured glenohumeral range of motion and isometric rotational strength in 38 shoulders in a random order at two time points within the same day and three testers assessed scapular control following the same procedure.

Glenohumeral range of motion

The test procedure employed to measure glenohumeral range of motion was identical to the one used by Clarsen et al. (2014a) in a previous risk factor study on elite male handball players. We used a digital inclinometer attached to a 30 cm Perspex ruler (Acumar Digital Inclinometer, Lafayette Instrument, Lafayette, Indiana, USA), with the player in supine and with their shoulder abducted to 90° with 0° rotation and the elbow flexed to 90° (Wilk et al., 2009; Cools et al., 2014a; Møller et al., 2017). The end of internal and external rotation was defined as the point at which the scapula was felt to move during palpation of the coracoid process and the spine of the scapula (Wilk et al., 2009).

Isometric strength

We used a digital handheld dynamometer (MicroFET, Hoggan Health Industries, Salt Lake City, Utah, USA) to measure isometric rotational strength on the dominant side, with the player in supine, similar to the procedure by Clarsen et al. (2014a). However, due to the use of multiple testers, we externally fixed the dynamometer to limit measurement error related to manual fixation.(Møller et al., 2017) In addition, we modified the position of the shoulder to 90° abduction with 0° rotation (Hayes et al., 2002; Cools et al., 2014a), as this position is more comparable to the overhead throwing motion in handball.

Scapular control

The procedure used to assess scapular control was identical to the one used by Clarsen et al. (2014a). We observed players perform five repetitions of bilateral flexion and abduction while holding an external weight: 5 kg for males and 3 kg for females (Møller et al., 2017). Each shoulder was rated as having normal control, slight scapular dyskinesis or obvious scapular dyskinesis (McClure et al., 2009).

The injury prevention exercise programme

When planning and developing the OSTRC Shoulder Injury Prevention Programme in Paper I, we predefined two fundamental premises of the programme. First, the exercises should be able to alter previously proposed and identified risk factors for shoulder injuries in elite handball, i.e. reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis (Almeida et al., 2013; Edouard et al., 2013; Clarsen et al., 2014a). And second, the programme should incorporate recommendations from previous studies reporting on the implementation of injury prevention exercise programmes in team sport (Cumps et al., 2007; Engebretsen et al., 2008; Soligard et al., 2008; Steffen et al., 2008; Kraemer & Knobloch, 2009; Kiani et al., 2010; Soligard et al., 2010; Petersen et al., 2011; Finch et al., 2014). Hence, the programme should require minimal equipment and fit into the handball warm-up, with a maximum duration of ten minutes, and coaches and team captains should manage to deliver the programme without involvement of their team medical staff. The development process is illustrated in Figure 1.

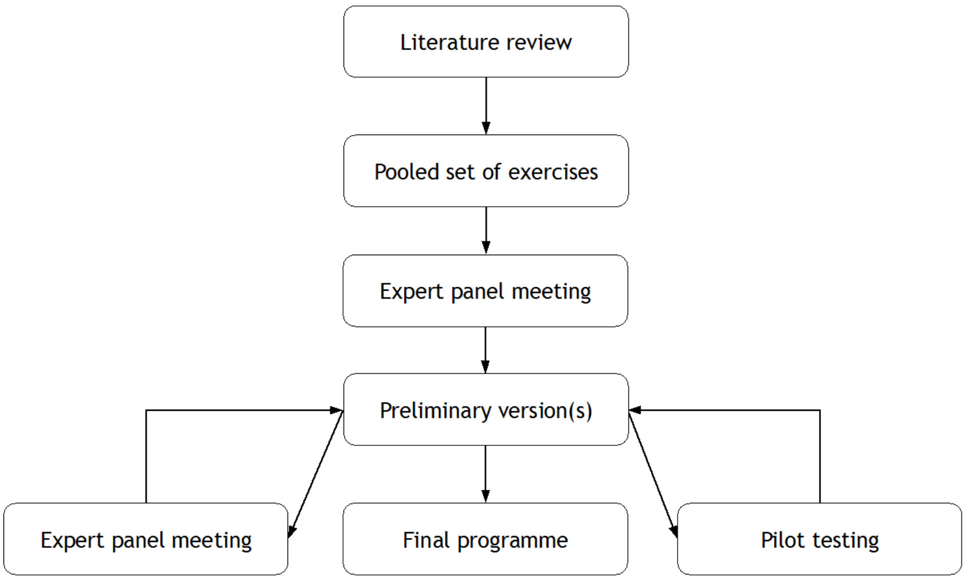


Figure 1. Flow chart illustrating the development of the OSTRC Shoulder Injury Prevention Programme.

Based on a literature review (Appendix I), we created a pooled set of exercises previously reported to alter the targeted risk factors. Due to a low number of experimental studies, we also included exercises demonstrated to produce high activation of the shoulder external rotators (supraspinatus, infraspinatus, teres minor), as well as scapular muscles emphasised in the rehabilitation of scapular dyskinesis (serratus anterior, middle trapezius, lower trapezius) (Cools et al., 2014b). Overall, the pooled set of exercises included the cross-body stretch and sleeper stretch to increase glenohumeral internal rotation (McClure et al., 2007; Laudner et al., 2008; Manske et al., 2010; Maenhout et al., 2012), various isotonic and plyometric exercises to strengthen shoulder external rotators (Moncrief et al., 2002; Reinold et al., 2004; Myers et al., 2005; Carter et al., 2007; Niederbracht et al., 2008), and various isotonic exercises to enhance scapular muscle strength (Moseley et al., 1992; Hintermeister et al., 1998; Decker et al., 1999; Ekstrom et al., 2003; Myers et al., 2005; Van de Velde et al., 2011), in which a selection considered the simultaneous impact on the upper trapezius muscle (Ludewig et al., 2004; Cools et al., 2007b; Andersen et al., 2012).

An external expert panel consisting of a fitness coach employed by the Norwegian Handball Federation (>10 years of experience) and four physiotherapists (5 to >10 years of experience) clinically working with handball players nationally and internationally reviewed the pooled set of exercises and participated in meeting to provide their feedback. The objectives of this meeting were to get their opinions on the content of the programme and thoughts on how we could enhance adoption and implementation. In relation to the content, they urged us to include exercises to enhance thoracic mobility and improve kinetic chain function, as these factors often are implicated in shoulder injuries (Lintner et al., 2008; Kibler et al., 2013a; Kibler et al., 2013b; Kibler et al., 2013c), despite a lack of evidence supporting their role as risk factors for shoulder injury. Based on their experience with player compliance, they expressed scepticism to exercises requiring players to be placed in a supine or prone position, and recommended exercises to be as sport-specific as possible (Cumps et al., 2007), e.g. strengthening of external rotators should be performed in a 90° abducted position due to its resemblance with the handball throw (Ellenbecker & Cools, 2010). In addition, they emphasised variation and progression of exercises, as well as inclusion of partner exercises to enhance motivation to comply with the programme (Cumps et al., 2007; Soligard et al., 2008; Steffen et al., 2008).

Subsequent to the expert panel meeting, we invited a female handball team in the second division (n=16), not included in the study, to test the preliminary exercise programme and respond to a questionnaire based on the RE-AIM framework. The objectives of this pilot were to obtain knowledge regarding potential end-users beliefs and experiences of content, duration, load and applicability of the programme (Donaldson & Finch, 2012; Finch et al., 2014). In addition, we had a short meeting with the players and coaches to receive verbal feedback. The knowledge obtained supported exercise variation and inclusion of partner exercises as previously mentioned, as well as sport-specific exercises imitating the throwing position. Subsequently, we performed two additional revisions of the exercise programme, including a second round of feedback from the expert panel.

The final version of the OSTRC Shoulder Injury Prevention Programme consisted of five exercises with different variations and levels aiming at increasing glenohumeral internal range of motion, external rotation strength and scapular muscle strength, as well as improving kinetic chain function and thoracic mobility. We recommended implementing the exercise programme three times per week as a part of the team's warm-up to handball training. Coaches and team captains were delivery agents and received, together with the team medical staff, specific instructions and training on the content and execution of the exercise programme. The complete exercise program is presented with illustrations in Appendix IV.

The final version did not solely include evidence-based exercises. In fact, the recommendations from the expert panel and the feedback provided by the potential end-users in the pilot study were highly weighted to include exercises that potentially would secure compliance with the programme. Hence, we primarily included exercises that were thought to be sports specific and applicable for the handball warm-up (Table 7).

Exercises targeting the serratus anterior muscle (1A-C) consisted of different variations of the push-up plus exercise (Moseley et al., 1992; Decker et al., 1999; Ludewig et al., 2004; Andersen et al., 2012), with modifications to enhance player motivation and sport specificity, e.g. inclusion of a handball and a partner. In addition, we extended the traditional push-up plus exercise with a backward slide of the body (1C) to simultaneously facilitate upward rotation of the scapula during shoulder flexion (Ekstrom et al., 2003). Initially we aimed to include side-lying external rotation, side-lying forward flexion, prone horizontal abduction with external rotation, and prone extension to target both scapular muscles and shoulder external rotators (Moncrief et al., 2002; Reinold et al., 2004; Cools et al., 2007a; Niederbracht et al., 2008). However, as both the expert panel and the potential end-users expressed scepticism to these exercises due to the position of the player, we refrained from adding them in fear of low compliance. Hence, abduction in the scapular plane with external rotation was added to target the middle and lower portions of the trapezius muscle (2A) (Moseley et al., 1992; Ekstrom et al., 2003), despite reports of high activity in the upper trapezius muscle during this exercise (Ekstrom et al., 2003). Furthermore, a modified version of bilateral rowing was added to target the middle trapezius (2B) (Hintermeister et al., 1998), as feedback from the expert panel and potential end-users suggested high compliance with this exercise. The throwing deceleration (2C) was added to increase strength in shoulder external rotators and our reports suggested high compliance with this exercise (Myers et al., 2005).

The exercises targeting dynamic mobility in the thoracic (3A), the latissimus dorsi muscle (3B) and the protractors and internal rotators of the shoulder (3C) were solely included based on recommendations from the expert panel. The sleeper stretch (4A) and cross-body stretch (4B) were included to increase internal rotation (McClure et al., 2007; Laudner et al., 2008; Manske et al., 2010; Maenhout et al., 2012), with inclusion of a partner in the cross-body stretch to enhance implementation (Soligard et al., 2008). Additional exercises included to increase shoulder external rotation strength (5A-C) were based on studies reporting high activity in the shoulder external rotators at 90° of abduction (Ballantyne et al., 1993; Reinold et al., 2004; Myers et al., 2005). This position corresponded also with the shoulder position favoured by the expert panel and potential end-users (Cumps et al., 2007). The plyometric exercises targeting external rotation strength (5B-C) were based on previous exercises showing increased eccentric peak torque of the external rotators (Carter et al., 2007), and we received promising feedback regarding expected compliance from both the expert panel and potential end-users.

Whenever possible, exercises to increase external rotation strength and scapular muscle strength were performed in a position involving segments in the kinetic chain proximal to the shoulder, e.g. push-up position (3A-C) involving core musculature or standing throw position (2A-C and 5A-C) involving energy transfer through the lower extremities, pelvis and trunk to the shoulder (Sciascia et al., 2012).

Table 7 Description of the OSTRC Shoulder Injury Prevention Programme (see appendix IV for pictures)

Exercise	Variation/level	Description to intervention teams	Dosage
1	A	Push-up plus* on elbows combined with alternating trunk rotation towards the ceiling	3 x 8-16 repetitions
	B	Static push-up plus position* on hands combined with ball pass with partner, alternating hands	
	C	Push-up plus* on hands combined with backwards slide of the body, maintain neutral spine	
2	A	Standing Y-flies**, pull the elastic band with straight arms towards the ceiling in a Y-position, pair exercise	3 x 8-16 repetitions
	B	Bow and arrow**, start by drawing shoulder back/down and follow through with arm and trunk rotation	
	C	Slow arm lowering**, tighten the elastic with two hands to maximum throwing position, return slowly with one hand (3 s)	
3	A	Alternating trunk rotation from a four point kneeling position, point hands towards ceiling	3 x 8-16 repetitions
	B	Dynamic latissimus dorsi stretch, stand with elbows against a wall, slide arm upwards, keep forearms vertical, maintain neutral spine	
	C	Dynamic W-stretch, stand with back against a wall, slide arms upwards, keep forearms, head and spine against wall	
4	A	Sleeper stretch, lie on your shoulder blade to stabilise it, keep shoulder slightly under 90°, push hand towards the floor	3 x 30 s
	B	Cross-body stretch, keep shoulder slightly under 90°, partner stretch elbow across body and prevents shoulder blade from moving	
5	A	External rotation**, keep the elbow in 90°, use a ball or small weight as resistance	3 x 10-20 repetitions
	B	Drop and catch**, keep the elbow in 90°, drop the ball and catch it quickly, return to start, use a ball or small weight as resistance	
	C	Backwards throw**, partner throws a ball from behind, catch the ball and throw it back using backwards rotation of the shoulder	

* The plus-up plus position is achieved by pushing hands/elbows towards the floor by pushing shoulder blades forward and out
** Pre-position your shoulders before starting the exercise by lifting your chest and pulling your shoulder blades slightly back and down

Exercises aiming to increase internal rotation (4A-B) were prescribed to be performed with a static stretch of 30 s and repeated three times per session, which is within the upper and lower prescription in previous studies reporting an effect of these exercises (McClure et al., 2007; Laudner et al., 2008; Manske et al., 2010; Maenhout et al., 2012). Exercises included to increase strength (1A-C, 2A-C and 5A-C) were instructed to be performed in three sets of either 8 to 16 repetitions or 10 to 20 repetitions, which is in line with recommendations to induce hypertrophy or increased muscular endurance (Bird et al., 2005). Similar exercise loads have been prescribed in previous studies showing increased strength of both shoulder external rotators and scapular muscles (Moncrief et al., 2002; Carter et al., 2007; Niederbracht et al., 2008; Van de Velde et al., 2011), as well as been applied in studies demonstrating injury preventive effect of strength exercises in team sport (Olsen et al., 2005; Walden et al., 2012). Delivery agents were instructed to inform players to progress an exercise if they exceeded the maximum repetitions stated (RM method) (DeLorme, 1945; Kraemer et al., 2002), e.g. by using a stiffer elastic band or heavier weighted ball. In contrast, players should regress an exercise if they did not reach the minimum repetitions stated. As no optimal exercise load was identified for dynamic mobility exercises (3A-C), we chose to prescribe the same load as for the strength exercises to secure programme continuity.

Prospective data collection

The same registration method was used to monitor shoulder problems during the 2014-2015 season in Paper I and Paper II. On the last Sunday of each month, six times in total, all players received a link by e-mail, providing them access to the OSTRC Overuse Injury Questionnaire (Appendix V) using online survey software (Questback v.9692, Questback AS, Oslo, Norway). Automatic reminders were sent to non-responders after three and seven days per e-mail using the survey software and manually per SMS (Pling, Front Information DA, Oslo, Norway). In addition, we visited teams throughout the season and asked non-responders to complete a paper version of the questionnaire.

The questionnaire consisted of four questions addressing the extent to which overuse shoulder injuries, expressed as shoulder problems, affected participation, training volume and performance, as well as the level of shoulder pain during the past week (Clarsen et al., 2013). We only asked players about their throwing shoulder, with shoulder problems defined as any pain, ache, stiffness, instability, looseness or other symptoms related to their shoulder (Clarsen et al., 2014a).

To avoid misreporting of acute shoulder injuries as shoulder problems, and ensure that we could exclude them from the dataset, we added a supplementary question in which players reported any acute shoulder injury during the past week, defined as an injury caused by a single identifiable event (Fuller et al., 2007). In addition, team medical staff reported any acute shoulder injury by e-mail at the end of each month and their records was crosschecked with player reports.

We recorded player exposure to handball training, match play and strength training in four additional questions in minutes. Based on these reports, we calculated the average weekly exposure for each measure and for the entire season.

In the intervention group (Paper I), we monitored compliance with the prevention programme by asking how often they had performed the programme during the past week, both with the team and by themselves. Based on these reports, we calculated the average weekly compliance with the programme per measure and for the entire season.

Outcome measures

The primary outcomes in Paper I were the prevalence of shoulder problems and substantial shoulder problems, with the average severity of shoulder problems as a secondary outcome. To be able to compare our results with Clarsen et al. (2014a), the primary outcome in Paper II was the average severity score of shoulder problems, with prevalence measures as secondary outcomes.

Prevalence measures

A player was defined as having a shoulder problem if they reported anything but the lowest response to all four questions in the questionnaire. If they reported a moderate or severe reduction in training volume or performance, or a total inability to participate, they were defined as having a substantial shoulder problem (Clarsen et al., 2013).

For each of the six measures during the season, we calculated the prevalence of shoulder problems and substantial shoulder problems by dividing the number of cases by the number of respondents. Based on these measures, we calculated the average prevalence for the entire season (Clarsen et al., 2013).

Severity measures

For each player response to the questionnaire, the response enabled the calculation of a severity score ranging from 0 to 100. These measures were monitored throughout the season for each player. At the end of the project, we calculated the individual average severity score in Paper II by summing each player's scores and dividing by the number of responses, and in Paper I we calculated the average severity score on a group level by summing the scores of all players and dividing by the number of respondents.

Implementation context

The survey

To be able to assess the end-users' perspective on the risk and prevention of shoulder injuries, as well as key issues related to the application of the OSTRC Shoulder Injury Prevention Programme in the trial, we developed a questionnaire based on the RE-AIM framework and a previous survey examining implementation of the Nordic Hamstring Exercise in football (Glasgow et al., 1999; Finch & Donaldson, 2010; Bahr et al., 2015).

The questionnaire consisted of a common section addressing attitudes, beliefs and current behaviours among team captains and coaches in both study arms. In the intervention-specific section, questions addressed their views on completion of the prevention programme. In the section specified for the control teams, we addressed their knowledge with the prevention programme used by the intervention teams. All questions were closed, with multiple response options.

Data collection

Towards the end of the intervention period, we emailed a link to all team captains and coaches, providing them access to the questionnaire using online survey software (Questback v.9692, Questback AS, Oslo, Norway). Automatic reminders were sent to non-responders after three and seven days per e-mail using the survey software and manually per SMS (Pling, Front Information DA, Oslo, Norway). In addition, reminders were completed per telephone, if necessary.

Acute injury mechanisms and referee performance

Analysis of acute injuries

The 55 videos, with visible acute injury situations, were included in an individual analysis performed by an expert panel consisting of a handball coach and four clinicians working with handball players nationally and internationally. As we were unable to identify any existing forms to analyse the mechanisms of acute injuries in handball, the expert panel developed a new form to describe the situations and mechanism leading to injury (Appendix VI), based on a form developed for similar purposes in volleyball (Skazalski et al., 2018). Following the individual analyses, a consensus meeting including the five handball experts and a moderator was organised, with consensus defined as three of the five experts in the panel agreeing on each of the variables related to an injury.

Outcome variables

All outcome variables are presented in the video analysis form (Appendix VI). Depending on ball possession, injuries were classified as an acute injury to an attacking player or a defending player. The cause of injury was divided into contact trauma (with opponent, teammate, static object or moving object), landing trauma following contact (with opponent or teammate) and non-contact trauma (during running, cutting, jumping or landing). At the time of injury, the action of both the attacking and defending player was analysed, with specification of the body part injured and the body part involved in tackling or hitting the opponent.

Evaluation of referee performance

In order to evaluate referee performance, we invited three referees employed by the Norwegian Handball Federation, all with extensive refereeing experience from international handball, to participate in an expert referee panel. The referees performed individual blinded evaluation of the 37 videos. Prior to the individual analyses, we accomplished blinding by editing the videos so that the decision of the referees could not be seen. Following the individual analyses, we performed an online consensus meeting, with consensus defined as two of the three referees in the expert panel agreeing on a decision.

Outcome variables

The evaluation criteria used by the expert referee panel to evaluate the acute injury situations were identical to the ones used by the referees during the championship, i.e. no foul, defensive foul (free throw or penalty in favour of attacking team) or offensive foul (free throw in favour of defending team), as well as whether foul play led to the use of sanctions, i.e. two-minute suspension, yellow card (warning) or red card (disqualification) (IHF, 2005, 2010).

Data management and statistics

All analyses were performed using SPSS (SPSS versions 21-24, IBM Corporation, New York, USA). In paper II and III, the two-tailed alpha level was set to 0.05 for all statistical tests, and all results are presented as the mean with either 95% confidence intervals (CI), the standard deviation (SD) and/or range.

Paper I

Prior to initiation of the second project, we estimated the sample size on the basis of the average prevalence of shoulder problems (28%) and substantial shoulder problems (12%) reported among elite male handball players using the same injury registration method employed in this project (Clarsen et al., 2014a). Based on analysis of variance of within-participant and within-team prevalence, we adjusted for cluster correlations (estimated intraclass correlation coefficient <0.1) and assumed that we would need to include 15 players from each of the 48 available teams (n=720). On this basis, we estimated being able to detect a 10% reduction in the prevalence of shoulder problems with a power of 0.94, and a 6% reduction with a power of 0.87, at a 5% significance level.

Initial data analyses revealed that 81% of the players (n=534) met our a priori criteria of at least three responses to the OSTRC Overuse Injury Questionnaire and complete injury data were available from 61% (n=405). When assessing differences in baseline characteristics between responders (≥3) and non-responders (<3), female players were found to have a higher response rate within both groups, with no group difference. No other significant differences were discovered between responders and non-responders within or between groups. We therefore, with the assumption of missing at random, performed multivariate imputation using a predictive mean matching approach with a maximum of 20 iterations to estimate missing data points in our responders (Van Buuren, 2012). This led to pooled data of five imputed datasets, which were used to analyse group differences.

Differences over time in the prevalence of shoulder problems and substantial shoulder problems between the intervention and control groups were assessed using generalised estimating equation (GEE) models. Binary logistic models with an exchangeable covariance matrix were used. Subject age and years of handball participation in both sexes and weight in males were added to the GEE models using a forward selection procedure, as these variables showed a possible difference between groups at baseline (p<0.2). If inclusion of a variable changed the beta-coefficient of at least 10% it was kept in the model. However, since we identified no confounding effects, univariate analyses were performed.

Paper II

Considering the aim of the paper, the same statistical methods used by Clarsen et al. (2014a) were performed. We excluded all players with no injury data (n=53) from the risk factor analyses and calculated a summary outcome measure for the remaining players (n=276) by dividing their cumulative severity score by their number of responses to the questionnaire, with ≥40 set as the cut-off point to dichotomize the outcome into injured and non-injured players. Only players with a valid test result, without the presence of pain during testing, were included in the analysis of glenohumeral range of motion (n=267), isometric strength (n=240) and scapular control (n=238) as risk factors for shoulder injury.

Multivariable logistic regression models were constructed with anthropometric and demographic variables possibly associated with shoulder injury ($p<0.2$) included in each model using a forward selection procedure. If inclusion of a variable changed the beta-coefficient of at least 10% it was kept in the model. Strength measures were adjusted for body mass.

To assess differences in isometric shoulder strength and range of motion between sexes, we used independent-sample t-tests or Mann-Whitney U tests, depending on the distribution of data. Wilcoxon signed-rank tests were used to investigate differences in range of motion between dominant and non-dominant shoulders, due to non-parametric data. Differences between sexes in scapular control was analysed with Chi-square tests.

To assess the reliability of glenohumeral range of motion and strength measurements in the pilot study, we calculated the intraclass correlation coefficient using a two-way mixed single measure model (absolute agreement) for interrater reliability and a two-way random single measure model (absolute agreement) for intrarater reliability . Spearman rank-order correlation coefficient was used to assess the inter- and intrarater reliability of subjective evaluation of scapular control.

Paper III

We used simple descriptive statistics to present the results of the survey, reported as absolute numbers with percentages of the different respondent groups.

Paper IV

We used simple descriptive statistics to present the results from the video analysis of acute injury situations and referee decisions, reported as absolute numbers with percentages of the population. To assess the agreement between the decisions made by the referees and the expert panel we calculated kappa correlation coefficients.

Results and discussion

Prevention of overuse shoulder injuries in elite handball (Paper I)

During the study period, a total of 90 players (14%) dropped out of the study, 51 players (15%) in the intervention group and 39 players (12%) in the control group. As players with insufficient injury data were excluded, our primary analyses included 534 players (264 intervention, 270 control). Of these, 249 players (47%) reported to have experienced a shoulder problem during the seven days prior to inclusion, 125 (47%) in the intervention group and 124 players (46%) in the control group. No differences were identified in baseline characteristics when comparing players with sufficient injury data between groups.

In total, 2940 questionnaire responses were recorded from the 534 players throughout the season (1454 intervention, 1486 control), with 600 responses classified as shoulder problems (250 intervention, 350 control) and 187 of these as substantial shoulder problems (68 intervention, 199 control). In addition, 33 cases of acute injuries (20 intervention, 13 control), which all were excluded from the analyses, were reported.

Players in the intervention group included in the primary analysis (n=264) reported on average to have completed the OSTRC Shoulder Injury Prevention Programme 1.6 times per week (95% CI 1.4 to 1.8). Only 28 players (11%) complied with our recommendations of three sessions per week, with 17 players (6%) reporting a higher average weekly compliance than recommended. Sixteen players (6%) did not complete the exercises programme at all during the season.

Effect of the intervention

Our primary analyses revealed a 28% lower risk of reporting shoulder problems during the season in the intervention group compared to the control group (OR 0.72, 95% CI 0.52 to 0.98, p=0.038). No significant difference was detected in the risk of reporting substantial shoulder problems over time between the intervention and control groups (OR 0.78, 95% CI 0.53 to 1.16, p=0.23).

As players were included irrespective of their baseline injury status or history, we performed subgroup analyses including players depending on their reporting of shoulder problems at inclusion. Interestingly, a 35% lower risk of reporting shoulder problems was revealed in the intervention group compared to the control group when including only players with shoulder problems at baseline (Table 8). In contrast, we found no significant effect when including only players without shoulder problems at baseline, even if their compliance was as good as players with shoulder problems (average weekly sessions: 1.57 vs 1.69, p=0.791), suggesting that the exercise programme mainly had effect on existing problems.

Table 8 Generalised estimating equation models including players meeting the a priori criteria of sufficient injury data in the intervention (n=264) and control group (n=270).

	Shoulder problem			Substantial shoulder problem		
Subgroup analyses	**OR**	**(95% CI)**	**P value**	**OR**	**(95% CI)**	**P value**
Without shoulder problem[a]	0.80	(0.47-1.37)	0.42	0.68	(0.36-1.31)	0.25
With shoulder problem[b]	0.65	(0.43-0.98)	0.04	0.86	(0.51-1.45)	0.58

[a]Including 285 players without shoulder problems at baseline (139 intervention, 146 control)
[b]Including 249 players with shoulder problems at baseline (125 intervention, 124 control)
Players in the control group represent the reference group.

To investigate the influence of compliance on the risk of reporting shoulder problems within the intervention group we performed subgroup analyses including players depending on their compliance (Table 9). These analyses did not reveal any clear dose-response association. However, players in the intervention group reporting more than zero compliance (n=248) had a 69% lower risk of reporting substantial shoulder problems compared to players reporting zero compliance (n=16; OR 0.31, 95% CI 0.15 to 0.67, p=0.003), suggesting that completing the exercise programme between one and two times per week may be sufficient. Nevertheless, as the average prevalence of substantial shoulder problems was observed to be greater among players reporting zero compliance (7%, 95% CI 0% to 14%) compared to any degree of compliance (5%, 95% CI 4% to 5%), these results may be influenced by inability to perform the exercise programme in the zero compliance group. Therefore, the optimal dose remains unknown.

Table 9 Generalised estimating equation models including players in the intervention group meeting the a priori criteria of sufficient injury data (n=264).

		Shoulder problem			Substantial shoulder problem		
Compliance group	**n**	**OR**	**(95% CI)**	**P value**	**OR**	**(95% CI)**	**P value**
0.1-1.0 sessions per week	77	0.49*	(0.20-1.21)	0.125	0.36*	(0.16-0.82)	0.02
1.1-2.0 sessions per week	88	0.69*	(0.27-1.75)	0.435	0.25*	(0.10-0.60)	0.002
>2.0 sessions per week	83	0.58*	(0.22-1.52)	0.271	0.35*	(0.15-0.82)	0.02

*Players reporting zero completed sessions during the season represent the reference group (n=16).

The six prevalence measures during the season are illustrated for both groups in Figure 2.

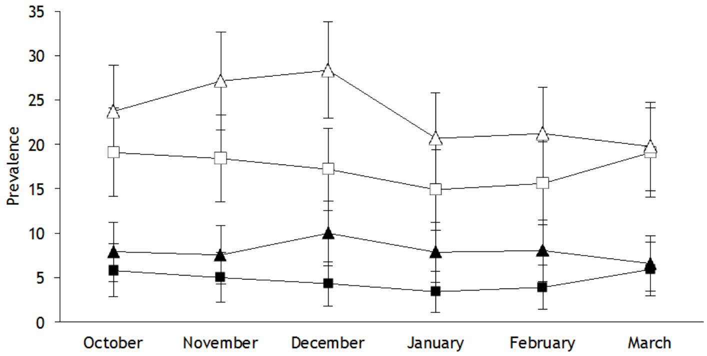


Figure 2. Prevalence of shoulder problems and substantial shoulder problems in the intervention group (open squares, shoulder problems; filled squares substantial shoulder problems) and control group (open triangles, shoulder problems; filled triangles substantial shoulder problems), with 95% confidence intervals, measured six times during the season.

Simple comparison of the prevalence measures revealed a lower average prevalence in the intervention group of both shoulder problems (mean difference: 6%) and substantial shoulder problems (mean difference: 3%) compared to the control group (Table 10).

Table 10 Average prevalence of shoulder problems and substantial shoulder problems in both groups and in both sexes.

Group	n	Shoulder problems		Substantial shoulder problems	
Intervention	331	17	(16-19)	5	(4-6)
Male players	171	16	(14-18)	4	(3-5)
Female players	160	19	(17-21)	5	(4-7)
Control	329	23	(21-26)	8	(7-9)
Male players	168	20	(15-26)	7	(6-7)
Female players	161	26	(26-27)	9	(8-11)

Data are shown in percentage (%) with 95% confidence intervals

This is the first randomised controlled trial to evaluate the effect of an exercise programme designed to prevent overuse shoulder injuries in elite handball, or overhead sport in general (Lauersen et al., 2014), although similar observations have been demonstrated in a six-month pilot study including 109 elite youth female handball players (53 intervention, 56 control) by Osterås et al. (2015). They found that the prevalence of shoulder complaints decreased during the intervention period among players completing specific shoulder strengthening exercises. Similar to our study, the exercises were implemented as a part of the warm-up and consisted of exercises to increase rotational shoulder strength and scapular muscle strength. Recently, the same research group reported conflicting results assessing the effect of a similar exercise programme in a seven-month randomised controlled trial including 106 elite youth female players (53 intervention, 53 control) (Sommervold & Østerås, 2017). Using current shoulder pain on a visual analog scale (VAS) as outcome, they reported no effect on the group mean VAS values measured seven times during the season. However, they did not perform any analyses to account for changes over time and the sample size can be questioned. Considering that established methods are emphasised as preferable when assessing overuse conditions in athletes, their registration of cases and use of outcome measure can also be questioned (Clarsen et al., 2013; Clarsen et al., 2014b; Bahr et al., 2017).

Female players within both groups in the current study reported a higher prevalence of shoulder problems (mean difference: 3% to 6%) and substantial shoulder problems (mean difference: 1% to 2%) compared to male players (Table 2). However, as a study investigating risk factors for shoulder injuries previously has been performed in elite male handball in Norway (Clarsen et al., 2014a), these differences may be influenced by increased awareness of shoulder problems among male players in this project.

Limitations of the study

One of the main limitations of this study is that we did not perform baseline and follow-up testing to examine the effect of the exercise programme on the different risk factors targeted. This information could have provided important knowledge to confirm previously identified risk factors and possibly revealed why the exercise programme had a preventive effect on shoulder problems. For example, if we could demonstrate that players in the intervention group increased their external rotation strength during the study period, this would have strengthened the relationship between external rotation strength and shoulder injury, and established increased external rotation strength as an effect of the exercise programme. Furthermore, this information may have allowed us to shorten the programme. Considering the low compliance in the current study and the fact that programme length was an important barrier to implementation (Paper III), shortening the programme may improve compliance.

There are also a number of limitations related to the methods used to monitor player exposure and compliance with the exercise programme. First, exposure data were self-reported as the number of minutes and compliance data were self-reported as the number of sessions completed during the past seven days; both are clearly vulnerable to recall bias. Second, the season averages for both exposure and compliance data are approximations based on the six measurements recorded during the season.

Implications for injury prevention

This is the first randomised controlled trial to evaluate the effect of an exercise programme designed to prevent overuse shoulder injuries in elite handball. Our results suggest that an exercise programme targeting glenohumeral internal rotation, external rotation strength, scapular muscle strength, kinetic chain and thoracic mobility should be included as a part of the general warm-up in elite handball.

Risk factors for overuse shoulder injuries in elite handball (Paper II)

Our results are based on 276 players from the control group of the intervention study (Paper I) who responded at least one time to the questionnaire throughout the season. As players were excluded if they did not have a test result or experienced pain during testing, between 238 and 267 players were included in each analysis. Sixteen players had an average severity score above the cut-off for being classified as injured (≥40) and constituted the injured group in risk factor analyses. Acute injuries reported during the season were not included when players were categorised as injured or not injured (n=13).

Risk factor analyses

Demographics

No associations were identified between overuse shoulder injury and demographic variables.

Glenohumeral range of motion

As shown in Figure 3, comparisons of range of motion between the dominant and non-dominant shoulder revealed significant differences, with dominant shoulders demonstrating reduced internal rotation in male (mean difference: 4° 95% CI 3° to 5°, $p<0.01$) and female players (mean difference: 6° 95% CI 5° to 8°, $p<0.01$), increased external rotation in male (mean difference: 2°, 95% CI 0.2° to 3°, $p<0.03$) and female players (mean difference: 3°, 95% CI 2° to 5°, $p<0.01$) and less total rotational motion in male (mean difference: 2°, 95% CI 1° to 4°, $p<0.01$) and female players (mean difference: 3°, 95% CI 1° to 4°).

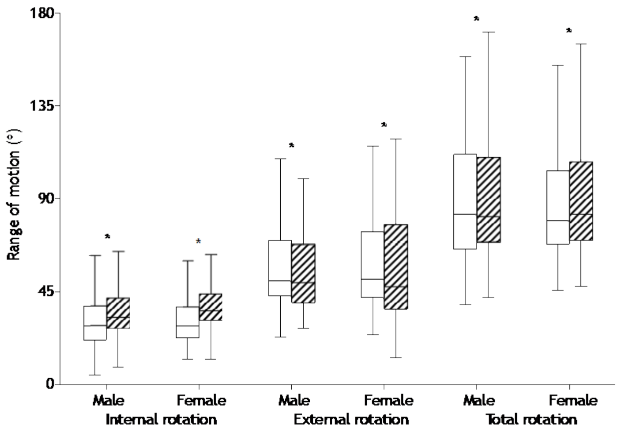


*Figure 3. Range of motion of dominant shoulders (white boxes) and non-dominant shoulders (hatched boxes) for both sexes; *p<0.05*

Similar findings have been demonstrated in a range of asymptomatic overhead athletes and are generally considered as normal adaptations to repeated overhead throwing (Ellenbecker et al., 1996; Baltaci et al., 2001; Ellenbecker et al., 2002; Reeser et al., 2010; Wilk et al., 2012; Almeida et al., 2013; Forthomme et al., 2013; Kibler et al., 2013a; Manske et al., 2013; Myklebust et al., 2013a; Camp et al., 2017). Nevertheless, several prospective cohort studies on overhead sport have reported associations between measures of glenohumeral range of motion and dominant shoulder injury, i.e. internal rotation deficit, reduced absolute internal rotation, total rotational motion deficit, reduced absolute total rotational motion and external rotation deficit (Table 2) (Shanley et al., 2011; Wilk et al., 2011; Clarsen et al., 2014a; Shanley et al., 2015; Wilk et al., 2015; Shitara et al., 2017). None of these risk factors were confirmed in the current study. In fact, our data demonstrated conflicting results compared to previous research, as an association between increased absolute internal rotation and shoulder injury was observed (OR 1.16 per 5, 95% CI 1.00 to 1.34, $p=0.046$). However, as the magnitude of this association appears to be limited (16% increased risk per 5° increase in internal rotation) and the reliability of our range of motion measurements is questionable (see limitations below), this result must be interpreted with caution.

Isometric strength dominant shoulder

Male players were stronger in both external rotation (mean difference: 0.23 N/kg, 95% CI 0.12 to 0.33, $p<0.01$) and external rotation (mean difference: 0.13 N/kg, 95% CI 0.02 to 0.25, $p<0.01$) in their dominant shoulder compared to female players. The average ratio of external to internal rotation strength was 96% (SD 17%) in male players and 91% (SD 18%) in female players (mean difference: 5%, 95% CI 1% to 9%, Figure 4).

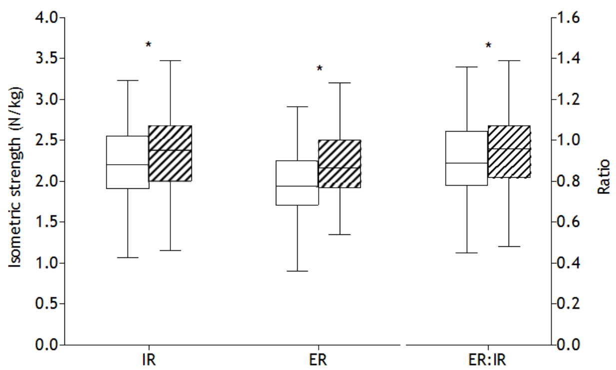


*Figure 4. Isometric strength differences in the dominant shoulder between sexes (female, white; male, hatched boxes). IR, internal rotation; ER, external rotation; ER:IR, ER to IR strength ratio; *p<0.05*

In contrast to previous prospective cohort studies reporting external rotation weakness and lower ratios of external to internal rotation strength as risk factors for shoulder injury in overhead sport (Table 3) (Byram et al., 2010; Edouard et al., 2013; Forthomme et al., 2013; Clarsen et al., 2014a; Møller et al., 2017; Shitara et al., 2017), our results did not reveal any significant associations between strength measures and injury risk.

Scapular dyskinesis

A total of 205 players (71%) were rated as having any degree of scapular dyskinesis in their dominant shoulder (102 male, 103 female) and 44 players (15%) were rated as having obvious scapular dyskinesis in their dominant shoulder (18 male, 26 female).

Similar to several cohort studies including overhead athletes (Table 4) (Forthomme et al., 2013; Myers et al., 2013; Struyf et al., 2014; Shitara et al., 2017), our results did not demonstrate any significant association between scapular dyskinesis and shoulder injury, which is in contrast to our previous cohort study in elite male handball, employing similar methods (Clarsen et al., 2014a). However, as multiple testers performed the assessments and the reliability of our scapular assessments is variable (see limitations below), these results must be interpreted with caution.

Limitations of the study

Test reliability

A key limitation of this study is that we, due to the large cohort and geographical challenges, used multiple testers, and there was large variability in both the inter- and intrarater reliability (Table 11). In particular, the poor inter and intrarater reliability of our range of motion measures reflects the variation of the data presented in Figure 3 and is clearly a threat to the internal validity of the current study. Similarly, as the interrater reliability of our scapular assessments was found to range from poor to good (ICC: 0.32 to 0.82), this may have increased the probability of a type II error when investigating the association between scapular dyskinesis and shoulder injury.

Table 11 ICC for measures of isometric rotational strength and glenohumeral range of motion.

	Interrater		Intrarater	
	ICC (3.1)	**(95% CI)**	**ICC (2.1)**	**(95% CI)**
Isometric strength				
IR	0.85	(0.69 to 0.93)	0.94	(0.86 to 0.98)
ER	0.86	(0.70 to 0.94)	0.86	(0.73 to 0.98)
Range of motion				
IR	0.31	(0.08 to 0.57)	0.65	(0.33 to 0.84)
ER	0.31	(0.08 to 0.56)	0.72	(0.45 to 0.87)

ICC, intraclass correlation coefficients; IR, internal rotation; ER, external rotation; ROM, range of motion

Test selection

To ensure comparability to our previous publication (Clarsen et al., 2014a), we used a similar selection of shoulder tests. However, two modifications were made to the isometric measurements of rotational shoulder strength and may have reduced the comparability. First, the shoulder position was changed to 90° of abduction due to its resemblance with the throwing position. And second, to limit measurement error related to manual fixation of multiple testers, we externally fixated the handheld dynamometer (Møller et al., 2017). Additionally, it can be questioned to which degree isometric testing in this position relates to shoulder strength in a throwing position. Similarly, the validity of both our scapular control assessments and range of motion measurements can be questioned, as they clearly differ from actual throwing. For example, when comparing range of motion measurements of external rotation with throwing kinematics, van den Tillaar (2016) reported a weak correlation, with greater values during actual throwing.

Risk factors interact and change over time

Similar to our previous publication (Clarsen et al., 2014a), we analysed the risk factors individually, without taking into account that they may interact. This conflicts with the recent recommendations by Bittencourt et al (2016), emphasising the importance of investigating how risk factors may interact, and is as a limitation of our study. Furthermore, risk factors should be considered as temporal and be expected to change over time (Meeuwisse et al., 2007), e.g. reduced strength throughout a competitive season. This suggests that repeated measurements and prospective monitoring of risk factors should be performed. However, as we did not assess potential interaction or changes with time, this must also be considered as a limitation.

Statistical power

The number of cases representing injured players in the risk factor analyses is an important limitation of the study. Similar to our previous publication (Clarsen et al., 2014a), we used ≥40 on the average severity score as a cut-off to classify players as injured, resulting in 16 cases in total in the current study (11 male, 5 female), versus 14 in the previous one. This cut-off can be justified from a clinical perspective, as we are likely to capture shoulder problems that truly affect the players. However, it challenges the internal validity of both studies and may have increased the likelihood of both type I and type II errors in the risk factor analyses. This can possibly explain the conflicting results between our studies, as both are underpowered. Naturally, this also inhibited us from performing sub-analyses separately for each gender.

Implications for injury prevention

The current study, employing similar methods to our previous publication, did not confirm risk factors reported to be associated with shoulder injuries in elite handball (Clarsen et al., 2014a), including reduced glenohumeral total rotational motion, external rotation weakness and scapular dyskinesis. However, considering the limitations of the current study and our previous publication, the relationship between these risk factors and shoulder injuries in elite handball remains unknown.

Methodological considerations (Paper I and II)

Inclusion of players irrespective of injury status or history

Traditionally, injury prevention studies and risk factor studies exclude players injured at baseline and only record new injuries throughout the study period, which is emphasised as an important premise to establish causal relationships between risk factors and injury, as well as to investigate the primary preventive effect of an intervention (Shrier, 2007; Jacobsson & Timpka, 2015). However, applying such an approach in Paper I and II would have been inappropriate, as exclusion of players reporting shoulder problems at baseline (n=249, 47%) would have resulted in a biased study population, not representative of elite handball players, where overuse shoulder injuries with periods of remission and exacerbation are common. Therefore, we included players present at training sessions, irrespective of their baseline injury status or history (Paper I and II). However, we did exclude players experiencing shoulder pain during the actual shoulder testing from the risk factor analyses (Paper II). Consequently, our results from Paper I encompass both primary and secondary prevention, and in Paper II, we are limited to assess associations between risk factors and overuse shoulder injury and causation cannot be assumed.

Prospective injury registration

To register shoulder problems during the season (Paper I and II), we distributed the OSTRC Overuse Injury Questionnaire to all players at a regular basis. This method is previously shown to capture more than 10 times as many cases than a standard injury surveillance method using a traditional time-loss definition, and is recommended in the study of overuse injuries in athletes (Clarsen et al., 2013). Ideally, we would have preferred players to respond to the questionnaire each week during the season, as originally described. However, considering the low response rate observed in a previous publication distributing the questionnaire bi-weekly in elite male handball (63%), we decided to only distribute the questionnaire on a monthly basis, six times in total.

As the questionnaire only allowed players to report shoulder problems and/or acute shoulder injuries during the past seven days, we are uncertain how players may have responded in cases where they were affected by a problem not related to the shoulder. This may have led to missing data or overestimation of shoulder problems. To exemplify, if a player experienced a lower back problem, he might omit to respond to the questionnaire or report the lower back problem as a shoulder problem. Thus, we should have included an additional question allowing players to specify whenever they sustained a problem not related to the shoulder.

Implementation context (Paper III)

Our results are based on 88 survey responses from team captains (n=44) and coaches (n=44) representing the teams constituting the intervention (21 teams) and control arm (23 teams) in our cluster-randomised controlled trial (Paper II). As the head coach of each team nominated the individual responsible for the team's prevention and physical training to take part in the survey, the coach group consisted of a varied selection of responders: 23 head coaches, 11 fitness coaches, six individuals with a combined responsibility for fitness and medical follow-up (e.g. physical therapist) and three assistant coaches.

Team captains and coaches perspective on shoulder injury prevention

The questionnaire section addressing attitudes, beliefs and current behaviours in both study arms (n=88, 44 coaches, 44 captains) revealed that the vast majority of coaches (n=37) and captains (n=39) believed that handball players are at high risk for shoulder injuries and that an exercise programme would have a preventive effect (coaches 43, captains 38). In fact, the majority responded to previously having performed prevention training to reduce the rate of shoulder injuries (coaches 35, captains 29) However, 12 coaches and 21 captains reported that it is more important to spend time on specific handball training than injury prevention training. According to the majority of coaches (n=35) and captains (n=21), their medical staff was strongly positive towards prevention of shoulder injuries, whereas players were reported to be positive (coaches 28, 26 captains). Coaching staff was reported to be strongly positive by coaches themselves (n=25) and to be positive by captains (n=29). The majority of both coaches (n=16) and captains (n=24) responded to have no knowledge of their administration's attitudes towards shoulder injury prevention.

No previous studies have investigated attitudes, beliefs and current behaviours towards shoulder injury prevention in handball. Our results show that the majority of coaches and captains in elite handball perceive that players are at high risk of injury and that the general belief is that an exercise programme will reduce the risk, suggesting that there is fertile ground for implementation.

Application of the exercise programme in the intervention group

All delivery agents (21 coaches, 21 captains) in the trial (Paper II) reported to be familiar with the OSTRC Shoulder Injury Prevention Programme and the majority believed that it would prevent shoulder injuries (19 coaches, 17 captains) The majority of respondents were satisfied with the education and follow-up they had received on the execution of the programme (coaches 17, captains 17) and reported that the programme was well suited as a part of the handball warm-up (coaches 13, captains 16), with good variation and progression of the exercises (coaches 17, captains 17). These factors have previously been reported as important facilitators to implementation of exercise programmes in team ball sport (Cumps et al., 2007; Soligard et al., 2008; Steffen et al., 2008; Kraemer & Knobloch, 2009; Kiani et al., 2010). Additional facilitators emphasised in our material were "expected preventive effect" (coaches 21, captains 13), "expected performance gains" (coaches 12, captains 7), "influence from the team medical staff" (coaches 7, captains 11) and "sense of duty" (coaches 6, captains 11).

Despite these results, suggesting that adoption and implementation of the exercise programme was successful, the majority of delivery agents reported that their team completed the exercise programme less than the three times per week recommended (coaches 15, captains 18). Less than half responded to have performed the programme as a part of the warm-up (coaches 10, captains 7), with before organised training (coaches 12, captains 14) reported as the most common completion setting, suggesting that alternative implementation settings should be explored. Only six coaches and five captains responded that they would continue to perform the full version of the exercise programme next season. Similar to previous injury prevention studies reporting on the uptake of exercise programmes (Petersen et al., 2005; Cumps et al., 2007; Engebretsen et al., 2008; Soligard et al., 2010; Petersen et al., 2011), "programme length" was emphasised as an important barrier to implementation (coaches 14, captains 17). Additional barriers emphasised in our material were "lack of player motivation" (coaches 16, captains 13) and "low priority of the head coach" (coaches 3, captains 8).

Limitations of the study

One of the main limitations of this study is that we did not validate nor test the reproducibility of the survey, which naturally is a threat towards the internal validity of our results. Additionally, as the survey only included team captains, we do not know to what extent their responses reflect the views of their teammates. Similarly, as the individual nominated to respond on behalf of the coaching staff varied among teams, we cannot generalise our results to head coaches at the elite level. Furthermore, we do not know if our results are transferable to lower completion levels or to younger age groups.

Implications for implementation of the exercise programme

Despite these limitations, our results provide important information on the facilitators to emphasise in future implementation of the OSTRC Shoulder Injury Prevention Programme. However, prior to widespread dissemination in the handball community, research efforts are warranted to reduce the length of the programme and initiatives to increase motivation to perform the programme should be explored.

Acute injury mechanisms and referee performance (Paper IV)

Our results regarding injury mechanisms are based on 55 videos of real-time acute match injuries during the 24th Men's Handball World Championship. When assessing referee performance in relation to acute injury situations, we only included videos showing the referees decision during the matches (n=37).

Description of acute injury mechanisms

The video analysis of the acute injury situations (n=55) revealed that contact trauma due to a tackling episode between opponents was the most frequent acute injury cause (n=27), followed by landing trauma subsequent to a tackling episode (n=8). Hence, a tackle between opponents was the most frequent event observed at time of injury in our video material (n=35). This supports the results of previous studies retrospectively reporting direct contact with an opponent as the main injury cause in handball (Nielsen & Yde, 1988; Seil et al., 1998; Junge et al., 2006; Langevoort et al., 2007). However, as these studies are based on retrospective reporting by the injured players or their medical team, ours are the first results based on real time analysis of acute injury situations.

The distribution of injuries was observed to be even between attackers (n=29) and defenders (n=22), with the majority of injuries occurring between the 6- and 9-m lines on the court (n=37). At the time of injury, the back position was the most common playing position for attackers (n=19) and mid-defence for defenders (n=15). Injured attackers were most frequently performing a jump shot at the time of injury (n=9), whereas defenders most frequently tackled the throwing arm of an attacker performing a jump shot when sustaining an injury (n=10). Hence, the most common playing situation observed at the time of injury were similar for both attackers and defenders.

Despite video analysis previously highlighted as an important approach to obtain accurate information on how injuries occur (Krosshaug et al., 2005), only one previous study has employed this method in handball, specifically to investigate the whole body and joint biomechanics at the time of non-contact anterior cruciate ligament injuries (Olsen et al., 2004). Thus, this paper provides new information on the mechanisms of acute injuries in elite handball, especially in relation to the events leading up to injuries during matches.

Injury mechanisms of specific body regions

When developing the analysis form, the expert panel agreed to include specific sections on injuries to the head/face, knee and ankle, as these body parts were emphasised as relevant for video analysis in the preceding injury surveillance study conducted during the championship (Bere et al., 2015). However, due to the limited number of cases included in this material, i.e. 17 head/face injuries, 6 ankle injuries and 4 knee injuries, our results must be interpreted with caution. Furthermore, it is important to note that our results only describe the joint biomechanics at a superficial level, without any kinematic analysis software. Thus, these descriptions should receive less attention.

No previous studies have reported on the mechanisms of head/face injuries in handball.
All injuries were classified as contact trauma (n=17), with a tackling episode observed at the time of injury in majority of situations (n=12). A straight blow to the front of the head/face region was the most common injury mechanism (n=10). An interesting observation was that despite more than half of the injuries requiring medical attention on court (n=11), only four players were withdrawn from play. This raised some questions in the expert panel: "Do the medical teams perform relevant and valid assessments of potential concussions during matches?" "Do they have the opportunity and time to perform such assessments?"

Referee decisions and performance

The recording of referee decisions in acute injury situations (n=37) showed that foul played was called in 62% of the cases (n=23), with only a minority leading to the use of sanctions (n=8), all two-minutes suspensions of defenders. All situations leading to foul play resulted in free throws, with the vast majority in favour of the attacking team (defensive foul, n=20), despite injuries being evenly distributed among attackers and defenders. None of the situations qualified for a penalty throw and no yellow or red cards were awarded by the referees in the video material.

As shown in Table 12, there was agreement between the referees and the expert panel in only 14 of the 37 situations leading to an acute injury (kappa: 0.22, 95% CI 0.07 to 0.36), with substantially stricter interpretation of the rules in the expert panel. In fact, the expert panel awarded two yellow cards and three two-minute suspensions in relation to three free throws and two penalties, all in favour of the attacking team (defensive foul), in five situations in which the referees called no foul. In addition, the expert panel sanctioned an attacking player perpetrating an offensive foul with a red card in one situation in which the referees called no foul. When investigating the overall use of sanctions, the expert panel awarded an additional five yellow cards and 11 two-minute suspensions in 16 situations in which the referees refrained from the use of sanctions.

Table 12 The decisions made by the referees versus the decisions made by the expert referee panel for acute injury situations (n=37)

	Referees					
Expert panel	No foul	Free throw[a]	Free throw[b]	Yellow card	Two-min suspension	Red card
No foul	8	1	1	-	-	-
Free throw[a]	-	2	-	-	-	-
Free throw[b]	-	-	-	-	-	-
Yellow card	2	3	-	-	1	-
Two-min suspension	3	6	2	-	4	-
Red card	1	0	-	-	3	-

[a]In favour of attacking team (defensive foul), [b]In favour of defending team (offensive foul)
The shaded cells denote agreement between the match referees and the expert panel

Previous information on foul play in relation to acute injuries in handball is solely based on retrospective data reported by team physicians, showing that foul play was present in 44% to 77% of acute injuries during international tournaments, in which the referees sanctioned 48% to 74% of these (Langevoort et al., 2007). Thus, our paper is the first to describe and evaluate referee decisions in relation to acute injury situations using appropriate methods, providing new information that may be valuable in guiding preventive measures towards stricter refereeing and potentially also rule amendments.

Limitations of the study

The time of injury was determined subjectively and was in most cases obvious according to the expert panel. However, as this may differ from the actual onset in real life, this must be considered as a limitation of the study. Furthermore, the cases included are limited to match play and there may be additional or different mechanisms involved during training. In addition, as the video material consisted of limited camera angles and only included a minimum of 5 s preceding and following the injury situations, our ability to describe the mechanisms may have been affected. And finally, the external validity is limited due to the homogenous population and the limited number of cases included, especially when reporting on the specific body parts.

The videos not showing the referees and their decisions (n=18) were excluded from the material and may have biased our sample. However, it seems reasonable to assume that these videos were random. The decisions made by the expert panel were used as the gold standard when evaluating the referee performance. However, we cannot be certain that their evaluations were correct, which is an important premise of this approach.

Additional limitations due to differences between live evaluations compared to on video may also have affected our results, as previous evidence shows that referees (ice hockey) tend to be stricter in their interpretation of rules when evaluating situations on video (Trudel et al., 2000). First, environmental factors, such as crowd noise and coach influence, may have affected the decision making during the championship (Wilkins et al., 1991; Nevill et al., 2002). In contrast, these factors will not be present during video evaluation. Second, the expert panel had access to multiple camera angles in most cases, with the opportunity to watch unlimited slow-motion replays, providing them with advantages in their evaluations. Third, as the videos were limited in length, this may have affected the expert panels ability to account for events occurring prior to the specific injury situation, e.g. not interfere if they consider the attacker not to be obstructed and will benefit from continued play. Finally, our results may be affected by cultural differences between the homogenous expert panel (Norwegian referees) and the championship referees (multinational) in relation to their tradition of refereeing and adherence to the rules of the game.

Implications for injury prevention

Despite the limitations of this study, our results provide new evidence supporting rule amendments and stricter rule enforcement as measures to consider in the prevention of acute injuries in elite handball. Specifically, delayed video review of matches with the possibility to retrospectively sanction players violating the rules, as well as extensive referee education with emphasis on playing situations with injury potential, i.e. tackling episodes when an attacker is performing a jump shot, should be communicated as potential measures and tested in future research.

Conclusions

1. The OSTRC Shoulder Injury Prevention Programme, an exercise programme to increase glenohumeral internal rotation, external rotation strength and scapular muscle strength, as well as improve kinetic chain and thoracic mobility, reduced the prevalence and risk of shoulder problems in elite handball and should be included as a part of the warm-up.

2. None of the risk factors previously reported to be associated with shoulder injuries in elite male handball, including glenohumeral total rotational motion, external rotation strength and scapular dyskinesis, could be confirmed in a mixed-sex cohort of elite handball players.

3. Coaches and captains in elite handball believed that players are at high risk of shoulder injuries and that an exercise programme targeting risk factors would be effective. This suggests that there is fertile ground for implementation of the OSTRC Shoulder Injury Prevention Programme. However, as programme length and lack of player motivation were important barriers to implementation, shortening the programme and strategies to enhance player motivation may be beneficial.

4. Tackling episodes occurring when an attacker performed a jump shot was the most common playing situation observed when both attackers and defenders sustained an acute injury in elite male handball. Compared to an expert referee panel, the referees were found to be substantially more lenient in their interpretation of rules and use of sanctions in acute injury situations.

Future perspectives

As described in this dissertation, the OSTRC Shoulder Injury Prevention Exercise Programme reduced the risk of shoulder problems in elite handball, suggesting that dissemination and widespread use in the handball community would be beneficial. However, it should be recognized that several challenges remains to succeed with implementation in a real-world sport setting. First, the time it takes to complete the programme was emphasised as an important barrier to implementation, suggesting that efforts to reduce the length of the programme is needed. In this regard, our research group has recently initiated a project to assess the effect of the programme on glenohumeral joint range of motion, shoulder rotational strength and scapular dyskinesis. These results may provide information to explain what caused the effect of the programme and potentially allow us to reduce the length, e.g. if only external rotation strength increases, exercises with this potential should be prioritised. Second, the majority of coaches and captains reported to complete the programme prior to organised training, suggesting that initiatives to make the programme more suitable as a part of the warm-up routine should be performed in collaboration with representatives from the handball community. And finally, future dissemination efforts should include initiatives to motivate coaches and players to adopt the programme, as lack of player motivation and lack of priority among the head coaches was reported as key barriers to implementation. These efforts should emphasise the preventative effect of the programme, as this was reported as the most important motivator to implementation.

Future research is needed to investigate risk factors for shoulder injuries in elite handball and should progress to assess how different risk factors interact (Bittencourt et al., 2016), with exposure to handball activity considered as the primary risk factor (Møller et al., 2017). Ideally, the exact individual throwing workload should be monitored prospectively. However, accurate and feasible methods to complete this are not yet available (Black et al., 2016).

Rule amendments and stricter rule enforcement should be considered to prevent acute match injuries in elite handball, especially in relation to tackling episodes when an attacker is performing a jump shot. Specific measures to consider are delayed video review of matches with the possibility to retrospectively sanction players violating the rules, as well as extensive referee education focusing on playing situations with injury potential, i.e. defender use of extended arms during tackles and attacker use of knee, elbow and hand during jump shots. These measures to reduce foul play should be communicated at an organisational level and be addressed by future research to assess the effects on acute injury rates.

References

Almeida, GP, Silveira, PF, Rosseto, NP, Barbosa, G, Ejnisman, B, Cohen, M. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *J Shoulder Elbow Surg* 2013: 22: 602-607.

Aman, M, Forssblad, M, Henriksson-Larsen, K. Incidence and severity of reported acute sports injuries in 35 sports using insurance registry data. *Scand J Med Sci Sports* 2016: 26: 451-462.

Aman, M, Forssblad, M, Larsen, K. Incidence and body location of reported acute sport injuries in seven sports using a national insurance database. *Scand J Med Sci Sports* Published Online First: 07 August 2017. doi: 10.1111/sms. 12956.

Andersen, CH, Zebis, MK, Saervoll, C, Sundstrup, E, Jakobsen, MD, Sjogaard, G, Andersen, LL. Scapular muscle activity from selected strengthening exercises performed at low and high intensities. *J Strength Cond Res* 2012: 26: 2408-2416.

Asker, M, Holm, LW, Kallberg, H, Walden, M, Skillgate, E. Female adolescent elite handball players are more susceptible to shoulder problems than their male counterparts. *Knee Surg Sports Traumatol Arthrosc* 2018:

Bahr, R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med* 2009: 43: 966-972.

Bahr, R. Why screening tests to predict injury do not work-and probably never will...: a critical review. *Br J Sports Med* 2016: 50: 776-780.

Bahr, R, Clarsen, B, Ekstrand, J. Why we should focus on the burden of injuries and illnesses, not just their incidence. *Br J Sports Med* Published Online First: 11 October 2017. doi: 10.1136/bjsports-2017-098160.

Bahr, R, Holme, I. Risk factors for sports injuries--a methodological approach. *Br J Sports Med* 2003: 37: 384-392.

Bahr, R, Krosshaug, T. Understanding injury mechanisms: a key component of preventing injuries in sport. *Br J Sports Med* 2005: 39: 324-329.

Bahr, R, Thorborg, K, Ekstrand, J. Evidence-based hamstring injury prevention is not adopted by the majority of Champions League or Norwegian Premier League football teams: the Nordic Hamstring survey. *Br J Sports Med* 2015: 49: 1466-1471.

Ballantyne, BT, O'Hare, SJ, Paschall, JL, Pavia-Smith, MM, Pitz, AM, Gillon, JF, Soderberg, GL. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. *Phys Ther* 1993: 73: 668-677.

Baltaci, G, Johnson, R, Kohl, H, 3rd. Shoulder range of motion characteristics in collegiate baseball players. *J Sports Med Phys Fitness* 2001: 41: 236-242.

Bere, T, Alonso, JM, Wangensteen, A, Bakken, A, Eirale, C, Dijkstra, HP, Ahmed, H, Bahr, R, Popovic, N. Injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar. *Br J Sports Med* 2015: 49: 1151-1156.

Bird, SP, Tarpenning, KM, Marino, FE. Designing resistance training programmes to enhance muscular fitness: a review of the acute programme variables. *Sports Med* 2005: 35: 841-851.

Bittencourt, NF, Meeuwisse, WH, Mendonca, LD, Nettel-Aguirre, A, Ocarino, JM, Fonseca, ST. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition-narrative review and new concept. *Br J Sports Med* 2016: 50: 1309-1314.

Black, GM, Gabbett, TJ, Cole, MH, Naughton, G. Monitoring Workload in Throwing-Dominant Sports: A Systematic Review. *Sports Med* 2016: 46: 1503-1516.

Blackburn, TA, McLeod, WD, White, B. EMG analysis of posterior rotator cuff exercises. *Athletic Training* 1990: 25: 40-45.

Brooks, JH, Fuller, CW. The influence of methodological issues on the results and conclusions from epidemiological studies of sports injuries: illustrative examples. *Sports Med* 2006: 36: 459-472.

Byram, IR, Bushnell, BD, Dugger, K, Charron, K, Harrell, FE, Jr., Noonan, TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med* 2010: 38: 1375-1382.

Camp, CL, Zajac, JM, Pearson, DB, Sinatro, AM, Spiker, AM, Werner, BC, Altchek, DW, Coleman, SH, Dines, JS. Decreased Shoulder External Rotation and Flexion Are Greater Predictors of Injury Than Internal Rotation Deficits: Analysis of 132 Pitcher-Seasons in Professional Baseball. *Arthroscopy* 2017: 33: 1629-1636.

Carter, AB, Kaminski, TW, Douex, AT, Jr., Knight, CA, Richards, JG. Effects of high volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players. *J Strength Cond Res* 2007: 21: 208-215.

Chu, SK, Jayabalan, P, Kibler, WB, Press, J. The Kinetic Chain Revisited: New Concepts on Throwing Mechanics and Injury. *PM R* 2016: 8: S69-77.

Clarsen, B, Bahr, R, Andersson, SH, Munk, R, Myklebust, G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med* 2014a: 48: 1327-1333.

Clarsen, B, Krosshaug, T, Bahr, R. Overuse injuries in professional road cyclists. *Am J Sports Med* 2010: 38: 2494-2501.

Clarsen, B, Myklebust, G, Bahr, R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med* 2013: 47: 495-502.

Clarsen, B, Rønsen, O, Myklebust, G, Flørenes, TW, Bahr, R. The Oslo Sports Trauma Research Center questionnaire on health problems: a new approach to prospective monitoring of illness and injury in elite athletes. *Br J Sports Med* 2014b: 48: 754-760.

Cools, AM, De Wilde, L, Van Tongel, A, Ceyssens, C, Ryckewaert, R, Cambier, DC. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. *J Shoulder Elbow Surg* 2014a: 23: 1454-1461.

Cools, AM, Declercq, GA, Cambier, DC, Mahieu, NN, Witvrouw, EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports* 2007a: 17: 25-33.

Cools, AM, Dewitte, V, Lanszweert, F, Notebaert, D, Roets, A, Soetens, B, Cagnie, B, Witvrouw, EE. Rehabilitation of scapular muscle balance: which exercises to prescribe? *Am J Sports Med* 2007b: 35: 1744-1751.

Cools, AM, Struyf, F, De Mey, K, Maenhout, A, Castelein, B, Cagnie, B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. *Br J Sports Med* 2014b: 48: 692-697.

Cools, AM, Witvrouw, EE, Declercq, GA, Danneels, LA, Cambier, DC. Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. *Am J Sports Med* 2003: 31: 542-549.

Cumps, E, Verhagen, E, Meeusen, R. Efficacy of a sports specific balance training programme on the incidence of ankle sprains in basketball. *J Sports Sci Med* 2007: 6: 212-219.

Dark, A, Ginn, KA, Halaki, M. Shoulder muscle recruitment patterns during commonly used rotator cuff exercises: an electromyographic study. *Phys Ther* 2007: 87: 1039-1046.

Decker, MJ, Hintermeister, RA, Faber, KJ, Hawkins, RJ. Serratus anterior muscle activity during selected rehabilitation exercises. *Am J Sports Med* 1999: 27: 784-791.

DeLorme, TL. Restoration of muscle power by heavy resistance exercises. *J Bone Joint Surg Am* 1945: 27: 645-667.

Dillman, CJ, Fleisig, GS, Andrews, JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther* 1993: 18: 402-408.

Donaldson, A, Finch, CF. Planning for implementation and translation: seek first to understand the end-users' perspectives. *Br J Sports Med* 2012: 46: 306-307.

Edouard, P, Degache, F, Oullion, R, Plessis, JY, Gleizes-Cervera, S, Calmels, P. Shoulder strength imbalances as injury risk in handball. *Int J Sports Med* 2013: 34: 654-660.

Ekstrom, RA, Donatelli, RA, Soderberg, GL. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. *J Orthop Sports Phys Ther* 2003: 33: 247-258.

Ellenbecker, TS, Cools, A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. *Br J Sports Med* 2010: 44: 319-327.

Ellenbecker, TS, Roetert, EP, Bailie, DS, Davies, GJ, Brown, SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc* 2002: 34: 2052-2056.

Ellenbecker, TS, Roetert, EP, Piorkowski, PA, Schulz, DA. Glenohumeral joint internal and external rotation range of motion in elite junior tennis players. *J Orthop Sports Phys Ther* 1996: 24: 336-341.

Engebretsen, AH, Myklebust, G, Holme, I, Engebretsen, L, Bahr, R. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. *Am J Sports Med* 2008: 36: 1052-1060.

Engebretsen, L, Soligard, T, Steffen, K, Alonso, JM, Aubry, M, Budgett, R, Dvorak, J, Jegathesan, M, Meeuwisse, WH, Mountjoy, M, Palmer-Green, D, Vanhegan, I, Renstrom, PA. Sports injuries and illnesses during the London Summer Olympic Games 2012. *Br J Sports Med* 2013: 47: 407-414.

Finch, C. A new framework for research leading to sports injury prevention. *J Sci Med Sport* 2006: 9: 3-9.

Finch, CF. An overview of some definitional issues for sports injury surveillance. *Sports Med* 1997: 24: 157-163.

Finch, CF, Donaldson, A. A sports setting matrix for understanding the implementation context for community sport. *Br J Sports Med* 2010: 44: 973-978.

Finch, CF, Doyle, TL, Dempsey, AR, Elliott, BC, Twomey, DM, White, PE, Diamantopoulou, K, Young, W, Lloyd, DG. What do community football players think about different exercise-training programmes? Implications for the delivery of lower limb injury prevention programmes. *Br J Sports Med* 2014: 48: 702-707.

Finch, CF, White, P, Twomey, D, Ullah, S. Implementing an exercise-training programme to prevent lower-limb injuries: considerations for the development of a randomised controlled trial intervention delivery plan. *Br J Sports Med* 2011: 45: 791-796.

Fleisig, GS, Andrews, JR, Cutter, GR, Weber, A, Loftice, J, McMichael, C, Hassell, N, Lyman, S. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med* 2011: 39: 253-257.

Forthomme, B, Wieczorek, V, Frisch, A, Crielaard, JM, Croisier, JL. Shoulder pain among high-level volleyball players and preseason features. *Med Sci Sports Exerc* 2013: 45: 1852-1860.

Fuller, CW, Ekstrand, J, Junge, A, Andersen, TE, Bahr, R, Dvorak, J, Hagglund, M, McCrory, P, Meeuwisse, WH. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Clin J Sport Med* 2006: 16: 97-106.

Fuller, CW, Molloy, MG, Bagate, C, Bahr, R, Brooks, JH, Donson, H, Kemp, SP, McCrory, P, McIntosh, AS, Meeuwisse, WH, Quarrie, KL, Raftery, M, Wiley, P. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Clin J Sport Med* 2007: 17: 177-181.

Giroto, N, Hespanhol Junior, LC, Gomes, MR, Lopes, AD. Incidence and risk factors of injuries in Brazilian elite handball players: A prospective cohort study. *Scand J Med Sci Sports* 2017: 27: 195-202.

Glasgow, RE, Vogt, TM, Boles, SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health* 1999: 89: 1322-1327.

Grimes, DA, Schulz, KF. Cohort studies: marching towards outcomes. *Lancet* 2002: 359: 341-345.

Hanson, D, Allegrante, JP, Sleet, DA, Finch, CF. Research alone is not sufficient to prevent sports injury. *Br J Sports Med* 2014: 48: 682-684.

Hass, CJ, Feigenbaum, MS, Franklin, BA. Prescription of resistance training for healthy populations. *Sports Med* 2001: 31: 953-964.

Hayes, K, Walton, JR, Szomor, ZL, Murrell, GA. Reliability of 3 methods for assessing shoulder strength. *J Shoulder Elbow Surg* 2002: 11: 33-39.

Herring, RM, Chapman, AE. Effects of changes in segmental values and timing of both torque and torque reversal in simulated throws. *J Biomech* 1992: 25: 1173-1184.

Hibberd, EE, Oyama, S, Spang, JT, Prentice, W, Myers, JB. Effect of a 6-week strengthening program on shoulder and scapular-stabilizer strength and scapular kinematics in division I collegiate swimmers. *J Sport Rehabil* 2012: 21: 253-265.

Hintermeister, RA, Lange, GW, Schultheis, JM, Bey, MJ, Hawkins, RJ. Electromyographic activity and applied load during shoulder rehabilitation exercises using elastic resistance. *Am J Sports Med* 1998: 26: 210-220.

Norges Idrettsforbund. Annual report 2016. Available at:
https://www.idrettsforbundet.no/globalassets/idrett/nokkeltallsrapport-2016-nif-28112017.pdf
Accessed 08 December 2017.

International Handball Federation (2005). Rules of the Game. Available at:
http://www.ihf.info/upload/Manual/IHF_STATUTS_CHAP_9A_GB.pdf
Accessed 10 November 2017.

International Handball Federation (2010). Changes to the Rules of the Game 2010. Available at:
http://www.ihf.info/files/Uploads/NewsAttachments/0_Overview%202010_GB.pdf
Accessed 10 November 2017.

International Handball Federation (2013) Fascination for Thousands of Years. Handball. History and Stories. Available at: http://ihf.info/upload/Book/issue0001/index.html
Accessed 07 November 2017.

International Handball Federation (2016). Rules of the Game. Available at:
http://www.ihf.info/files/Uploads/NewsAttachments/0_New-Rules%20of%20the%20Game_GB.pdf
Accessed 10 November 2017.

Jacobsson, J, Timpka, T. Classification of Prevention in Sports Medicine and Epidemiology. *Sports Med* 2015: 45: 1483-1487.

Jørgensen, U. Epidemiology of injuries in typical Scandinavian team sports. *Br J Sports Med* 1984: 18: 59-63.

Junge, A, Dvorak, J. Influence of definition and data collection on the incidence of injuries in football. *Am J Sports Med* 2000: 28: 40-46.

Junge, A, Engebretsen, L, Alonso, JM, Renstrom, P, Mountjoy, M, Aubry, M, Dvorak, J. Injury surveillance in multi-sport events: the International Olympic Committee approach. *Br J Sports Med* 2008: 42: 413-421.

Junge, A, Engebretsen, L, Mountjoy, ML, Alonso, JM, Renstrom, PA, Aubry, MJ, Dvorak, J. Sports injuries during the Summer Olympic Games 2008. *Am J Sports Med* 2009: 37: 2165-2172.

Junge, A, Langevoort, G, Pipe, A, Peytavin, A, Wong, F, Mountjoy, M, Beltrami, G, Terrell, R, Holzgraefe, M, Charles, R, Dvorak, J. Injuries in team sport tournaments during the 2004 Olympic Games. *Am J Sports Med* 2006: 34: 565-576.

Karcher, C, Buchheit, M. On-court demands of elite handball, with special reference to playing positions. *Sports Med* 2014: 44: 797-814.

Kiani, A, Hellquist, E, Ahlqvist, K, Gedeborg, R, Michaelsson, K, Byberg, L. Prevention of soccer-related knee injuries in teenaged girls. *Arch Intern Med* 2010: 170: 43-49.

Kibler, WB, Kuhn, JE, Wilk, K, Sciascia, A, Moore, S, Laudner, K, Ellenbecker, T, Thigpen, C, Uhl, T. The disabled throwing shoulder: spectrum of pathology-10-year update. *Arthroscopy* 2013a: 29: 141-161 e126.

Kibler, WB, Ludewig, PM, McClure, PW, Michener, LA, Bak, K, Sciascia, AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. *Br J Sports Med* 2013b: 47: 877-885.

Kibler, WB, Wilkes, T, Sciascia, A. Mechanics and pathomechanics in the overhead athlete. *Clin Sports Med* 2013c: 32: 637-651.

King, DA, Gabbett, TJ, Gissane, C, Hodgson, L. Epidemiological studies of injuries in rugby league: suggestions for definitions, data collection and reporting methods. *J Sci Med Sport* 2009: 12: 12-19.

Kraemer, R, Knobloch, K. A soccer-specific balance training program for hamstring muscle and patellar and achilles tendon injuries: an intervention study in premier league female soccer. *Am J Sports Med* 2009: 37: 1384-1393.

Kraemer, WJ, Ratamess, NA, French, DN. Resistance training for health and performance. *Curr Sports Med Rep* 2002: 1: 165-171.

Krosshaug, T, Andersen, TE, Olsen, OE, Myklebust, G, Bahr, R. Research approaches to describe the mechanisms of injuries in sport: limitations and possibilities. *Br J Sports Med* 2005: 39: 330-339.

Kruger, K, Pilat, C, Uckert, K, Frech, T, Mooren, FC. Physical performance profile of handball players is related to playing position and playing class. *J Strength Cond Res* 2014: 28: 117-125.

Langevoort, G, Myklebust, G, Dvorak, J, Junge, A. Handball injuries during major international tournaments. *Scand J Med Sci Sports* 2007: 17: 400-407.

Laudner, KG, Sipes, RC, Wilson, JT. The acute effects of sleeper stretches on shoulder range of motion. *J Athl Train* 2008: 43: 359-363.

Lauersen, JB, Bertelsen, DM, Andersen, LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med* 2014: 48: 871-877.

Lintner, D, Noonan, TJ, Kibler, WB. Injury patterns and biomechanics of the athlete's shoulder. *Clin Sports Med* 2008: 27: 527-551.

Ludewig, PM, Cook, TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther* 2000: 80: 276-291.

Ludewig, PM, Hoff, MS, Osowski, EE, Meschke, SA, Rundquist, PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med* 2004: 32: 484-493.

Lyman, S, Fleisig, GS, Andrews, JR, Osinski, ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med* 2002: 30: 463-468.

Lyman, S, Fleisig, GS, Waterbor, JW, Funkhouser, EM, Pulley, L, Andrews, JR, Osinski, ED, Roseman, JM. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001: 33: 1803-1810.

Maenhout, A, Van Eessel, V, Van Dyck, L, Vanraes, A, Cools, A. Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program. *Am J Sports Med* 2012: 40: 2105-2112.

Manske, R, Wilk, KE, Davies, G, Ellenbecker, T, Reinold, M. Glenohumeral motion deficits: friend or foe? *Int J Sports Phys Ther* 2013: 8: 537-553.

Manske, RC, Meschke, M, Porter, A, Smith, B, Reiman, M. A randomized controlled single-blinded comparison of stretching versus stretching and joint mobilization for posterior shoulder tightness measured by internal rotation motion loss. *Sports Health* 2010: 2: 94-100.

Marshall, RN, Elliott, BC. Long-axis rotation: the missing link in proximal-to-distal segmental sequencing. *J Sports Sci* 2000: 18: 247-254.

Matsuura, T, Iwame, T, Suzue, N, Arisawa, K, Sairyo, K. Risk factors for shoulder and elbow pain in youth baseball players. *Phys Sportsmed* 2017: 45: 140-144.

McClure, P, Balaicuis, J, Heiland, D, Broersma, ME, Thorndike, CK, Wood, A. A randomized controlled comparison of stretching procedures for posterior shoulder tightness. *J Orthop Sports Phys Ther* 2007: 37: 108-114.

McClure, P, Tate, AR, Kareha, S, Irwin, D, Zlupko, E. A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train* 2009: 44: 160-164.

McDonagh, MJ, Davies, CT. Adaptive response of mammalian skeletal muscle to exercise with high loads. *Eur J Appl Physiol Occup Physiol* 1984: 52: 139-155.

Meeuwisse, WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* 1994: 4: 166-170.

Meeuwisse, WH, Tyreman, H, Hagel, B, Emery, C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sport Med* 2007: 17: 215-219.

Michalsik, LB, Aagaard, P, Madsen, K. Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players. *Int J Sports Med* 2013: 34: 590-599.

Michalsik, LB, Aagaard, P, Madsen, K. Technical activity profile and influence of body anthropometry on playing performance in female elite team handball. *J Strength Cond Res* 2015: 29: 1126-1138.

Michalsik, LB, Madsen, K, Aagaard, P. Match performance and physiological capacity of female elite team handball players. *Int J Sports Med* 2014: 35: 595-607.

Mohseni-Bandpei, MA, Keshavarz, R, Minoonejhad, H, Mohsenifar, H, Shakeri, H. Shoulder pain in Iranian elite athletes: the prevalence and risk factors. *J Manipulative Physiol Ther* 2012: 35: 541-548.

Møller, M, Attermann, J, Myklebust, G, Wedderkopp, N. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. *Br J Sports Med* 2012: 46: 531-537.

Møller, M, Nielsen, RO, Attermann, J, Wedderkopp, N, Lind, M, Sorensen, H, Myklebust, G. Handball load and shoulder injury rate: a 31-week cohort study of 679 elite youth handball players. *Br J Sports Med* 2017: 51: 231-237.

Moncrief, SA, Lau, JD, Gale, JR, Scott, SA. Effect of rotator cuff exercise on humeral rotation torque in healthy individuals. *J Strength Cond Res* 2002: 16: 262-270.

Moore, SD, Uhl, TL, Kibler, WB. Improvements in shoulder endurance following a baseball-specific strengthening program in high school baseball players. *Sports Health* 2013: 5: 233-238.

Moseley, JB, Jr., Jobe, FW, Pink, M, Perry, J, Tibone, J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. *Am J Sports Med* 1992: 20: 128-134.

Myers, JB, Oyama, S, Hibberd, EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. *J Shoulder Elbow Surg* 2013: 22: 1154-1159.

Myers, JB, Pasquale, MR, Laudner, KG, Sell, TC, Bradley, JP, Lephart, SM. On-the-Field Resistance-Tubing Exercises for Throwers: An Electromyographic Analysis. *J Athl Train* 2005: 40: 15-22.

Myklebust, G, Engebretsen, L, Braekken, IH, Skjølberg, A, Olsen, OE, Bahr, R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med* 2003: 13: 71-78.

Myklebust, G, Hasslan, L, Bahr, R, Steffen, K. High prevalence of shoulder pain among elite Norwegian female handball players. *Scand J Med Sci Sports* 2013a: 23: 288-294.

Myklebust, G, Skjølberg, A, Bahr, R. ACL injury incidence in female handball 10 years after the Norwegian ACL prevention study: important lessons learned. *Br J Sports Med* 2013b: 47: 476-479.

Nevill, AM, Balmer, NJ, Williams, AM. The influence of crowd noise and experience upon refereeing decisions in football. *Psychology of Sport and Exercise* 2002: 3: 261-272.

Norges Håndballforbund (1997). Norsk håndball gjennom 60 år. NHF, Oslo.

Norges Håndballforbund (2017a). Available at: https://www.handball.no
Accessed 09 November 2017.

Norges Håndballforbund (2017b) Key numbers 2016. Available at:
https://www.handball.no/regioner/nhf-sentralt/om-oss/organisasjon/nokkeltall/
Accessed 09 November 2017.

Niederbracht, Y, Shim, AL, Sloniger, MA, Paternostro-Bayles, M, Short, TH. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *J Strength Cond Res* 2008: 22: 140-145.

Nielsen, AB, Yde, J. An epidemiologic and traumatologic study of injuries in handball. *Int J Sports Med* 1988: 9: 341-344.

O'Brien, J, Finch, CF. The Implementation of Musculoskeletal Injury-Prevention Exercise Programmes in Team Ball Sports: A Systematic Review Employing the RE-AIM Framework. *Sports Medicine* 2014: 44: 1305-1318.

Oliveira, VMA, Pitangui, ACR, Gomes, MRA, Silva, HAD, Passos, M, Araujo, RC. Shoulder pain in adolescent athletes: prevalence, associated factors and its influence on upper limb function. *Braz J Phys Ther* 2017: 21: 107-113.

Olsen, OE, Myklebust, G, Engebretsen, L, Bahr, R. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. *Am J Sports Med* 2004: 32: 1002-1012.

Olsen, OE, Myklebust, G, Engebretsen, L, Bahr, R. Injury pattern in youth team handball: a comparison of two prospective registration methods. *Scand J Med Sci Sports* 2006a: 16: 426-432.

Olsen, OE, Myklebust, G, Engebretsen, L, Holme, I, Bahr, R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ* 2005: 330: 449.

Olsen, SJ, 2nd, Fleisig, GS, Dun, S, Loftice, J, Andrews, JR. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med* 2006b: 34: 905-912.

Østerås, H, Sommervold, M, Skjølberg, A. Effects of a strength-training program for shoulder complaint prevention in female team handball athletes. A pilot study. *J Sports Med Phys Fitness* 2015: 55: 761-767.

Petersen, J, Thorborg, K, Nielsen, MB, Budtz-Jørgensen, E, Hölmich, P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. *Am J Sports Med* 2011: 39: 2296-2303.

Petersen, W, Braun, C, Bock, W, Schmidt, K, Weimann, A, Drescher, W, Eiling, E, Stange, R, Fuchs, T, Hedderich, J, Zantop, T. A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Arch Orthop Trauma Surg* 2005: 125: 614-621.

Piry, H, Fallahi, A, Kordi, R, Rajabi, R, Rahimi, M, Yosefi, M. Handball injuries in elite asian players. *World Appl Sci J* 2011: 10: 1559-1564.

Pluim, BM, Fuller, CW, Batt, ME, Chase, L, Hainline, B, Miller, S, Montalvan, B, Renstrom, P, Stroia, KA, Weber, K, Wood, TO. Consensus statement on epidemiological studies of medical conditions in tennis, April 2009. *Br J Sports Med* 2009: 43: 893-897.

Povoas, SC, Seabra, AF, Ascensao, AA, Magalhaes, J, Soares, JM, Rebelo, AN. Physical and physiological demands of elite team handball. *J Strength Cond Res* 2012: 26: 3365-3375.

Prestkvern, SR. (2013). Skulderproblemer blant eliteseriespillere i norsk herrehåndball - Er det en sammenheng mellom pasnings- og skuddeksponering og spillernes skulderproblemer? Master thesis, Norwegian School of Sport Sciences 2013.

Reeser, JC, Joy, EA, Porucznik, CA, Berg, RL, Colliver, EB, Willick, SE. Risk factors for volleyball-related shoulder pain and dysfunction. *PM R* 2010: 2: 27-36.

Reinold, MM, Wilk, KE, Fleisig, GS, Zheng, N, Barrentine, SW, Chmielewski, T, Cody, RC, Jameson, GG, Andrews, JR. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. *J Orthop Sports Phys Ther* 2004: 34: 385-394.

Roetert, EP, Ellenbecker, TS, Chu, DA, Bugg, BS. Tennis-specific shoulder and trunk strength training. *Strength and Conditioning* 1997: 19: 31-39.

Rousanoglou, E, Noutsos, K, Bayios, I, Boudolos, K. Ground reaction forces and throwing performance in elite and novice players in two types of handball shot. *J Hum Kinet* 2014: 40: 49-55.

Saw, R, Dennis, RJ, Bentley, D, Farhart, P. Throwing workload and injury risk in elite cricketers. *Br J Sports Med* 2011: 45: 805-808.

Sciascia, A, Thigpen, C, Namdari, S, Baldwin, K. Kinetic chain abnormalities in the athletic shoulder. *Sports Med Arthrosc Rev* 2012: 20: 16-21.

Seil, R, Rupp, S, Tempelhof, S, Kohn, D. Sports injuries in team handball. A one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. *Am J Sports Med* 1998: 26: 681-687.

Shanley, E, Kissenberth, MJ, Thigpen, CA, Bailey, LB, Hawkins, RJ, Michener, LA, Tokish, JM, Rauh, MJ. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. *J Shoulder Elbow Surg* 2015: 24: 1005-1013.

Shanley, E, Rauh, MJ, Michener, LA, Ellenbecker, TS, Garrison, JC, Thigpen, CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med* 2011: 39: 1997-2006.

Shitara, H, Kobayashi, T, Yamamoto, A, Shimoyama, D, Ichinose, T, Tajika, T, Osawa, T, Iizuka, H, Takagishi, K. Prospective multifactorial analysis of preseason risk factors for shoulder and elbow injuries in high school baseball pitchers. *Knee Surg Sports Traumatol Arthrosc* 2017: 25: 3303-3310.

Shrier, I. Understanding causal inference: the future direction in sports injury prevention. *Clin J Sport Med* 2007: 17: 220-224.

Skazalski, C, Kruczynski, J, Bahr, M, Bere, T, Whiteley, R, Bahr, R. Landing-related ankle injuries do not occur in plantarflexion as once thought: A systematic video analysis of ankle injuries in world-class volleyball. *Br J Sports Med* 2018: 52: 74-82.

Soligard, T, Myklebust, G, Steffen, K, Holme, I, Silvers, H, Bizzini, M, Junge, A, Dvorak, J, Bahr, R, Andersen, TE. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ* 2008: 337: a2469.

Soligard, T, Nilstad, A, Steffen, K, Myklebust, G, Holme, I, Dvorak, J, Bahr, R, Andersen, TE. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. *Br J Sports Med* 2010: 44: 787-793.

Soligard, T, Steffen, K, Palmer, D, Alonso, JM, Bahr, R, Lopes, AD, Dvorak, J, Grant, ME, Meeuwisse, W, Mountjoy, M, Pena Costa, LO, Salmina, N, Budgett, R, Engebretsen, L. Sports injury and illness incidence in the Rio de Janeiro 2016 Olympic Summer Games: A prospective study of 11274 athletes from 207 countries. *Br J Sports Med* 2017: 51: 1265-1271.

Sommervold, M, Østerås, H. What is the effect of a shoulder-strengthening program to prevent shoulder pain among junior female team handball players? *Open Access J Sports Med* 2017: 8: 61-70.

Steffen, K, Myklebust, G, Olsen, OE, Holme, I, Bahr, R. Preventing injuries in female youth football--a cluster-randomized controlled trial. *Scand J Med Sci Sports* 2008: 18: 605-614.

Struyf, F, Nijs, J, Meeus, M, Roussel, NA, Mottram, S, Truijen, S, Meeusen, R. Does scapular positioning predict shoulder pain in recreational overhead athletes? *Int J Sports Med* 2014: 35: 75-82.

Sundstrup, E, Jakobsen, MD, Andersen, CH, Zebis, MK, Mortensen, OS, Andersen, LL. Muscle activation strategies during strength training with heavy loading vs. repetitions to failure. *J Strength Cond Res* 2012: 26: 1897-1903.

Swanik, KA, Huxel Bliven, K, Swanik, CB. Rotator-cuff muscle-recruitment strategies during shoulder rehabilitation exercises. *J Sport Rehabil* 2011: 20: 471-486.

Townsend, H, Jobe, FW, Pink, M, Perry, J. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. *Am J Sports Med* 1991: 19: 264-272.

Trudel, P, Dionne, JP, Bernard, D. Differences between assessments of penalties in ice hockey by referees, coaches, players and parents. *Safety in Ice Hockey* 2000: 3: 274-290.

Tyler, TF, Mullaney, MJ, Mirabella, MR, Nicholas, SJ, McHugh, MP. Risk Factors for Shoulder and Elbow Injuries in High School Baseball Pitchers: The Role of Preseason Strength and Range of Motion. *Am J Sports Med* 2014: 42: 1993-1999.

Van Buuren, S. Flexible Imputation of Missing Data, Boca Raton, Chapman & Hall/CRC, 2012

Van de Velde, A, De Mey, K, Maenhout, A, Calders, P, Cools, AM. Scapular-muscle performance: two training programs in adolescent swimmers. *J Athl Train* 2011: 46: 160-167.

Van den Tillaar, R. Comparison of range of motion tests with throwing kinematics in elite team handball players. *J Sports Sci* 2016: 34: 1976-1982.

Van Den Tillaar, R, Cabri, JM. Gender differences in the kinematics and ball velocity of overarm throwing in elite team handball players. *J Sports Sci* 2012: 30: 807-813.

Van den Tillaar, R, Ettema, G. A three-dimensional analysis of overarm throwing in experienced handball players. *J Appl Biomech* 2007: 23: 12-19.

Van den Tillaar, R, Ettema, G. Is there a proximal-to-distal sequence in overarm throwing in team handball? *J Sports Sci* 2009: 27: 949-955.

Van den Tillaar, R, Zondag, A, Cabri, J. Comparing performance and kinematics of throwing with a circular and whip-like wind up by experienced handball players. *Scand J Med Sci Sports* 2013: 23: e373-380.

Van Mechelen, W, Hlobil, H, Kemper, HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med* 1992: 14: 82-99.

Vila, H, Manchado, C, Rodriguez, N, Abraldes, JA, Alcaraz, PE, Ferragut, C. Anthropometric profile, vertical jump, and throwing velocity in elite female handball players by playing positions. *J Strength Cond Res* 2012: 26: 2146-2155.

Vleck, VE, Bentley, DJ, Millet, GP, Cochrane, T. Triathlon event distance specialization: training and injury effects. *J Strength Cond Res* 2010: 24: 30-36.

Wagner, H, Buchecker, M, von Duvillard, SP, Muller, E. Kinematic description of elite vs. Low level players in team-handball jump throw. *J Sports Sci Med* 2010: 9: 15-23.

Wagner, H, Kainrath, S, Müller, E. Coordinative and tactical parameters of team-handball throw. The correlation of level of performance, throwing quality and selected technique-tactical parameters. *Leistungssport* 2008: 38: 35-41.

Wagner, H, Pfusterschmied, J, Tilp, M, Landlinger, J, von Duvillard, SP, Muller, E. Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. *Scand J Med Sci Sports* 2014: 24: 345-354.

Wagner, H, Pfusterschmied, J, Von Duvillard, SP, Muller, E. Skill-dependent proximal-to-distal sequence in team-handball throwing. *J Sports Sci* 2012: 30: 21-29.

Wagner, H, Pfusterschmied, J, von Duvillard, SP, Müller, E. Performance and kinematics of varoius throwing techniques in team-handball. *J Sports Sci Med* 2011: 73-80.

Walden, M, Atroshi, I, Magnusson, H, Wagner, P, Hagglund, M. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *BMJ* 2012: 344: e3042.

Weber, AE, Kontaxis, A, O'Brien, SJ, Bedi, A. The biomechanics of throwing: simplified and cogent. *Sports Med Arthrosc Rev* 2014: 22: 72-79.

Wedderkopp, N, Kaltoft, M, Holm, R, Froberg, K. Comparison of two intervention programmes in young female players in European handball--with and without ankle disc. *Scand J Med Sci Sports* 2003: 13: 371-375.

Wedderkopp, N, Kaltoft, M, Lundgaard, B, Rosendahl, M, Froberg, K. Injuries in young female players in European team handball. *Scand J Med Sci Sports* 1997: 7: 342-347.

Wedderkopp, N, Kaltoft, M, Lundgaard, B, Rosendahl, M, Froberg, K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports* 1999: 9: 41-47.

Wilk, KE, Macrina, LC, Arrigo, C. Passive range of motion characteristics in the overhead baseball pitcher and their implications for rehabilitation. *Clin Orthop Relat Res* 2012: 470: 1586-1594.

Wilk, KE, Macrina, LC, Fleisig, GS, Aune, KT, Porterfield, RA, Harker, P, Evans, TJ, Andrews, JR. Deficits in Glenohumeral Passive Range of Motion Increase Risk of Shoulder Injury in Professional Baseball Pitchers: A Prospective Study. *Am J Sports Med* 2015: 43: 2379-2385.

Wilk, KE, Macrina, LC, Fleisig, GS, Porterfield, R, Simpson, CD, 2nd, Harker, P, Paparesta, N, Andrews, JR. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011: 39: 329-335.

Wilk, KE, Reinold, MM, Macrina, LC, Porterfield, R, Devine, KM, Suarez, K, Andrews, JR. Glenohumeral internal rotation measurements differ depending on stabilization techniques. *Sports Health* 2009: 1: 131-136.

Wilkins, HA, Petersen, SR, Quinney, HA. Time-motion analysis of and heart rate responses to amateur ice hockey officiating. *Can J Sport Sci* 1991: 16: 302-307.

Windt, J, Gabbett, TJ. How do training and competition workloads relate to injury? The workload-injury aetiology model. *Br J Sports Med* 2017: 51: 428-435.

Yde, J, Nielsen, AB. Sports injuries in adolescents' ball games: soccer, handball and basketball. *Br J Sports Med* 1990: 24: 51-54.

Paper I

Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players

Stig Haugsboe Andersson, Roald Bahr, Benjamin Clarsen, Grethe Myklebust

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2016-096226).

Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway

Correspondence to Stig Haugsboe Andersson, Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, P.O. Box 4014 Ullevål Stadion, Oslo 0806, Norway; s.h.andersson@nih.no

Accepted 31 May 2016
Published Online First 16 June 2016

To cite: Andersson SH, Bahr R, Clarsen B, *et al. Br J Sports Med* 2017;**51**:1073–1080.

ABSTRACT

Background Shoulder problems are highly prevalent among elite handball players. Reduced glenohumeral rotation, external rotation weakness and scapula dyskinesis have been identified as risk factors.

Aim Evaluate the effect of an exercise programme designed to reduce the prevalence of shoulder problems in elite handball.

Methods 45 elite handball teams (22 female teams, 23 male teams, 660 players) were cluster randomised (22 teams, 331 players in the intervention group, 23 teams, 329 players in the control group) and followed for 1 competitive season (7 months). The Oslo Sports Trauma Research Center (OSTRC) Shoulder Injury Prevention Programme, an exercise programme to increase glenohumeral internal rotation, external rotation strength and scapular muscle strength, as well as improve kinetic chain and thoracic mobility, was delivered by coaches and captains 3 times per week as a part of the handball warm-up. The main outcome measures, prevalence of shoulder problems and substantial shoulder problems, were measured monthly.

Results The average prevalence of shoulder problems during the season was 17% (95% CI 16% to 19%) in the intervention group and 23% (95% CI 21% to 26%) in the control group (mean difference 6%). The average prevalence of substantial shoulder problems was 5% (95% CI 4% to 6%) in the intervention group and 8% (95% CI 7% to 9%) in the control group (mean difference 3%). Using generalised estimating equation models, a 28% lower risk of shoulder problems (OR 0.72, 95% CI 0.52 to 0.98, p=0.038) and 22% lower risk of substantial shoulder problems (OR 0.78, 95% CI 0.53 to 1.16, p=0.23) were observed in the intervention group compared with the control group.

Conclusions The OSTRC Shoulder Injury Prevention Programme reduced the prevalence of shoulder problems in elite handball and should be included as a part of the warm-up.

Trial registration number ISRCTN96217107.

INTRODUCTION

Shoulder injuries, predominantly from overuse, have been highlighted as an area warranting preventative efforts in a wide variety of throwing sports,[1–13] where the shoulder is exposed to large demands due to repeated overhead motion at high velocity.[14–16] Elite handball is no exception; a history of shoulder pain is common (44–75%), the point prevalence of current shoulder pain is high (20–52%) and the average weekly prevalence of shoulder problems (28%) and substantial shoulder problems (12%) is significant.[2 7 17]

Several internal modifiable risk factors for shoulder injury have been investigated among throwing athletes, predominantly handball and baseball players. In handball, reduced glenohumeral internal rotation and excessive glenohumeral external rotation have been suggested as risk factors in a cross-sectional study.[18] In a prospective study, a reduction of total glenohumeral rotation has been associated with shoulder problems.[2] Similarly, in baseball, reduced glenohumeral internal rotation and total rotational range of motion have been linked to shoulder injury.[3 5 19–21] Regarding rotator cuff strength, external rotation weakness and low ratios of concentric and eccentric external to internal rotation strength have been reported as risk factors in handball and baseball.[2 6 22–24] In addition, weakness in glenohumeral abduction strength has been associated with shoulder injury in baseball.[6 24 25] Recently, the presence of scapular dyskinesis was reported as a risk factor correlated with shoulder problems in elite handball.[2] However, this factor has not been associated with shoulder injury among baseball players.[26] Reduced kinetic chain function and limited thoracic mobility are often implicated in shoulder injuries,[27 28] despite a lack of evidence associating these factors with shoulder injury.

There are no randomised controlled trials targeting prevention of overuse shoulder injuries in elite handball, or throwing sports in general.[29] Thus, the main objective of this randomised controlled trial was to evaluate the effect of an exercise programme designed to reduce the prevalence of shoulder problems in elite handball.

METHODS

Study design and participants

This was a two-armed cluster-randomised controlled trial. The authors followed and completed the Consolidating Standards for Reporting Clinical Trials (CONSORT) with the subsequent extension to cluster randomised trials.[30] During the off-season (June to July 2014) we invited, in collaboration with the Norwegian Handball Federation, every male and female handball team (n=48) in the two top divisions (elite level) in Norway to participate in the study. Of these, 46 teams agreed to participate and were randomised by team into an intervention or control group (figure 1). A neutral, blinded person who had no further involvement in the study conducted and revealed the

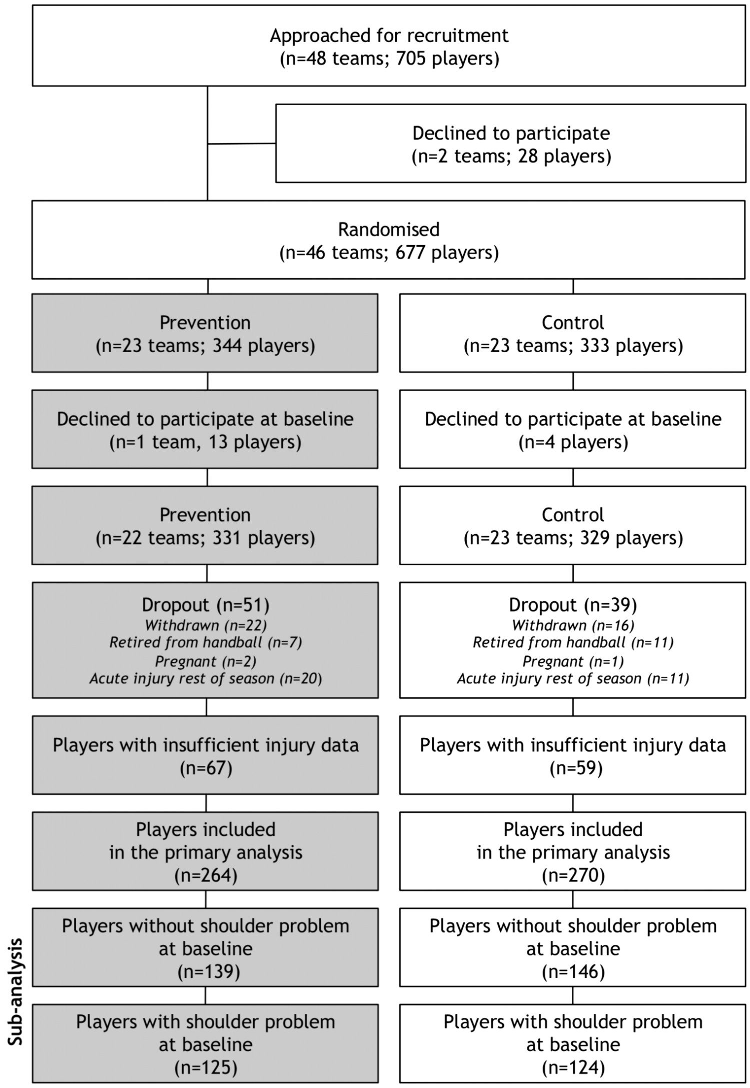


Figure 1 Study flow chart showing the recruitment, dropout and the number of players included and analysed.

randomisation after the final team had been recruited to ensure concealment of allocation. A computer-generated list of random team numbers was used to randomise teams stratified by gender and competition level, where all players from the same team were assigned to the same group. The randomisation aimed to achieve a balanced number of female and male teams from the two top divisions in the intervention and control groups.

We visited each team (n=46) during a training session in the preseason (August to mid September 2014) and invited every player present to participate in the study. All players with a team contract were eligible for participation, irrespective of their baseline injury status or history (N=677). Players who consented to participate completed baseline questionnaires and were followed for the duration of the regular season (September 2014 through March 2015). Six times during the season, players reported any shoulder problems using the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire,[31] as described in a previous study on risk factors for shoulder problems among male elite handball players.[2] During our baseline visit, we instructed teams in the intervention group on how to use the exercise programme to be implemented during the subsequent week. We asked control teams to warm up as usual.

Baseline questionnaires

We registered demographic and anthropometric data, dominant arm, playing position and number of years as an active handball player. Players reported a history of shoulder pain and current shoulder pain using a modified version of the Fahlström questionnaire, previously used in studies on elite handball players.[2 7] Players reported acute shoulder injuries within the past 6 months and shoulder surgery within the past 12 months. This information was crosschecked with the team medical staff. Finally, we asked them to report any shoulder problems during the previous weeks using the OSTRC Overuse Injury Questionnaire.[31]

Intervention

We created a preliminary version of the exercise programme based on risk factors for shoulder problems identified among elite handball players.[2 18 22] An expert panel consisting of a fitness coach employed by the Norwegian Handball Federation and four physiotherapists clinically working with handball players nationally and internationally reviewed the exercise programme. A female handball team in a lower division, not included in the study, tested the exercise programme and responded to a questionnaire based on the Reach Effectiveness Adoption Implementation Maintenance framework to provide information regarding their beliefs and experiences of content, duration, load and applicability of the exercise programme.[32 33]

The final version of the OSTRC Shoulder Injury Prevention Programme consisted of five exercises with different variations and levels, aiming at increasing the glenohumeral internal range of motion, external rotation strength and scapular muscle strength. In addition, exercises to improve the kinetic chain and thoracic mobility were included on the basis of recommendations from the expert panel. Examples of exercises included in the programme are illustrated in figure 2. Detailed information on the OSTRC Shoulder Injury Prevention Programme is available as an online supplementary appendix.

Players in the intervention group were targets for the exercise programme. Coaches and team captains were delivery agents and received, together with team medical staff, specific training on the content and execution of the exercise programme. We recommended implementing the exercise programme three times per week as a part of the team's regular warm-up to training, before any throwing activity. Teams received posters of the exercise programme, as well as the equipment needed. We instructed the team medical staff to be present at least one session every week during the first 4 weeks, and every second week for the rest of the season, to supervise the quality of the exercises and ensure that players experiencing pain conducted the exercises correctly and with the correct load.

We emphasised the quality of movement, correct positioning of the scapula, good posture and core stability. If a team did not have their own medical staff, we recruited a physiotherapist. We completed follow-up visits to all teams in the intervention group during the mid-season (December 2015 through January 2016) to supervise exercise quality, answer questions and encourage them to complete the exercise programme as recommended. Once players were familiar with the exercises, the programme took about 10 min to complete.

Monitoring of shoulder problems

The OSTRC Overuse Injury Questionnaire was sent electronically by mail to all players in the study on the last Sunday of each month from October 2014 to March 2015, six times in total, using online survey software (Questback V.9692, Questback AS, Oslo, Norway). Automatic reminders were sent to non-responders after 3 and 7 days per email and SMS (Pling, Front Information DA, Oslo, Norway). In addition, we visited teams throughout the season to ensure a high response rate by asking non-responders to complete the questionnaire on paper. The questionnaire gathers information on the extent to which overuse shoulder injuries, expressed as shoulder problems, affect participation, training volume and performance, as well as the level of shoulder pain experienced during the past week. Players were only asked about their dominant shoulder, with shoulder problems defined as any pain, ache, stiffness, instability, looseness or other symptoms related to their shoulder.[31] In a supplementary question, players reported any acute injury to the dominant shoulder during the past week, defined as an injury caused by a single identifiable event.[34 35] Team medical staff also reported any acute shoulder injury by mail at the end of each month (October 2014 to March 2015) and their records were crosschecked with player reports to avoid misreporting of an acute shoulder injury as an overuse injury. Acute injuries were excluded from the analyses.

Outcome measures

Primary outcomes were the prevalence of shoulder problems and substantial shoulder problems in the dominant arm, as measured six times during the season. We calculated the prevalence of shoulder problems in both groups by dividing the number of players who reported any problem (ie, anything but the minimum value in any of the four questions) by the number of questionnaire respondents.[31] To filter problems with fewer functional consequences, we calculated the prevalence of substantial shoulder problems in the same way, but only including shoulder problems leading to moderate or severe reductions in training volume or performance, or a total inability to participate.[31] Secondary outcome was the severity score of shoulder problems reported during the season. The severity score ranged from 0 to 100 and was calculated on the basis of the four questions in the OSTRC Overuse Injury Questionnaire for every player reporting a shoulder problem.[31] The severity scores for all players were summed and divided by the number of respondents. In addition, we calculated the relative impact of shoulder problems in both groups by summing player severity scores during the season and dividing by the total number of responses.

Compliance

We monitored the degree to which the players in the intervention group completed the exercise programme according to our recommendations through self-reporting. Six times during the season, players reported how many times they had completed the exercise programme during the past 7 days, both with the team and by themselves. The total number of sessions completed was summed and divided by the number of respondents to calculate the average weekly compliance with the exercise programme for each measure.

Exposure

Players reported their exposure to handball training, match play and additional strength training six times during the season. We calculated the average weekly exposure to handball training, match play and strength training (minutes) for each measure in both groups by summing up the number of minutes reported and dividing by the number of respondents.

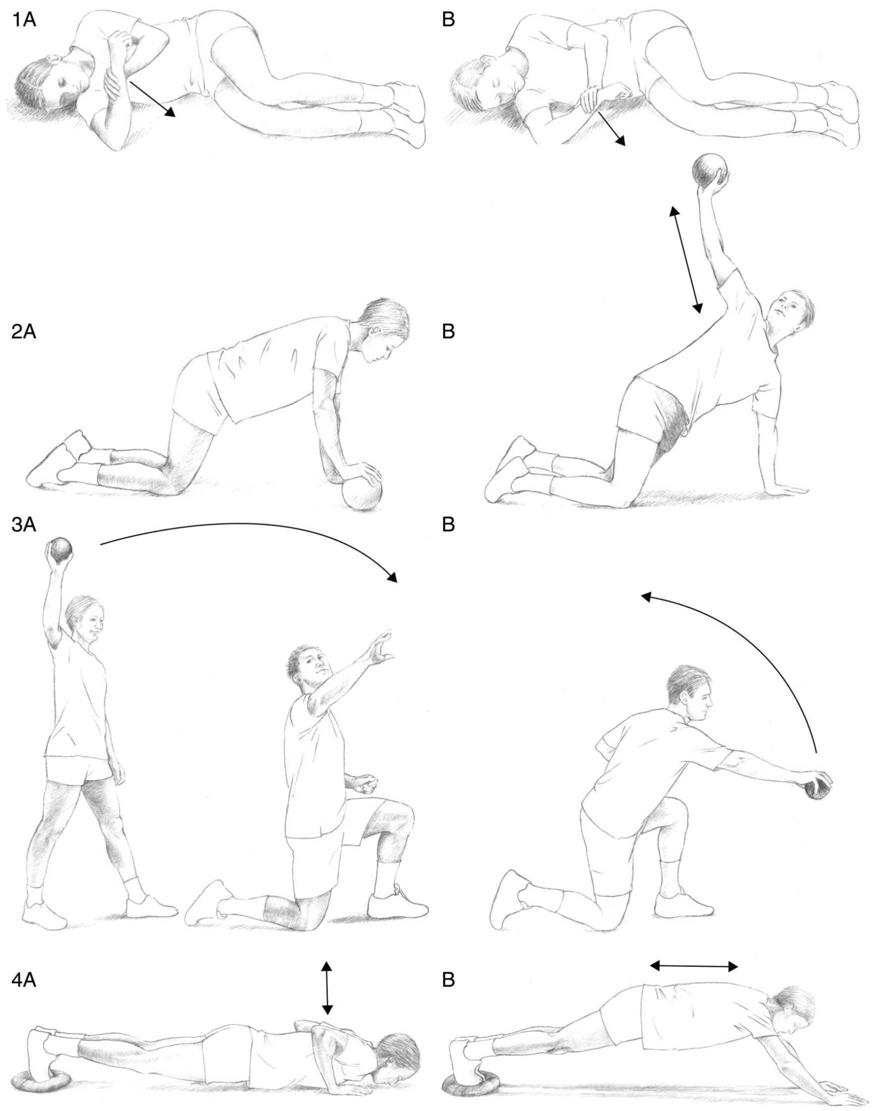


Figure 2 Examples of exercises aiming to improve glenohumeral range of motion (1A, B), thoracic mobility (2A, B), external rotation strength (3A, B), scapular muscle strength (4A, B) and kinetic chain (4A, B; A, start position; B, end position).

Sample size

We estimated the sample size on the basis of the average prevalence of shoulder problems (28%) and substantial shoulder problems (12%) reported in a prospective risk factor study of shoulder problems among male elite handball players.[2] We adjusted for cluster correlations (estimated intraclass correlation coefficient <0.1) based on analysis of variance of within-participant and within-team prevalence, and assumed that we could include 15 players from each of the 48 available teams (n=720). On this basis, we estimated being able to detect a 10% reduction in the prevalence of shoulder problems with a power of 0.94, and a 6% reduction with a power of 0.87, at a 5% significance level.

Statistical methods

Theoretically, we set three responses to the OSTRC Overuse Injury Questionnaire as a minimum to include a player in the analyses. Initial data analyses showed that player response to the questionnaire was sufficient to estimate missing values using multiple imputations. We performed multiple imputations with the assumption of missing at random and used multivariate imputation by chained equation algorithm in combination with a predictive mean matching approach, which led to the pooled results of five multiple imputed data sets.[36] In order to assess differences in the prevalence of shoulder problems and substantial shoulder problems between the intervention and control groups over time, we used generalised estimating equation (GEE) models. We used an exchangeable covariance matrix and the significance level (α) was 0.05 for all analyses. Any anthropometric or demographic variables showing a possible difference between groups at baseline ($p<0.2$) were added to the GEE models using a forward selection procedure. However, since we identified no confounding effects, univariate analyses were performed. All analyses were performed using SPSS statistical software (SPSS V.21, IBM Corporation, New York, New York, USA).

RESULTS

Participants

A total of 22 prevention teams (n=331) and 23 control teams (n=329) entered the study, with no group differences in gender or competition level. Dropout during the study and the numbers included in the analyses are shown in figure 1. The male players in the intervention group were younger compared with the control group, with no other group differences in anthropometrics or demographics (table 1). Players reported having played handball for an average of 14 years (SD 5, range 4–37). The majority were right-handed (78%). There were no group differences in playing position, with 40% backs, 24% wings, 14% line players, 13% goalkeepers and 7% reporting multiple positions.

Shoulder pain and problems at baseline

At the time of inclusion, 145 players (45%) in the intervention group and 155 players (48%) in the control group reported a history of shoulder pain during the previous handball season. Current shoulder pain was reported by 93 players (29%) in the intervention group and 96 players (30%) in the control group. At baseline, 155 players (47%) in the intervention group and 156 players (48%) in the control group reported a shoulder problem during the previous 7 days based on the OSTRC Overuse Injury Questionnaire. Of these, 45 players (14%) in the intervention group and 46 players (14%) in the control group reported a substantial shoulder problem. There were no group differences in the prevalence of shoulder pain or problems reported at baseline.

Shoulder injuries and surgery at baseline

Five players (1.6%) in the intervention group and seven players (2.2%) in the control group reported an acute shoulder injury within the past 6 months; however, all participated in normal handball activity. Team medical staff confirmed this and specified the diagnoses: two superior labral lesions and three anterior shoulder dislocations in the intervention group and six superior labral lesions and one anterior dislocation in the control group. One player (0.3%) in the intervention group and two players (0.6%) in the control group had undergone shoulder surgery within 12 months before baseline; however, all three were participating in normal handball activity. There were no group differences in the prevalence of acute shoulder injuries or surgery reported at baseline.

Response rate

The average response rate for the OSTRC Overuse Injury Questionnaire was 87% (range 84–93%) in the intervention group and 85% (range 82–87%) in the control group. Complete injury data were available from 57% and 65% of the players in the intervention and control groups, respectively. Eighty per cent (n=264) of the players in the intervention group and 82% (n=270) in the control group met the a priori criteria of at least three responses. Female players had a higher response rate, with no group differences between the intervention (90%) and control groups (89%). The average response rate for the exposure data was 67% (range 58–79%) in the intervention group and 49% (range 30–67%) in the control group. The average response rate for the compliance data in the intervention groups was similar to that for the injury data, 87% (range 84–92%).

Exposure

There were no group differences in the average weekly exposure to handball training or match play (table 2). However, the players in the control group reported having completed 17 more minutes of strength training per week on average ($p=0.004$).

Compliance

On average, the OSTRC Shoulder Injury Prevention Programme was completed 1.6 times per week (range 1.4–1.8) in the intervention group, 53% of the 3 times recommended. Twenty-one players (7%) did not complete the exercise programme at all during the season. Seventy-nine players (28%) reported an average compliance of between 0.1 and 1.0, 91 players (32%) between 1.1 and 2.0, and 90 players (32%) >2.0 sessions per week. The average compliance per week did not differ between players without shoulder problems compared with players with shoulder problems at baseline (1.57 vs 1.60, $p=0.791$).

Acute shoulder injuries

A total of 20 and 13 acute injuries were reported in the intervention and control groups, respectively, corresponding to an average prevalence of acute shoulder injuries throughout the season of 1.4% (95% CI 0.8% to 1.9%) in the intervention group and 0.9% (95% CI 0.5% to 1.2%) in the control group

Table 1 Age, height and body mass by gender for both groups

	Intervention (n=331)		Control (n=329)	
Characteristics	Female (n=160)	Male (n=171)	Female (n=161)	Male (n=168)
Age (years)	22.5 (4.2)	21.9 (3.7)*	21.6 (3.3)	23.5 (4.8)*
Height (cm)	173.6 (5.7)	187.8 (7.1)	173.2 (5.8)	188.6 (6.8)
Body mass (kg)	70.0 (7.6)	88.8 (7.1)	70.1 (7.6)	91.0 (12.4)

Results are shown as the mean (SD).
*p<0.05 intervention versus control group.

Table 2 Average weekly exposure to handball training, match play and strength training in both groups

Activity type	Intervention (n=331)	Control (n=329)
Handball training	366 (336 to 395)	371 (349 to 393)
Match play	32 (27 to 36)	34 (29 to 38)
Strength training	83 (79 to 87)*	100 (94 to 108)*

Data are shown in minutes with 95% CIs.
*p<0.05 intervention versus control group.

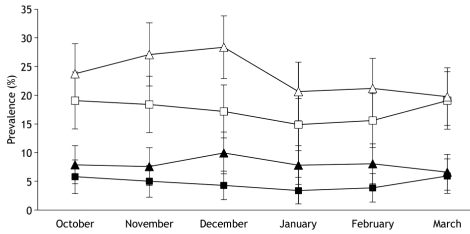


Figure 3 Prevalence of shoulder problems (open symbols) and substantial shoulder problems (filled symbols) in the intervention (squares) and control group (triangles), with 95% CIs, measured six times during the season.

(mean difference 0.5%). These injuries were excluded from the following analysis examining the effect of the exercise programme.

Effect of the intervention

The average prevalence of overuse shoulder problems during the season was 17% (95% CI 16% to 19%) in the intervention group and 23% (95% CI 21% to 26%) in the control group (mean difference: 6%). The average prevalence of substantial shoulder problems was 5% (95% CI 4% to 6%) in the intervention group and 8% (95% CI 7% to 9%) in the control group (mean difference 3%). The six prevalence measures in both groups are illustrated in figure 3. GEE analysis revealed a 28% lower risk of reporting shoulder problems over time in the intervention group compared with the control group (OR 0.72, 95% CI 0.52 to 0.98, p=0.038). We did not detect a significant difference in the risk of reporting substantial shoulder problems over time between the intervention and control groups (OR 0.78, 95% CI 0.53 to 1.16, p=0.23).

Within the intervention group, compliance did not influence the risk of shoulder problems (table 3). However, players in the intervention group who reported an average compliance of at least 0.1 sessions per week (n=248) had a 69% lower risk of reporting substantial shoulder problems than players reporting zero compliance (n=16; OR 0.31, 95% CI 0.15 to 0.67, p=0.003).

The average severity score of the shoulder problems reported was 29 (95% CI 28 to 31) in the intervention group and 35 (95% CI 32 to 37) in the control group (mean difference 5). The relative impact of shoulder problems was 64% lower in the intervention group (intervention group 5.2 vs control group 8.1).

GEE models including only players with shoulder problems at baseline revealed a 35% lower risk of reporting shoulder problems in the intervention group than the control group (OR 0.65, 95% CI 0.43 to 0.98, p=0.04). However, we detected no significant difference in the risk of reporting substantial shoulder problems between groups (OR 0.86, 95% CI 0.51 to 1.45, p=0.58). When only including players without shoulder problems at baseline, we identified no significant group difference in the risk of reporting shoulder problems (OR 0.80, 95% CI 0.47 to 1.37, p=0.42) or substantial shoulder problems (OR 0.68, 95% CI 0.36 to 1.31, p=0.25) during the season.

Unintended effects

No severe shoulder injuries were reported due to completion of the exercise programme in the intervention group. However, at the start of the study, two coaches reported a total of four cases of players experiencing muscle soreness after completing the exercise programme.

DISCUSSION

Our main finding was that a 10 min exercise programme, the OSTRC Shoulder Injury Prevention Programme, reduced the prevalence of shoulder problems and substantial shoulder problems among elite handball players; the risk of reporting shoulder problems during the competitive season was 28% lower in the intervention group.

This is the first randomised controlled trial investigating an exercise programme designed to reduce overuse shoulder injuries in elite throwing athletes,[29] although similar observations were reported from a 6-month pilot study with 53 female junior handball players (three teams) in the intervention group.[37] They found that the prevalence of shoulder symptoms decreased significantly during the intervention period among players completing specific shoulder-strengthening exercises. The exercise programme was completed as a part of the warm-up three times per week and consisted of three exercises, push-up plus, standing glenohumeral internal and external rotation with elastic band as resistance, similar to exercises included in the current study.

On average, the exercise programme was completed 1.6 times per week in the intervention group, only 53% of the 3 times recommended. No clear dose–response relationship was identified. However, players within the intervention group actually performing the exercise programme had a 69% lower risk of reporting substantial shoulder problems compared with players not performing the exercise programme in the intervention group. On this basis, it seems that it is enough to complete the exercise programme between one and two times per week to achieve the reported effect.

Subanalyses including only players with a self-reported shoulder problem at baseline revealed a 35% significantly lower risk of reporting shoulder problems during the season in the intervention group. In contrast, we found no significant effect of the exercise programme when including only players without a

Table 3 Generalised estimating equation model including players in the intervention group meeting the a priori criteria of sufficient injury data (n=264)

		Shoulder problem			Substantial shoulder problem		
Compliance group (sessions/week)	n	OR	(95% CI)	p Value	OR	(95% CI)	p Value
0.1 to 1.0	77	0.49	(0.20 to 1.21)	0.125	0.36	(0.16 to 0.82)	0.02
1.1 to 2.0	88	0.69	(0.27 to 1.75)	0.435	0.25	(0.10 to 0.60)	0.002
>2.0	83	0.58	(0.22 to 1.52)	0.271	0.35	(0.15 to 0.82)	0.02

Players reporting zero completed sessions during the season represent the reference group (n=16).

shoulder problem at baseline, even if their compliance was as good as that among players with shoulder problems at baseline.

Methodological considerations

A major strength of this trial is the use of cluster randomisation to avoid crossover effects between the intervention and control groups. We also stratified for gender and competition level to ensure that groups were comparable. An injury surveillance method recently developed and validated to study overuse injuries was employed to capture the true extent of shoulder problems.[31 38] Parallel registration of acute shoulder injuries was done by players and team medical staff to avoid misreporting of acute injuries as overuse injuries. This allowed us to assess the effect of the exercise programme on the prevalence of overuse problems alone. However, a limitation of the injury registration method is the lack of detailed diagnostic information on each case. Our definition of a shoulder problem encompasses all physical symptoms and may have multiple causes, such as subacromial and internal impingement, tendon pathology, glenoid labrum injuries, glenohumeral joint instability and acromioclavicular joint dysfunction.[14 15 39 40] The effect of the exercise programme reported in this trial may differ between these; we were unable to discriminate between such relationships.

Traditionally, injury prevention studies exclude players injured at baseline and only record new cases throughout the study, with incidence as the measure for risk. Applying such an approach in the current trial would be inappropriate. First, excluding players reporting a shoulder problem at baseline would have resulted in a biased study population, not representative of athletes from throwing sports, where shoulder problems are very common. Therefore, we included all players participating in normal handball activity, irrespective of their baseline injury status or history. Second, overuse shoulder problems are often chronic, with periods of remission and exacerbation. Only a handful of the cases reported in this trial represented first-time problems. Therefore, the proportion of players affected by shoulder problems at any given time, the population prevalence, is a more appropriate measure of the magnitude of the problem.[38]

The prevalence of shoulder problems reported in the control group is lower than in a recent study on risk factors for shoulder problems among male elite handball players using the same injury registration method,[2] possibly due to a crossover effect. Before agreeing to participate in the study and before the randomisation process, all coaches and players received the same information about the study, both orally and in writing. This may have increased the awareness of shoulder problems in the control group, even though we encouraged them to train as usual. We had no control over whether the control group performed exercises similar to our exercise programme. In fact, the control group reported doing more strength training than the intervention group, possibly because they replaced the exercise programme with additional strength training. Nevertheless, any bias arising from contamination would result in an underestimation of the preventive effect reported in this trial.

Simple comparison of prevalence measures between the intervention and control groups revealed a lower average prevalence of shoulder problems and substantial shoulder problems reported during the season in the intervention group. The main benefits of this comparison are that it is easy to calculate and takes into account all available injury data. It is, however, made on crude summary measures of prevalence and does not account for change over time, confounding or missing. A high response rate and sufficient completeness of injury data allowed us to address missing using multiple imputation techniques. We could therefore perform GEE analysis to include players meeting our a priori criteria of at least three responses to the OSTRC Overuse Injury Questionnaire. The GEE is a more robust analysis which accounts for repeated measures and allowed us to compare changes in prevalence of shoulder problems between the intervention and control groups over time, revealing a significantly lower risk of reporting shoulder problems in the intervention group. However, we underestimated the number of players needed to establish the effects of the exercise programme on substantial shoulder problems.

Baseline demographics, anthropometrics or injury status/history of injury had no confounding effect on the comparison of prevalence of shoulder problems or substantial shoulder problems between groups over time. However, a limitation of our GEE analysis was the inability to include player exposure as a potential confounder, due to a lower response rate for the exposure data, although we found no difference in the reported exposure to handball training or match play between groups.

The exercise programme evaluated in this trial is comprehensive and includes exercises to improve glenohumeral rotation, external rotation strength and scapular muscle strength, as well as improve kinetic chain and thoracic mobility. We did not conduct baseline and follow-up testing to examine the effect of the exercise programme on the different risk factors targeted; this is a limitation of the study.

When developing and introducing the exercise programme, we followed recommendations from implementation research, for example, limit the length of the programme, enhance variation in the exercises and equip the delivery agents with skills to confidently implement the programme.[41 42] Despite this, the players in the intervention group reported only having completed the exercise programme 53% of the three times recommended per week; this is a limitation of the study. To ensure quality in the performance of the exercises, we instructed the team medical staff to be present at certain periods during the intervention. However, the extent to which this was followed remains unknown; this is a limitation of the study.

The methods used to monitor player exposure and compliance with the exercise programme deviate from former injury prevention studies and have several limitations.[43–45] First, exposure was self-reported as the number of minutes and compliance was self-reported as the number of sessions completed during the past 7 days; both are vulnerable to recall bias. Second, the season averages for exposure and compliance are approximations based on the six measurements taken during the season.

Implications

Our results suggest that an exercise programme targeting glenohumeral internal rotation, external rotation strength, scapular muscle strength, kinetic chain and thoracic mobility should be included as a part of the general warm-up in elite handball. Whether the preventive effect observed in this trial can be generalised to other throwing athletes is not known. However, the internal modifiable risk factors associated with shoulder problems in other throwing sports are similar to those in handball.[2 3 5 6 18–25] It therefore seems reasonable to assume that the OSTRC Shoulder Injury Prevention Programme could benefit other throwing athletes as well.

CONCLUSION

The OSTRC Shoulder Injury Prevention Programme, an exercise programme to increase glenohumeral internal rotation, external rotation strength and scapular muscle strength, as well as improve kinetic chain and thoracic mobility, reduced the prevalence and risk of shoulder problems in elite handball and should be included as a part of the warm-up in throwing sports.

What are the findings?

The Oslo Sports Trauma Research Center (OSTRC) Shoulder Injury Prevention Programme, an exercise programme to increase glenohumeral internal rotation, external rotation strength and scapular muscle strength, as well as improve kinetic chain and thoracic mobility, reduced the prevalence and risk of reporting shoulder problems in elite handball.

How might it impact on clinical practice in the future?

The OSTRC Shoulder Injury Prevention Programme should be included as a part of the warm-up in throwing sports.

Twitter Follow Stig Andersson at @stighandersson and Benjamin Clarsen at @benclarsen

Acknowledgements The authors would like to thank A Aune, A Skjølberg, C Skovly, D Major, EE Eriksen, HK Vileid, K Røed, K Søderstrøm, M Fagerheim, MJ Olsen, OT Østvold, RM Kristensen and R Nesje for their assistance in data collection. They also thank all players and coaches who participated in the study, as well as the team medical staff. The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic Committee & Confederation of Sport, and Norsk Tipping AS.

Contributors All authors contributed to project planning, data collection and manuscript preparation. SHA was responsible for data analysis. SHA is responsible for the overall content as the guarantor.

Competing interests None declared.

Ethics approval The South-Eastern Norway Regional Committee for Research Ethics approved the study. Participation was voluntary and the authors obtained individual written informed consent from players or guardians.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement All data are available on request.

REFERENCES

1. Clarsen B, Bahr R, Heymans MW, *et al*. The prevalence and impact of overuse injuries in five Norwegian sports: application of a new surveillance method. *Scand J Med Sci Sports* 2015;25:323–30.
2. Clarsen B, Bahr R, Andersson SH, *et al*. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med* 2014;48:1327–33.
3. Shanley E, Rauh MJ, Michener LA, *et al*. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med* 2011;39:1997–2006.
4. Shanley E, Rauh MJ, Michener LA, *et al*. Incidence of injuries in high school softball and baseball players. *J Athl Train* 2011;46:648–54.
5. Shanley E, Kissenberth MJ, Thigpen CA, *et al*. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. *J Shoulder Elbow Surg* 2015;24:1005–13.
6. Byram IR, Bushnell BD, Dugger K, *et al*. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med* 2010;38:1375–82.
7. Myklebust G, Hasslan L, Bahr R, *et al*. High prevalence of shoulder pain among elite Norwegian female handball players. *Scand J Med Sci Sports* 2013;23:288–94.
8. Lyman S, Fleisig GS, Waterbor JW, *et al*. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001;33:1803–10.
9. Moller M, Attermann J, Myklebust G, *et al*. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. *Br J Sports Med* 2012;46:531–7.
10. Giroto N, Hespanhol Junior LC, Gomes MR, *et al*. Incidence and risk factors of injuries in Brazilian elite handball players: a prospective cohort study. *Scand J Med Sci Sports* Published Online first: 10 Dec 2015. doi:10.1111/sms.12636
11. Krajnik S, Fogarty KJ, Yard EE, *et al*. Shoulder injuries in US high school baseball and softball athletes, 2005–2008. *Pediatrics* 2010;125:497–501.
12. Sauers EL, Dykstra DL, Bay RC, *et al*. Upper extremity injury history, current pain rating, and health-related quality of life in female softball pitchers. *J Sport Rehabil* 2011;20:100–14.
13. Ranson C, Gregory PL. Shoulder injury in professional cricketers. *Phys Ther Sport* 2008;9:34–9.
14. Wilk KE, Obma P, Simpson CD, *et al*. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther* 2009;39:38–54.
15. Kibler WB, Kuhn JE, Wilk K, *et al*. The disabled throwing shoulder: spectrum of pathology-10-year update. *Arthroscopy* 2013;29:141–61.
16. Karcher C, Buchheit M. On-court demands of elite handball, with special reference to playing positions. *Sports Med* 2014;44:797–814.
17. Mohseni-Bandpei MA, Keshavarz R, Minoonejhad H, *et al*. Shoulder pain in Iranian elite athletes: the prevalence and risk factors. *J Manipulative Physiol Ther* 2012;35:541–8.
18. Almeida GP, Silveira PF, Rosseto NP, *et al*. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *J Shoulder Elbow Surg* 2013;22:602–7.
19. Wilk KE, Macrina LC, Fleisig GS, *et al*. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011;39:329–35.
20. Myers JB, Laudner KG, Pasquale MR, *et al*. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med* 2006;34:385–91.
21. Ruotolo C, Price E, Panchal A. Loss of total arc of motion in collegiate baseball players. *J Shoulder Elbow Surg* 2006;15:67–71.
22. Edouard P, Degache F, Oullion R, *et al*. Shoulder strength imbalances as injury risk in handball. *Int J Sports Med* 2013;34:654–60.
23. Andrade MS, Vancini RL, de Lira CA, *et al*. Shoulder isokinetic profile of male handball players of the Brazilian National Team. *Braz J Phys Ther* 2013;17:572–8.
24. Trakis JE, McHugh MP, Caracciolo PA, *et al*. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *Am J Sports Med* 2008;36:2173–8.
25. Tyler TF, Mullaney MJ, Mirabella MR, *et al*. Risk factors for shoulder and elbow injuries in high school baseball pitchers: the role of preseason strength and range of motion. *Am J Sports Med* 2014;42:1993–9.
26. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. *J Shoulder Elbow Surg* 2013;22:1154–9.
27. Kibler WB, Ludewig PM, McClure PW, *et al*. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. *Br J Sports Med* 2013;47:877–85.
28. Lintner D, Noonan TJ, Kibler WB. Injury patterns and biomechanics of the athlete's shoulder. *Clin Sports Med* 2008;27:527–51.
29. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med* 2014;48:871–7.
30. Campbell MK, Piaggio G, Elbourne DR, *et al*. Consort 2010 statement: extension to cluster randomised trials. *BMJ* 2012;345:e5661.
31. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med* 2013;47:495–502.
32. Donaldson A, Finch CF. Planning for implementation and translation: seek first to understand the end-users' perspectives. *Br J Sports Med* 2012;46:306–7.
33. Finch CF, White P, Twomey D, *et al*. Implementing an exercise-training programme to prevent lower-limb injuries: considerations for the development of a randomised controlled trial intervention delivery plan. *Br J Sports Med* 2011;45:791–6.
34. Fuller CW, Molloy MG, Bagate C, *et al*. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Clin J Sport Med* 2007;17:177–81.
35. Timpka T, Alonso JM, Jacobsson J, *et al*. Injury and illness definitions and data collection procedures for use in epidemiological studies in athletics (track and field): consensus statement. *Br J Sports Med* 2014;48:483–90.
36. van Buuren S. *Flexible imputation of missing data*. Boca Raton: Chapman & Hall/CRC Press, 2012:342.
37. Osteras H, Sommervold M, Skjolberg A. Effects of a strength-training program for shoulder complaint prevention in female team handball athletes. A pilot study. *J Sports Med Phys Fitness* 2015;55:761–7.
38. Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med* 2009;43:966–72.
39. Dean BJ, Gwilym SE, Carr AJ. Why does my shoulder hurt? A review of the neuroanatomical and biochemical basis of shoulder pain. *Br J Sports Med* 2013;47:1095–104.

40 Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy* 2003;19:404–20.
41 White PE, Otago L, Saunders N, *et al*. Ensuring implementation success: how should coach injury prevention education be improved if we want coaches to deliver safety programmes during training sessions? *Br J Sports Med* 2014;48:402–3.
42 Finch CF, Doyle TL, Dempsey AR, *et al*. What do community football players think about different exercise-training programmes? Implications for the delivery of lower limb injury prevention programmes. *Br J Sports Med* 2014;48:702–7.
43 Soligard T, Nilstad A, Steffen K, *et al*. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. *Br J Sports Med* 2010;44:787–93.
44 Walden M, Atroshi I, Magnusson H, *et al*. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *BMJ* 2012;344:e3042.
45 Steffen K, Emery CA, Romiti M, *et al*. High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial. *Br J Sports Med* 2013;47:794–802.

Paper II

BJSM Online First, published on August 7, 2017 as 10.1136/bjsports-2017-097648

Risk factors for overuse shoulder injuries in a mixed-sex cohort of 329 elite handball players: previous findings could not be confirmed

Stig Haugsboe Andersson, Roald Bahr, Benjamin Clarsen, Grethe Myklebust

Department of Sports Medicine, Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, Oslo, Norway

Correspondence to Stig Haugsboe Andersson, Oslo Sports Trauma Research Center Department of Sports Medicine Norwegian School of Sport Sciences PB 4014 Ullevål Stadion 0806 Oslo, Norway; s.h.andersson@nih.no

Accepted 18 June 2017

ABSTRACT

Background Shoulder injuries are common among handball players and predominantly characterised by overuse characteristics. Reduced total glenohumeral rotation, external rotation weakness and scapular dyskinesis have been identified as risk factors among elite male handball players.

Aim To assess whether previously identified risk factors are associated with overuse shoulder injuries in a large cohort of elite male and female handball players.

Methods 329 players (168 male, 161 female) from the two upper divisions in Norway were included and tested prior to the 2014–2015 season. Measures included glenohumeral internal and external rotation range of motion, isometric internal and external rotation strength, and assessment of scapular dyskinesis. Players were followed prospectively for one competitive season, with prevalence and severity of shoulder problems registered monthly using the Oslo Sports Trauma Research Center Overuse Injury Questionnaire. A severity score based on players' questionnaire responses was used as the outcome measure in multivariable logistic regression to investigate associations between candidate risk factors and overuse shoulder injury.

Results No significant associations were found between total rotation (OR 1.05 per 5° change, 95% CI 0.98 to 1.13), external rotation strength (OR 1.05 per 10 N change, 95% CI 0.92 to 1.20) or obvious scapular dyskinesis (OR 1.23, 95% CI 0.25 to 5.99) and overuse shoulder injury. A significant positive association was found between greater internal rotation (OR 1.16 per 5° change, 95% CI 1.00 to 1.34) and overuse shoulder injury.

Conclusion None of the previously identified risk factors were associated with overuse shoulder injuries in a mixed-sex cohort of elite handball players.

INTRODUCTION

Shoulder injuries are common among handball players,[1 2] particularly at the elite level. In the Norwegian elite division, 52% of male players experienced shoulder problems at some point during the season,[3] and 58% of female players reported a history of shoulder injury.[4] Among elite players, a majority of shoulder problems are thought to be related to overuse.[3–5] Recent attention has therefore been directed towards the prevention of overuse shoulder injuries in elite handball,[6] and identification of risk factors is a key step to develop successful prevention programmes.[7]

Several studies have investigated internal modifiable risk factors for shoulder injuries among overhead athletes, with particular focus on glenohumeral range of motion (ROM),[3 8–10] shoulder strength[3 11 12] and scapular control.[3 13–15] In handball, cross-sectional studies have suggested several potential risk factors for shoulder injuries, including reduced glenohumeral internal rotation (IR), excessive glenohumeral external rotation (ER), low ratios of concentric ER to concentric IR strength and high ratios of eccentric IR to concentric ER strength.[9 12 16] In a prospective risk factor study of 206 male Norwegian elite handball players, Clarsen *et al*[3] observed significant associations between obvious scapular dyskinesis, total rotation (TROM), ER strength and the risk of shoulder injury. In a recent critical review, it was argued that identified risk factors should be confirmed in relevant populations.[17]

Therefore, the aim of the current study was to investigate if the risk factors reported by Clarsen *et al*[3] could be confirmed in a large, mixed-sex cohort of Norwegian elite handball players using the same methods. Our hypothesis was that the risk of overuse shoulder injury would be associated with scapular dyskinesis, reduced total rotation and low ER strength.

METHODS

Study design and participants

This was a prospective cohort study involving the control group arm of a recently published randomised controlled trial.[6] The cohort consisted of 23 handball teams (12 male; 11 female) from the two upper divisions in Norway. We visited each team during a preseason training session and invited every player present to participate in the study. All players with a team contract were eligible for participation, irrespective of their baseline injury status or history (n=333). Players who consented to participate (n=329) completed questionnaires and shoulder testing at baseline (figure 1), and were followed for the duration of the regular season (September 2014–March 2015). Six times during the season, players reported any shoulder problems using the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire,[18] as described in previous studies of shoulder problems among elite handball players.[3 6]

Baseline testing

Six different test teams of two sports physiotherapists conducted baseline testing. Each test team visited between three and four teams in the period from August to mid-September 2014. Within each

CrossMark

To cite: Andersson SH, Bahr R, Clarsen B, *et al*. *Br J Sports Med* Published Online First: [*please include* Day Month Year]. doi:10.1136/bjsports-2017-097648

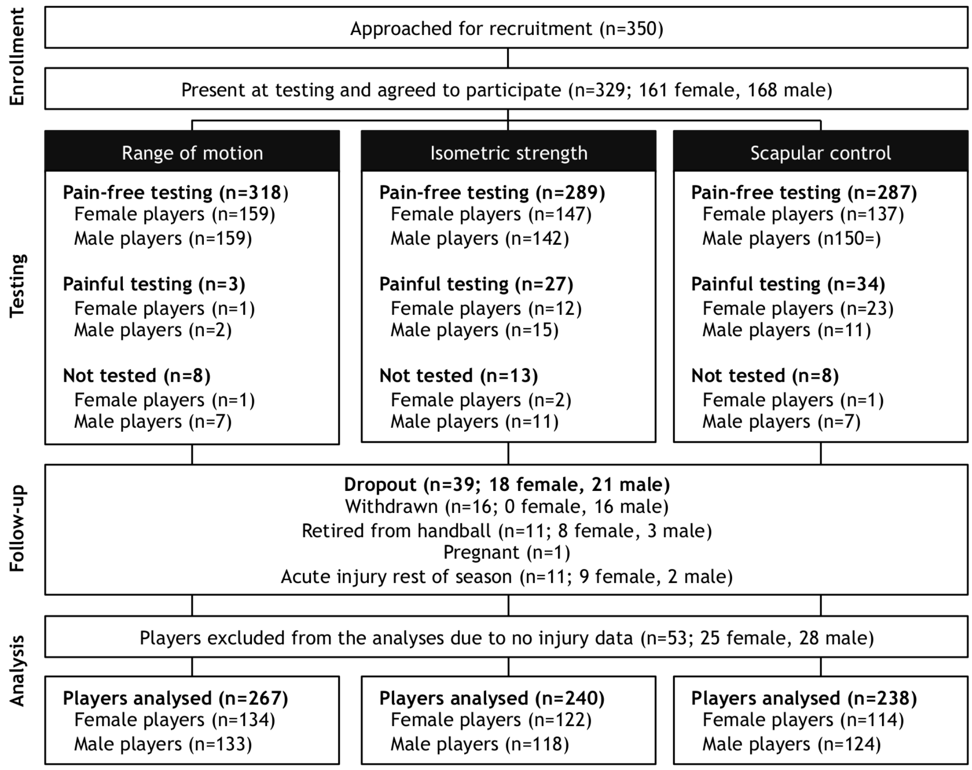


Figure 1 Study flow chart showing the number of players included and tested at baseline, dropout during the study and the number included in the analyses.

test team, one tester was responsible for administering questionnaires and evaluating scapular control, and the other measured players' strength and glenohumeral ROM. Prior to baseline testing, 3 days of training was carried out to ensure that examiners were familiar with the measurement techniques.

Questionnaires

Players reported baseline injury status and history using a modified version of the Fahlström questionnaire, as used in previous studies of elite handball players.[3 4 6] In addition, players reported any shoulder problems during the week prior to baseline testing using the OSTRC Overuse Injury Questionnaire.[6]

Range of motion

Glenohumeral joint IR and ER ROM was measured bilaterally using a digital inclinometer attached to a 30 cm Perspex ruler (Acumar Digital Inclinometer, Lafayette Instrument, Lafayette, Indiana, USA), with the player in supine and with their shoulder abducted to 90° with 0° rotation and elbow flexed to 90°.[3 19–21] If necessary, a folded towel was used to align the upper arm in the frontal plane. The examiners palpated the scapula with their thumb on the coracoid process and four fingers on the spine of the scapula to control scapular compensation. The end of IR and ER ROM was defined as the point at which the scapula was felt to move, as previously described by Wilk *et al*.[19] The examiners performed two repeated measurements and the average was recorded as the players' IR and ER values. TROM was calculated by summing these values.

Isometric strength

Isometric IR and ER shoulder strength was measured on the dominant side using a handheld dynamometer (microFET, Hoggan Health Industries, Salt Lake City, Utah, USA), with the player in supine and with their shoulder abducted to 90° with 0° rotation and elbow flexed to 90°.[20–22] The opposite arm was placed resting on the hip. The handheld dynamometer was externally fixed to limit measurement error related to manual fixation from multiple examiners.[21] Players were verbally and manually assisted to stabilise their scapula prior to testing. We used no external fixation of the scapula during the actual testing. Players performed the strength measures three times and the best attempt was recorded.

Scapular control

The examiners observed players performing five repetitions of flexion and abduction in the glenohumeral joint while holding an external weight: 5 kg for male players and 3 kg for female players.[3 21] The examiners were situated 3 m behind the players and rated shoulders bilaterally as having normal scapular control, slight scapular dyskinesis or obvious dyskinesis for each of the two motions individually, according to the method proposed by McClure *et al*[23] and previously used in studies on handball players.[3 21]

The methods used to measure ROM, isometric strength and scapular control has been described in detail in the appendices of previous publications.[3 21]

Monitoring of shoulder problems

We emailed the OSTRC Overuse Injury Questionnaire to all players in the study on the last Sunday of each month from October 2014 to March 2015, six times in total, using online survey software (Questback V.9692, Questback AS, Oslo, Norway). Automatic reminders were sent to non-responders after 3 and 7 days per email and short message service (Pling, Front Information DA, Oslo, Norway). In addition, we visited teams throughout the season and asked non-responders to complete a paper version of the questionnaire. The questionnaire, used in a previous study on shoulder problems in elite handball,[3 6] addresses the extent to which overuse shoulder injuries, expressed as shoulder problems, affect participation, training volume and performance, as well as the level of shoulder pain experienced during the past week.[18] Players reported shoulder problems only in their dominant shoulder, with shoulder problems defined as any pain, ache, stiffness, instability, looseness or other symptoms related to their shoulder.[3 6] Acute shoulder injuries were recorded as previously described and excluded from the analyses.[6]

Outcome measures

For each player response to the OSTRC Overuse Injury Questionnaire, the response enabled the calculation of a severity score ranging from 0 to 100.[18] At the end of the study, we calculated the individual average severity score by summing each player's scores and dividing by their number of questionnaire responses. The average severity scores were dichotomised using a cut-off value of 40 to distinguish players with an overuse shoulder injury from uninjured players. This was used as the outcome measure in the risk factor analyses, as previously described.[3] In addition, we calculated the prevalence of shoulder problems for the dominant shoulder for both sexes each time the questionnaire was administered by dividing the number of players who reported any problem (ie, anything but the minimum value in any of the four questions) by the number of questionnaire respondents.[18] To filter out problems with fewer functional consequences, we calculated the prevalence of substantial shoulder problems in the same way, including only shoulder problems leading to moderate or severe reductions in training volume or performance, or a total inability to participate.[18] At the end of the study, the average prevalence of shoulder problems and substantial shoulder problems was calculated for both sexes.

Exposure

By the end of each month, players reported their exposure to handball training, match play and additional strength training during the past week. We calculated the mean weekly exposure in each measure for both sexes by summing up the number of minutes reported and dividing by the number of respondents. At the end of the study, we calculated the individual average weekly exposure by summing each player's exposure data and dividing by their number of responses.

Statistical methods

Players with no injury data and players with missing test results or pain during baseline testing were excluded from the risk factor analyses. We used multivariable logistic regression models to investigate associations between candidate risk factors and overuse shoulder injury (average severity score ≥40).[3]

The following were analysed as potential risk factors for injury to the dominant shoulders: IR strength, ER strength, ratio of ER to IR strength (ER:IR ratio), ER:IR ratio of <75%, <80% and <85%, IR ROM, ER ROM, TROM, >5° TROM difference between shoulders, <5° ER gain and glenohumeral IR deficits of ≥5°, ≥10°, ≥15° and ≥20°, obvious scapular dyskinesis during flexion and/or abduction, slight or obvious scapular dyskinesis during flexion and/or abduction, average weekly exposure to handball training, match play, and additional strength training. A range of cut-off values were used for ER:IR ratio and IR deficits, as previous studies in throwing sports have reported associations with shoulder injury with different cut-offs for these variables.[3 8 10–12 24]

We adjusted strength measures for body mass, and demographic variables possibly associated to shoulder injury ($p<0.2$) were added to each model using a forward selection procedure. We compared dominant and non-dominant shoulder ROM using paired-samples t-tests for both sexes. Isometric shoulder strength and shoulder ROM were compared between sexes using independent-samples t-tests. Scapular control was compared between sexes using X^2 test.

To assess the reliability of the baseline tests, we performed a pilot prior to the study including a convenience sample of 19 asymptomatic adults (10 male and 9 female). The reliability of strength and ROM measures was assessed by calculating the intraclass correlation coefficient (ICC), using a two-way mixed single measure model (absolute agreement) for inter-rater reliability and two-way random single measure model (absolute agreement) for intrarater reliability.[3 20] Spearman's r (R_s) was used to assess the inter-rater and intrarater reliability of subjective rating of scapular control.

RESULTS

Players had played handball for an average of 14 years (SD 5, range 4–37) and 78% were right-handed. There were no sex differences in playing position distribution, with 41% backs, 25% wings, 15% line players, 13% goalkeepers and 6% reporting multiple positions. Dropout during the study and the number that was tested and included in each analysis are presented in figure 1.

Shoulder injury status and history at baseline

At the time of testing, 87 male players (52%) and 68 female players (43%) reported a history of shoulder pain during the previous handball season. Current shoulder pain was reported by 47 male players (28%) and by 49 female players (31%). Based on the OSTRC Overuse Injury Questionnaire, 82 male players (49%) and 74 female players (46%) reported a shoulder problem during the previous 7 days. Of these, 21 male players (13%) and 25 female players (16%) reported substantial shoulder problems. There were no sex differences in the prevalence of shoulder pain or problems reported at baseline.

Shoulder testing

Range of motion

Women and men both had less IR in their dominant shoulders than their non-dominant shoulders, male players with a mean

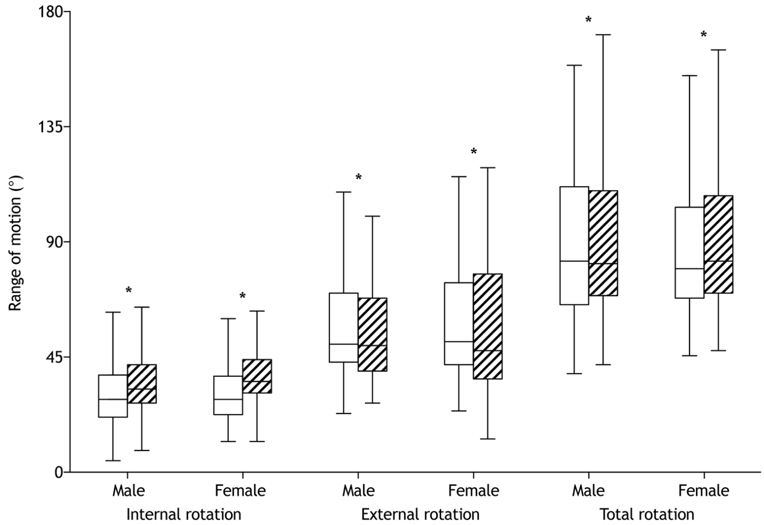


Figure 2 Range of motion of dominant shoulders (white boxes) and non-dominant shoulders (hatched boxes) for both sexes; *p<0.05.

difference of 4° (95% CI 3° to 5°, p<0.01; figure 2) and female players with a mean difference of 6° (95% CI 5° to 8°, p<0.01; figure 2). Female players had significantly more IR in their non-dominant shoulders compared with male players (mean difference: 5°, 95% CI 1° to 8 °, p<0.01). A total of 16 players (5%), 8 male and 8 female, had greater than 20° glenohumeral IR deficit. The ER ROM was greater in the dominant shoulders for both sexes, male players with a mean difference of 2° (95% CI 0.2° to 3°, p<0.03; figure 2) and female players with a mean difference of 3° (95% CI 2° to 5°, p<0.01; figure 2). One hundred and eighty-seven players (59%), 103 male and 84 female, had <5° ER gain in their dominant shoulder. Significantly less TROM in the dominant shoulders was observed in both sexes, male players with a 2° mean difference (95% CI 1° to 4°, p<0.01; figure 2) and female players with 3° mean difference (95% CI 1° to 4°, p<0.01; figure 2). A total of 135 players (42%), 71 male and 64 female, had >5° TROM loss on their dominant side. There were no significant sex differences in ER ROM and TROM measures.

Isometric strength dominant shoulder

Compared with female players, male players were significantly stronger in both ER (mean difference: 0.23 N/kg, 95% CI 0.33 to 0.12, p<0.01; figure 3) and IR (mean difference: 0.13 N/kg, 95% CI 0.25 to 0.02, p<0.01; figure 3) in their dominant

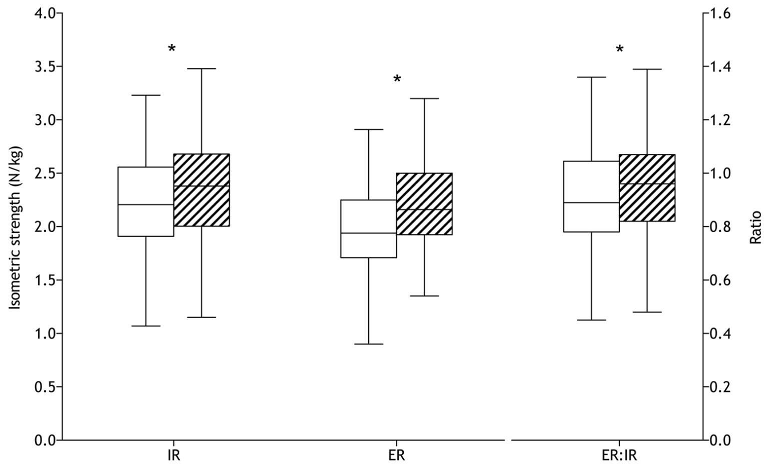


Figure 3 Isometric strength differences in the dominant shoulder between sexes (female, white; male, hatched boxes). IR, internal rotation; ER, external rotation; ER:IR, ER to IR strength ratio; *p<0.05.

Table 1 ICC for measures of strength and ROM

	Inter-rater		Intrarater	
	ICC (3.1)	(95% CI)	ICC (2.1)	(95% CI)
Strength				
IR	0.85	(0.69 to 0.93)	0.94	(0.86 to 0.98)
ER	0.86	(0.70 to 0.94)	0.86	(0.73 to 0.98)
ROM				
IR	0.31	(0.08 to 0.57)	0.65	(0.33 to 0.84)
ER	0.31	(0.08 to 0.56)	0.72	(0.45 to 0.87)

ER, external rotation; ICC, intraclass correlation coefficients; IR, internal rotation; ROM, range of motion.

shoulders. The average ER:IR ratio in the dominant shoulders was 91% (SD 18%) among female players and 96% (SD 17%) among male players (mean difference: 5%, 95% CI 1% to 9%, p=0.017; figure 3). A total of 71 players (25%), 43 male and 28 female players, had an ER:IR ratio of less than 80%.

Scapular control

A total of 161 players (56%), 81 male and 80 female players, were rated as having slight scapular dyskinesis in their dominant shoulders during flexion and 100 players (35%) during abduction (43 male, 57 female). Thirty-two players (11%), 13 male and 19 female, were rated as having obvious scapular dyskinesis in their dominant shoulders during flexion and 22 (8%) during abduction (11 male; 11 female). There were no significant sex differences in scapular control.

Reliability of shoulder tests

The inter-rater and intrarater reliability (ICC) of strength and ROM measures is presented in table 1. The inter-rater reliability (R_s) of subjective rating of scapular control into three groups (normal, slight and obvious dyskinesis) varied from 0.57 to 0.82 for flexion and from 0.32 to 0.55 for abduction. The intrarater reliability (R_s) was 0.68 for flexion and 0.85 for abduction. As shown in table 1, the inter-rater reliability of ROM measures was fair.

Response rate

The average response rate for the OSTRC Overuse Injury Questionnaire during the season was 85% (range 82%–87%). Complete injury data were available from 65% (215 players) of the cohort, while 16% (53 players) had no injury data during the season. Female players had a higher average response rate (90%, range 88%–93%) compared with male players (79%, range 78%–80%). The average response rate for the exposure data was 49% (range 30%–67%).

Exposure

There were no sex differences in the average weekly exposure to match play or strength training (table 2). However, male players reported higher average weekly exposure to handball training (mean difference: 47 min, 95% CI 22 to 72, p<0.01; table 3).

Table 2 Average weekly exposure to handball training, match play and strength training in both sexes

Activity type	Male (n=168)	Female (n=161)
Handball training	402 (381 to 423)*	355 (339 to 370)*
Match play	35 (32 to 39)	34 (31 to 38)
Strength training	106 (96 to 116)	93 (85 to 101)

Data are shown in minutes with 95% CIs.
*p<0.05 female versus male.

Table 3 Average prevalence of shoulder problems and substantial shoulder problems during the season in both sexes

	Male (n=168)	Female (n=161)
Shoulder problems	20 (15 to 26)	26 (26 to 27)
Substantial shoulder problems	7 (6 to 7)	9 (8 to 11)

Data are shown in percentage (%) with 95% CIs.

Shoulder problems during the season

The average prevalence of shoulder problems during the season was 23% (95% CI 21% to 26%). The average prevalence of substantial shoulder problems was 8% (95% CI 7% to 9%). Female players reported a higher prevalence of both shoulder problems (mean difference: 6%) and substantial shoulder problems (mean difference: 2%) compared with male players (table 3).

Risk factor analyses

No associations were identified between overuse shoulder injury and sex, age, height, body mass, dominant arm, player position, team affiliation, competition level, years of handball participation, shoulder pain at baseline or history of shoulder pain last season.

Shoulder tests

No associations were detected between overuse shoulder injury and obvious scapular dyskinesis, total rotation or external rotation strength (figure 4). As shown in the figure, increased IR ROM was significantly associated with overuse shoulder injury.

Exposure

No associations were observed between overuse shoulder injury and average weekly exposure to handball training, match play or additional strength training.

DISCUSSION

Based on the findings of our previous study exploring potential risk factors for shoulder problems among elite male handball players,[3] we hypothesised that the risk of overuse shoulder injury would be associated with obvious scapular dyskinesis, reduced total rotation and low external rotation strength. However, in this study, none of these three factors were associated with injury. In fact, players with *greater* IR range of motion had a higher probability of experiencing overuse shoulder injuries throughout the season.

Our prospective injury data extend previous epidemiological studies reporting that shoulder injuries, predominantly from overuse, are common among handball players.[1–4 25] These studies, conducted in a range of player populations, have used a variety of designs, measurement methods and injury definitions. The injury registration method used in the current study was designed specifically to capture overuse problems,[18] and has previously been used to study shoulder problems among elite male handball players.[3] Similar to Clarsen *et al*,[3] we found that the prevalence of shoulder problems was among the highest reported with this method, regardless of anatomical region or sport.[25 26]

Our results revealed a higher average prevalence of shoulder problems (26% vs 20%) and substantial shoulder problems (9%

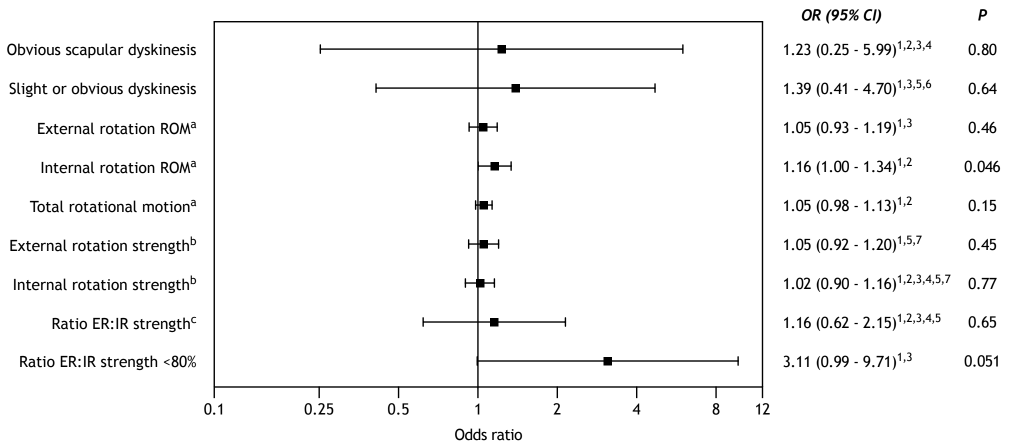


Figure 4 ORs and 95% CIs for associations between risk factors and overuse shoulder injury (average severity score ≥40) based on multivariable logistic regression analyses adjusted for [1]sex, [2]shoulder pain at baseline, [3]history of shoulder pain last season, [4]player position, [5]body mass (kg), [6]height (cm) and [7]age (years). Expressed per [a]5° change, [b]10 N change and [c]5% change. ER, external rotation; IR, internal rotation; ROM, range of motion.

vs 7%) among female elite handball players than male. This indicates that female sex may represent a risk factor for overuse shoulder injury, although this was not confirmed in the univariate statistical analysis. For the whole cohort, our results showed lower average prevalence of shoulder problems (23% vs 28%) and substantial shoulder problems (8% vs 12%) compared with Clarsen *et al*.[3] This may be due to an increased awareness of shoulder problems, since Clarsen *et al*[3] monitored male handball players in the top division, who also formed part of our cohort. In addition, our prevalence results may be affected by a crossover effect, since our study population represented the control group in a randomised intervention study aiming to reduce the prevalence of shoulder problems.[6] Nevertheless, our results reiterate the importance of targeting the throwing shoulder with preventative efforts and may provide guidance when determining which risk factors to target in prevention programmes.

Glenohumeral ROM and overuse shoulder injury

In throwing sports, reduced IR and increased ER have been reported in the dominant arm of asymptomatic athletes.[3 4 8–10 24 27] This is considered as a normal soft tissue and/or bony adaptation to repeated throwing,[28] and has even been suggested to prevent shoulder injuries.[29] However, several studies have reported an association between reduced IR and total ROM in the dominant shoulder and throwing-related shoulder injuries.[3 8 9] We did not identify any associations between IR deficits or TROM differences and overuse shoulder injury, despite using a range of cut-off values to define these terms.

Reduced ER ROM has also been proposed as a potential risk factor,[27] but we did not identify any association with shoulder injury. However, we did find that *increased* IR was a significant risk factor. This contrasts with the results of Clarsen *et al*,[3] who suggested that stretching should be considered in the development of injury prevention programmes. As the magnitude of the association appears to be limited (16% increased risk per 5° increase in IR) and the reliability of the IR measurements may be questioned, this result must be interpreted with caution; IR stretching should therefore not be abandoned as a prevention strategy based on our data.

Glenohumeral rotation strength and overuse shoulder injury

Weakness in ER is a risk factor for shoulder injury in elite male handball.[3] In the current study, we found no association between ER strength and overuse shoulder injury, despite excellent reliability of the strength measures performed. However, non-significant trends in our data suggest that lower ER:IR ratios may also be worth considering as a risk factor. Similar findings have been reported among elite youth handball players and baseball pitchers, where lower ER:IR ratios have been associated with shoulder injury.[11 12 24] In addition, Møller *et al*[21] recently reported that reduced ER strength exacerbated the association between handball load and shoulder injury among elite youth handball players increasing their load by 20% or more per week. Based on this overall body of evidence, it appears reasonable to suggest that exercises to strengthen ER should be included in injury prevention programmes.

Scapular dyskinesis and overuse shoulder injury

Scapular dyskinesis is common among overhead athletes with shoulder pain, across a variety of shoulder pathologies.[13 15 30–32] However, it has also been demonstrated to be common among asymptomatic overhead athletes,[14 15 33 34] and there is conflicting evidence from prospective cohort studies on the association between scapular dyskinesis and shoulder pain among overhead athletes.[3 14 15] In contrast to Clarsen *et al*,[3] we did not find any association between scapular dyskinesis and shoulder injury. However, Møller *et al*[21] recently reported that scapular dyskinesis exacerbated the association between handball load and shoulder injury among elite youth handball players increasing their load between 20% and 60% per week. Due to methodological limitations of this study (discussed below) and variable reliability, the relationship between scapular dyskinesis and shoulder injury remains unclear in elite handball players.

 Andersson SH, *et al*. *Br J Sports Med* 2017;**0**:1–9. doi:10.1136/bjsports-2017-097648

Handball load and overuse shoulder injury

There is growing evidence supporting a rapid increase in training load as a risk factor for overall injury.[35 36] Recently, Møller *et al*[21] reported that a large weekly increase in handball load represents the primary risk factor for shoulder injuries among elite youth players. Our results show that both female and male elite handball players have high exposure to handball training, match play and strength training. However, we did not find any association between any of these exposure measures and overuse shoulder injury. These results must however be interpreted with caution, as the exposure measures are only average weekly approximates based on self-reporting, do not include any measure of intensity and clearly are vulnerable to recall bias.

Future risk factor studies should strive to investigate the association between load and shoulder injuries prospectively, and examine whether the association is influenced by internal modifiable risk factors. Ideally, the exact individual throwing workload should be monitored prospectively. However, accurate and feasible methods to complete this are not yet available.[37]

Methodological considerations

A major strength of this study is the use of a prospective cohort design with a large representative sample of elite male and female handball players. We employed an injury surveillance method developed, validated and recommended to study overuse injuries.[18 38 39] The method was previously used in the study of shoulder injuries among elite handball players and allows comparability.[3 6] Players and team medical staff reported acute injuries alongside their reports of shoulder problems to avoid misreporting acute injuries as overuse injuries; this allowed us to assess the association between risk factors and overuse injuries alone.

Test selection

A key consideration is the choice of tests and measurement techniques to assess risk factors. We used the same tests as Clarsen *et al*,[3] with minor modifications, to ensure comparability and maximise the clinical relevance. As previously discussed, the reliability of the strength measurements was observed to be excellent. However, the reliability of the ROM measurements and subjective rating of scapular control varied from fair to good and from fair to excellent, respectively.

The validity of the strength measurements can be questioned. They are isometric and performed with the player in a supine position for IR and ER with players' shoulder abducted to 90° and elbows flexed to 90°. This position is reliable[20 22] and was selected for its resemblance to the throwing position in handball compared with the neutral shoulder position used by Clarsen *et al*.[3] This difference should be borne in mind when comparing the results. To limit measurement error related to manual fixation, we externally fixated the handheld dynamometer. However, to which degree isometric testing in this position relates to shoulder strength in a throwing motion is unknown.

Similar to Clarsen *et al*,[3] we used single testers with a digital inclinometer rather than two testers with a bubble goniometer for ROM measurements. Both methods are reliable.[20] However, there may be systematic differences in the results.[40 41] Therefore, our ROM values in this study may be compared directly with previous results on elite male handball players,[3] but not to previous research in general. The use of multiple testers to perform ROM measurements and the fair inter-rater reliability observed represent limitations, indicate that our results must be interpreted with caution and may explain the difference in results between this study and Clarsen *et al*,[3] where only two testers performed all measurements.

When evaluating the presence of scapular dyskinesis, we used subjective assessment based on criteria recommended in a consensus statement and previously used on elite male handball players.[3 42] The method used consists of three rating options, and proved valid and reliable for assessing three-dimensional scapular motion in overhead athletes.[23 34] It has been suggested that a two-option rating (normal or abnormal) is more reliable.[43] Clarsen *et al*[3] did, however, not find this, and we therefore used the three-option rating to ensure comparability. Due to the use of multiple testers and the inter-tester reliability, ranging from fair to excellent when assessing scapular control, our results must be interpreted with caution and may explain the difference in results between the current study and Clarsen *et al*,[3] where one experienced physiotherapist performed all evaluations.

Inclusion of players irrespective of injury status or history

Traditionally, risk factor studies exclude players injured at baseline and only record new cases throughout the study, allowing for an assumption of cause and effect. However, applying such an approach in the current study would have resulted in a biased cohort, not representative of elite handball players, where overuse shoulder injuries with periods of remission and exacerbation are common. Therefore, we included all players present at training sessions, irrespective of their injury status or history, and only excluded players experiencing pain during actual testing from analyses. Consequently, we are limited to assess associations between risk factors and overuse shoulder injury and causation cannot be assumed.

Diagnostic accuracy

In contrast to Clarsen *et al*[3], we excluded acute injuries from the analyses. However, we were not able to differentiate between specific shoulder injury diagnoses, since we did not have diagnostic information on each case.[3 6] Our definition of overuse shoulder injury encompassed all physical symptoms and the condition may have had multiple causes, such as subacromial and internal impingement, tendon pathology, glenoid labrum injuries, glenohumeral joint instability and acromioclavicular joint dysfunction, all commonly observed in throwing athletes.[28 29 44] The risk factors may differ among these conditions, but our study design meant we were unable to link risk factors with specific conditions.

Missing data

The response rate and the number of players with complete injury data are high compared with previous studies using the same surveillance method.[25] Nevertheless, we excluded 53 players from the risk factor analyses, as they had not reported their injury data. In addition, players with missing test results and pain during testing were excluded (figure 1). Consequently, our statistical power decreased and this may have affected the accuracy of our coefficient estimates. Another limitation was the low response rate for the exposure data, which may have limited our ability to detect any association between exposure and shoulder injury.

CONCLUSION

Our prospective cohort study of over 300 elite handball players did not confirm previously identified, so-called 'established' risk factors for overuse shoulder injuries, including total ROM, ER strength and scapular dyskinesis.

What are the findings?

- Greater glenohumeral *internal rotation* range of motion was associated with increased probability of experiencing overuse shoulder injuries.
- Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis were not associated with overuse shoulder injuries in a mixed-sex cohort of elite handball players.
- There was a trend to higher probability of experiencing overuse shoulder injuries among players with a ratio of external to internal rotation strength below 80%.
- The prevalence of overuse shoulder injuries was greater among elite female handball players than male players.

How might it impact on clinical practice in the future?

The role of glenohumeral internal rotation stretching, external rotation strengthening and scapular stability training in preventing overuse shoulder injuries in elite handball remains unclear.

Acknowledgements The authors thank A Aune, A Skjølberg, C Skovly, D Major, E E Eriksen, H K Vileid, K Røed, K Søderstrøm, M Fagerheim, M J Olsen, O T Østvold, R M Kristensen and R Nesje for their assistance in data collection. We also thank all players and coaches who participated in the study, as well as the team medical staff. The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the IOC, the Norwegian Olympic and Paralympic Committee and Confederation of Sport, and Norsk Tipping AS.

Contributors SHA drafted the manuscript and performed the data analysis. SHA and the main supervisor, GM, are responsible for the overall content as guarantors.

Competing interests None declared.

Ethics approval The study was reviewed by the Regional Committee for Medical and Health Research Ethics (REK 2014/653 A), which concluded that, according to the Act on Medical and Health Research (the Health Research Act 2008), the study did not require full review by REK. The study was approved by the Norwegian Social Science Data Service (NSD 2014/38187).

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement All data are available upon request to SHA (s.h. andersson@nih.no).

REFERENCES

1. Giroto N, Hespanhol Junior LC, Gomes MR, *et al*. Incidence and risk factors of injuries in Brazilian elite handball players: A prospective cohort study. *Scand J Med Sci Sports* 2017;27:195–202.
2. Moller M, Attermann J, Myklebust G, *et al*. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. *Br J Sports Med* 2012;46:531–7.
3. Clarsen B, Bahr R, Andersson SH, *et al*. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med* 2014;48:1327–33.
4. Myklebust G, Hasslan L, Bahr R, *et al*. High prevalence of shoulder pain among elite Norwegian female handball players. *Scand J Med Sci Sports* 2013;23:288–94.
5. Seil R, Rupp S, Tempelhof S, *et al*. Sports injuries in team handball. A one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. *Am J Sports Med* 1998;26:681–7.
6. Andersson SH, Bahr R, Clarsen B, *et al*. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *Br J Sports Med* 2016:bjsports-2016-096226 (Published Online First: 16 June 2016).
7. Bahr R, Holme I. Risk factors for sports injuries--a methodological approach. *Br J Sports Med* 2003;37:384–92.
8. Wilk KE, Macrina LC, Fleisig GS, *et al*. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011;39:329–35.
9. Almeida GP, Silveira PF, Rosseto NP, *et al*. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *J Shoulder Elbow Surg* 2013;22:602–7.
10. Shanley E, Kissenberth MJ, Thigpen CA, *et al*. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. *J Shoulder Elbow Surg* 2015;24:1005–13.
11. Byram IR, Bushnell BD, Dugger K, *et al*. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med* 2010;38:1375–82.
12. Edouard P, Degache F, Oullion R, *et al*. Shoulder strength imbalances as injury risk in handball. *Int J Sports Med* 2013;34:654–60.
13. Laudner KG, Myers JB, Pasquale MR, *et al*. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther* 2006;36:485–94.
14. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. *J Shoulder Elbow Surg* 2013;22:1154–9.
15. Struyf F, Nijs J, Meeus M, *et al*. Does scapular positioning predict shoulder pain in recreational overhead athletes? *Int J Sports Med* 2014;35:75–82.
16. Andrade MS, Vancini RL, de Lira CA, *et al*. Shoulder isokinetic profile of male handball players of the Brazilian National Team. *Braz J Phys Ther* 2013;17:572–8.
17. Bahr R. Why screening tests to predict injury do not work-and probably never will…: a critical review. *Br J Sports Med* 2016;50:776–80.
18. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med* 2013;47:495–502.
19. Wilk KE, Reinold MM, Macrina LC, *et al*. Glenohumeral internal rotation measurements differ depending on stabilization techniques. *Sports Health* 2009;1:131–6.
20. Cools AM, De Wilde L, Van Tongel A, *et al*. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. *J Shoulder Elbow Surg* 2014;23:1454–61.
21. Møller M, Nielsen RO, Attermann J, *et al*. Handball load and shoulder injury rate: a 31-week cohort study of 679 elite youth handball players. *Br J Sports Med* 2017;51:bjsports-2016-096927.
22. Hayes K, Walton JR, Szomor ZL, *et al*. Reliability of 3 methods for assessing shoulder strength. *J Shoulder Elbow Surg* 2002;11:33–9.
23. McClure P, Tate AR, Kareha S, *et al*. A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train* 2009;44:160–4.
24. Trakis JE, McHugh MP, Caracciolo PA, *et al*. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *Am J Sports Med* 2008;36:2173–8.
25. Clarsen B, Bahr R, Heymans MW, *et al*. The prevalence and impact of overuse injuries in five Norwegian sports: Application of a new surveillance method. *Scand J Med Sci Sports* 2015;25:323–30.
26. Andersen CA, Clarsen B, Johansen TV, *et al*. High prevalence of overuse injury among iron-distance triathletes. *Br J Sports Med* 2013;47:857–61.
27. Manske R, Wilk KE, Davies G, *et al*. Glenohumeral motion deficits: friend or foe? *Int J Sports Phys Ther* 2013;8:537–53.
28. Kibler WB, Kuhn JE, Wilk K, *et al*. The disabled throwing shoulder: spectrum of pathology-10-year update. *Arthroscopy* 2013;29:141–61.
29. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy* 2003;19:404–20.
30. Cools AM, Declercq GA, Cambier DC, *et al*. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scand J Med Sci Sports* 2007;17:25–33.
31. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther* 2009;39:90–104.
32. Struyf F, Cagnie B, Cools A, *et al*. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. *J Electromyogr Kinesiol* 2014;24:277–84.
33. Kibler WB, Ludewig PM, McClure P, *et al*. Scapular Summit 2009: introduction. July 16, 2009, Lexington, Kentucky. *J Orthop Sports Phys Ther* 2009;39:A1–A13.
34. Tate AR, McClure P, Kareha S, *et al*. A clinical method for identifying scapular dyskinesis, part 2: validity. *J Athl Train* 2009;44:165–73.
35. Drew MK, Finch CF. The relationship between training load and Injury, illness and soreness: a systematic and Literature Review. *Sports Med* 2016;46:861–83.
36. Soligard T, Schwellnus M, Alonso JM, *et al*. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med* 2016;50:1030–41.

37 Black GM, Gabbett TJ, Cole MH, *et al*. Monitoring Workload in Throwing-Dominant Sports: a systematic review. *Sports Med* 2016;46:1503–16.
38 Clarsen B, Bahr R. Matching the choice of injury/illness definition to study setting. *purpose and design: one size does not fit all! Br J Sports Med* 2014;48:510–2.
39 Gallagher J, Needleman I, Ashley P, *et al*. Self-reported outcome measures of the impact of injury and illness on athlete performance: a systematic review. *Sports Med* (Published Online First: 19 December 2016).
40 Mullaney MJ, McHugh MP, Johnson CP, *et al*. Reliability of shoulder range of motion comparing a goniometer to a digital level. *Physiother Theory Pract* 2010;26:327–33.
41 Kolber MJ, Hanney WJ. The reliability and concurrent validity of shoulder mobility measurements using a digital inclinometer and goniometer: a technical report. *Int J Sports Phys Ther* 2012;7:306–13.
42 Kibler WB, Ludewig PM, McClure PW, *et al*. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. *Br J Sports Med* 2013;47:877–85.
43 Uhl TL, Kibler WB, Gecewich B, *et al*. Evaluation of clinical assessment methods for scapular dyskinesis. *Arthroscopy* 2009;25:1240–8.
44 Dean BJ, Gwilym SE, Carr AJ. Why does my shoulder hurt? A review of the neuroanatomical and biochemical basis of shoulder pain. *Br J Sports Med* 2013;47:1095–104.

Paper III

ATTITUDES, BELIEFS AND BEHAVIOUR TOWARDS SHOULDER INJURY PREVENTION IN ELITE HANDBALL: FERTILE GROUND FOR IMPLEMENTATION

Stig Haugsboe Andersson, Roald Bahr, Magnus Johnsen Olsen, Grethe Myklebust

Corresponding Author
Stig Haugsboe Andersson
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences
PB 4014 Ullevål Stadion
0806 Oslo, Norway
Tel: +4790065819
Email: s.h.andersson@nih.no

Co-authors
Roald Bahr
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences, Oslo, Norway

Magnus Johnsen Olsen
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences, Oslo, Norway

Grethe Myklebust
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences, Oslo, Norway

ABSTRACT

Objectives To examine attitudes, beliefs and current behaviour towards risk factors and prevention of shoulder injuries, and to investigate the application of an exercise programme during a cluster-randomised controlled trail aiming to prevent shoulder injuries in elite handball.

Methods All captains and coaches of 44 elite handball teams (22 male, 22 female) constituting the intervention (21 teams) and control arm (n=23 teams) in a cluster-randomised controlled trial were invited to take part in a survey. A questionnaire, based on the Reach, Efficacy, Adoption, Implementation and Maintenance framework, addressing the end-user perspective on risk factors and prevention of shoulder injuries, as well as key issues related to the application of the Oslo Sports Trauma Research Center (OSTRC) Shoulder Injury Prevention Programme, was distributed using electronic survey software.

Results The response rate was 100%. Overall, the majority of coaches (84%) and captains (89%) believed that handball players are at high risk for shoulder injuries. All delivery agents in the trial reported to be familiar with the exercise programme and the majority believed in a preventative effect (coaches 90%, captains 81%). Only a minority reported full compliance with the recommended frequency (coaches 29%, captains 14%), with programme being too time consuming (coaches 67%, captains 81%) and lack of player motivation (coaches 76%, captains 62%) as the main barriers.

Conclusion There is fertile ground for implementation of the OSTRC Shoulder Injury Prevention Programme in elite handball, with programme length and lack of player motivation as the main barriers to overcome.

INTRODUCTION

Existing research on overuse shoulder injuries in elite handball has addressed all stages of the traditional van Mechelen four-stage approach to prevention of sports injuries.[1] Shoulder pain and problems are established as common burdens affecting participation and performance,[2-6] as well as daily life (Stage 1).[3] Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis have been identified as internal modifiable risk factors in prospective studies (Stage 2),[2] although not confirmed in a recent study using similar methods.[6] Nevertheless, the four-stage approach was recently completed with a trial reporting preventative effect of the Oslo Sports Trauma Research Center (OSTRC) Shoulder Injury Prevention Programme on the prevalence and risk of shoulder problems in elite handball (Stage 3 and 4).[7]

Despite the widespread use of the van Mechelen model since its origin in the early 90s, several papers have highlighted the need for integration of implementation science in sports injury prevention research.[8-12] It is argued that randomised controlled trials evaluating the effect of injury prevention exercise programmes in sports, such as the OSTRC Shoulder Injury Prevention Programme, are performed in highly controlled settings and do not reflect the final implementation context.[11 12] Consequently, dissemination and widespread use of evidence-based programmes in the real-world sport setting may be inhibited,[12 13] as the full potential will only be realised if the targeted end-users adopt, implement and maintain the programmes as intended.[12] To meet these challenges, Finch outlined the Translating Research into Injury Prevention Practice (TRIPP) framework,[12] an extension to the traditional approach. She recommended that researchers should seek to understand how evidence-based injury prevention exercise programmes can be translated into actions that can be implemented in the real-world sport setting (Stage 5). Key elements at this stage are information regarding attitudes, beliefs and current behaviour towards injury causes, predisposing factors and preventative measures, as well as identification of facilitators and barriers to implementation of programmes.[10 12] Finally, the effectiveness should be evaluated in a real-world sport setting by implementing the programmes among the intended end users, while taking into account the elements identified in stage 5 (Stage 6).[12] In addition, to successfully understand the full complexities of the implementation context and enhance implementation efforts in sports injury prevention, integration of a five dimensioned framework from implementation science has been developed: the Reach Efficacy Adoption Implementation Maintenance (RE-AIM) framework.[9 11] Despite these recommendations, information on the RE-AIM dimensions in published trials evaluating the effect of injury prevention exercise programmes in sports is lacking. [9]

Thus, the main objectives of this study were to use the RE-AIM framework to examine attitudes, beliefs and current behaviour towards risk factors and prevention of shoulder injuries, and to investigate the application of the OSTRC Shoulder Injury Prevention Programme during a cluster-randomised controlled trial aiming to prevent overuse shoulder injuries in elite handball.

METHODS

Study design and participants

This was a cross-sectional and retrospective survey involving 44 elite handball teams (22 male, 22 female) constituting the intervention (21 teams) and control arms (23 teams) in a cluster-randomised controlled trial aiming to prevent overuse shoulder injuries.[7] Towards the end of the intervention period (August 2014 to March 2015), we invited all team captains (n=44) and a coaching staff representative (n=44), nominated by the head coach as the individual responsible for the team´s prevention and physical training, to take part in the survey. In most cases, the head coach (n=23) and the fitness coach (n=11) was nominated as the representative, followed by individuals with a combined responsibility for fitness and medical follow-up (n=6, e.g. physical therapist) and assistant coaches (n=3). All captains and coaches from both study arms consented to participate and represented four separate respondent groups in the survey (21 intervention coaches; 21 intervention captains, 23 control coaches; 23 control captains).

The injury prevention exercise programme

Full details of the development, content and implementation of the injury prevention exercise programme used in the trial have been published previously.[7] Briefly, the OSTRC Shoulder Injury Prevention Programme consisted of five exercises with different variations and levels (15 in total) to be implemented three times per week as a part of the intervention team´s regular warm-up to handball training. The exercises aimed at increasing glenohumeral internal range of motion,[2 14] external rotation strength and scapular muscle strength,[2 15] as well as to improve kinetic chain and thoracic mobility.

The programme was developed in collaboration between authors and an external expert panel consisting of four physiotherapists, clinically working with handball players, and a fitness coach employed by the Norwegian Handball Federation. As a part of the development process, a female team not included in the study, tested the programme and responded to a questionnaire based on the RE-AIM framework to provide information regarding their beliefs and experiences of the content, duration, load and applicability of the programme.[10 13]

The programme targeted all players in the intervention teams and was delivered by team coaches and captains, which, together with the team medical staff, received specific training on the execution of the exercises in the programme. Once players were familiar with the exercises, the programme took about 10 minutes to complete. Team medical staff were asked to be present to supervise the quality of the exercises and ensure that players experiencing pain were performing the exercises as intended, at least one session per week during the first 4 weeks performing the programme, and every second week for the rest of intervention period. In addition, follow-up visits by the research group were completed to all intervention teams to stimulate adherence and ensure quality of the exercises.

The survey

A questionnaire, with variations depending on group affiliation, was developed in collaboration between authors and pilot tested by two coaches and two players not involved in the study to ensure readability and understanding. The questions, which were worded identically for coaches and captains within each study arm, were based on the RE-AIM framework and a previous survey aiming to examine implementation of the Nordic Hamstring Exercise in elite football.[16] All questions were closed, with multiple response options. The questionnaire consisted of a section addressing attitudes, beliefs and current behaviour towards the risk for and prevention of shoulder injuries in both study arms.
An intervention-specific section addressed views on and experiences with completion of the OSTRC Shoulder Injury Prevention Programme. In addition, a section specific for the control

teams investigated knowledge with the prevention programme used by the intervention teams and included description of five randomly selected exercises from the programme to examine completion of these or similar exercises during the season.

Data collection

The coaches and captains received a link by e-mail, providing them access to the questionnaire using online survey software (Questback V. 9692, Questback AS, Oslo, Norway). The questionnaires were distributed and completed during February 2015. Automatic reminders were sent to non-responders after 3 and 7 days both per e-mail using the survey software and per SMS (Pling, Front Information DA, Oslo, Norway), or per telephone. Responders were encouraged to take contact to clarify any questions regarding the content of the questionnaire, and two did. The data were analysed using SPSS statistical software (SPSS V.24, IBM Corporation, New York, USA).

RESULTS

The overall response rate was 100%. Table 1 shows how coaches and captains in both study arms responded to questions addressing attitudes, beliefs and behaviour towards the risk for and prevention of shoulder injuries. Irrespective of group affiliation, the majority of coaches and captains reported that they believed that handball players are at high risk for shoulder injuries and that performance of a shoulder injury prevention exercise programme definitely or to some degree would reduce the risk. Poor fitness in general, tackles, throwing load and length of career were the most frequent risk factors reported. The majority of respondents reported to previously having performed shoulder injury prevention and disagreed that it is more important to spend time on specific handball training.

[Table 1 near here]

Table 2 shows how the four respondent groups experienced attitudes towards shoulder injury prevention among different stakeholders in their team. The majority of respondents reported that their team medical staff was strongly positive, whereas players were positive. The majority of coaches in both study arms reported that the coaching staff was strongly positive, whereas the majority of captains reported that coaches were positive. The majority of all respondents had no knowledge of the attitudes of their administration.

[Table 2 near here]

All coaches (n=21, 100%) and captains (n=21, 100%) in the intervention teams reported that all players of their team were familiar with the OSTRC Shoulder Injury Prevention Programme. The majority of intervention coaches and captains (delivery agents) agreed that the education and follow-up they had received regarding the programme had been sufficient and that the programme was well suited as a part of the handball warm-up, with good variation and progression of the exercises (table 3). Less than 30% of coaches and less than 15% of captains reported that their team had completed the programme three times per week as recommended and less than half reported that they had performed it as a part of the handball warm-up. Only a minority of the surveyed coaches and captains agreed that they would continue to use the complete programme the next season. Among both coaches and captains, belief that the programme will prevent shoulder injuries was the most frequently reported facilitator to perform the programme and the majority agreed that the programme would prevent shoulder injuries when used systematically (table 4). Lack of player motivation and too time consuming programme were most frequently reported by coaches and captains as the barriers to complying with the programme as recommended (table 4).

[Table 3 and 4 near here]

According to the majority of intervention coaches and captains, their medical staff was strongly positive to the OSTRC Shoulder Injury Prevention programme, whereas the coaching staff was positive and players were neutral (Figure 1). Regarding the team administration, the majority of coaches and captains had no knowledge of their attitudes.

[Figure 1 near here]

In the control teams, approximately one third of the captains and the vast majority of coaches reported that their team did perform shoulder injury prevention training (table 5). The majority of coaches and captains reported that the coaching staff, the players and the medical staff of their team all were familiar with details of the programme used by the intervention teams. Only a few coaches and captains reported that this knowledge had affected their efforts towards shoulder injury prevention (table 5).

[Table 5 near here]

Table 6 shows the control coaches and captains responses to questions regarding completion of five specific exercises from OSTRC Shoulder Injury Prevention Programme or similar. The majority of coaches and captains reported that they had completed two of the exercises on a sporadic to regular basis. None of the exercises were completely unknown to neither coaches nor captains.

[Table 6 near here]

DISCUSSION

Our main findings were that the vast majority of coaches and captains in elite handball believed that players are at high risk for shoulder injuries, and that a shoulder injury prevention exercise programme targeting risk factors would reduce the risk, suggesting that there is fertile ground for implementation. However, the minority of delivery agents reported to have implemented the OSTRC Shoulder Injury Prevention Programme as recommended in the trial, with lack of player motivation and too time consuming programme as the main barriers. This suggests that initiatives to reduce the programme length and strategies to influence player motivation are needed to succeed with widespread dissemination.

The recently reported preventative effect of the OSTRC Shoulder Injury Prevention Programme suggests that dissemination and widespread use in the handball community would be beneficial.[7] However, to succeed in a real-world sport setting, knowledge regarding attitudes, beliefs and current behaviour towards shoulder injury prevention among delivery agents and end-users, as well as identification of facilitators and barriers to implementation of the programme is crucial.[10 12] Overall, the coaches and captains surveyed had the impression that handball players are at high risk for shoulder injuries, suggesting that their perceived susceptibility for shoulder injuries is in line with the literature,[2-6] an important premise to succeed with implementation.[10] The vast majority of coaches and captains in both groups believed that a shoulder injury prevention programme targeting risk factors would reduce the risk for shoulder injuries and the majority had previously employed preventative measures towards shoulder injuries. Only a minority reported that it is more important to spend time on specific handball training than injury preventative training. Hence, the elite handball community seems primed for adoption and implementation of the OSTRC Shoulder Injury Prevention Programme, as there seems to be a common beneficial belief.

All delivery agents in the trial reported to be familiar with the prevention programme and the majority believed that the programme would prevent shoulder injuries, which in fact was reported as the main facilitator to implementation among both coaches and captains. These findings support the importance of emphasising the preventative effect of the programme when aiming for a widespread dissemination. Additional common facilitators reported were satisfactory education and follow-up, programme variation and progression, expected performance gains and the practicability to implement the programme as a part of the training session. These facilitators were in line with previous studies reporting on implementation of injury prevention exercise programmes in team sports,[10 17-22] and should be emphasised in future dissemination. Influence from the team medical staff was further highlighted as a common facilitator in our data. However, as requirement of medical staff previously has been reported as a barrier to implementation and the fact that only a few handball teams will have access to one, even in the top divisions in Norway, this facilitator should receive less emphasis.[20]

Despite these results suggesting that adoption of the prevention programme was successful among the delivery agents, they still responded to deviate from the implementation recommendations, with the majority responding to perform the programme between one to three times per week, which is in line with the self-reported player compliance in the trial.[7] Similar to previous studies reporting on the uptake of injury prevention exercise programmes in team ball sport, [20 23-25] the time it takes to complete the programme was emphasised as an important barrier and only a minority of the surveyed coaches and captains reported that they would continue to use the complete programme the next season. Considering that the OSTRC Shoulder Injury Prevention Programme targets several risk factors associated with shoulder injury in handball, future research should investigate how these factors are altered among players performing the programme in order to reduce the number of exercises. In addition, despite the majority agreeing that the programme was well suited as a part of the warm-up, less than half reported to perform the programme in this setting. This implies that alternative settings should be considered when planning future dissemination, e.g. before the organised training, during other organised or individual training, as these were reported to be common delivery settings in the trial.

Future dissemination efforts should also include initiatives to motivate coaches and players to adopt the programme, as lack of player motivation and lack of priority among the head coaches was reported as important barriers to implementation. These efforts should seek to communicate the preventative effect of the programme to end-users and delivery agents, as this was reported as the most important motivator among both coaches and captains. Unfortunately, there is no guarantee that increased knowledge of the preventative effect automatically will translate into changed behaviour, as the learning process and experiences of each individual will affect adoption and implementation of the programme.[26] In order to succeed with behavioural modifications towards preventative measures, it is suggested that it should be included as a part of skill training from an early age to become an accepted part of their routine and culture.[26] Thus, dissemination of the programme should target players from a young age and instructions on how to perform the programme should be a mandatory at all levels of coach education.

A common understanding among the stakeholders within a team is emphasised as an important premise to succeed with implementation of preventative measures.[11] According to our results there were discrepancies in the attitudes towards the programme in the trial, with the team medical staff reported to be strongly positive, the coaching staff to be positive and the players to be neutral. In addition, the majority of coaches and captains reported to be unaware of their administration´s attitudes towards the programme, illustrating that communication between stakeholders can be improved. In order to succeed in future dissemination of the programme, all stakeholders need to be addressed to reach a common understanding on the advantage of implementation.

Interestingly, the majority of coaches and captains in the control teams reported to have detailed knowledge of the prevention programme used by the intervention teams in the trial, with the vast majority of coaches reporting to perform prevention training to reduce the risk of shoulder injuries. In fact, the majority of surveyed coaches and captains reported to perform two of the exercises in OSTRC Shoulder Injury Prevention Programme on a sporadic to regular basis. Thus, it seems that there is fertile ground for implementation of the programme across the whole population surveyed. However, this suggest also that there was a considerable cross-over effect in the trial, indicating that the efficacy of the prevention programme as reported in the trial may have been underestimated.

This study has limitations that need to be addressed. The survey included only team captains, and it is not known to what extent their attitudes, beliefs and current behaviour represent the views of their teammates. Considering the role of a team captain, it is possible that they are more devoted and conscious towards preventative measures. Further, as the person nominated to represent the coaching staff varied between teams, we cannot generalise our results to all head coaches at the elite level. In addition, as the surveyed coaches and captains all were at the elite level, it is possible that coaches and players at lower level of competition (e.g. amateur level) have different views.

CONCLUSION

Coaches and captains in elite handball believed that players are at high risk of shoulder injuries and that an exercise programme targeting risk factors would be effective, suggesting that there is fertile ground for implementation of the OSTRC Shoulder Injury Prevention Programme. However, as programme length and lack of player motivation were important barriers to implementation, shortening the programme and strategies to enhance player motivation may be beneficial.

ACKNOWLEDGEMENTS

The authors thank all team captains and coaches who participated in the study. The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic and Paralympic Committee & Confederation of Sport, and Norsk Tipping AS.

CONTRIBUTORS

All authors contributed to project planning and manuscript preparation. MJO and SA performed the data collection. SA drafted the manuscript and performed the data analysis. SA and the main supervisor, GM, are responsible for the overall content as guarantors.

FUNDING

No specific study funding.

COMPETING INTERESTS

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

ETHICAL APPROVAL

This study was nested within a cluster-randomsied controlled trial reviewed by the Regional Committee for Medical and Health Research Ethics (REK 2014/653 A), which concluded that, according to the Act on Medical and Health Research (the Health Research Act 2008), the study did not require full review by REK. The trial was approved by the Norwegian Social Science Data Service (NSD 2014/38187).

TRANSPARENCY

The study guarantors (SA and GM) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported and that no important aspects of the study have been omitted.

DATA SHARING

All data are available upon request.

REFERENCES

1 van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med* 1992;14:82-99.

2 Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med* 2014;48:1327-33.

3 Myklebust G, Hasslan L, Bahr R, Steffen K. High prevalence of shoulder pain among elite Norwegian female handball players. *Scand J Med Sci Sports* 2013;23:288-94.

4 Mohseni-Bandpei MA, Keshavarz R, Minoonejhad H, Mohsenifar H, Shakeri H. Shoulder pain in Iranian elite athletes: the prevalence and risk factors. *J Manipulative Physiol Ther* 2012;35:541-8.

5 Giroto N, Hespanhol Junior LC, Gomes MR, Lopes AD. Incidence and risk factors of injuries in Brazilian elite handball players: a prospective cohort study. *Scand J Med Sci Sports* 2017;27:195-202.

6 Andersson SH, Bahr R, Clarsen B, Myklebust G. Risk factors for overuse shoulder injuries in a mixed-sex cohort of 329 elite handball players: previous findings could not be confirmed. *Br J Sports Med* Published Online First: 07 August 2017. doi: 10.1136/bjsports-2017-097648.

7 Andersson SH, Bahr R, Clarsen B, Myklebust G. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *Br J Sports Med* 2017;51:1073-80.

8 Hanson D, Allegrante JP, Sleet DA, Finch CF. Research alone is not sufficient to prevent sports injury. *Br J Sports Med* 2014;48:682-4.

9 O'Brien J, Finch CF. The implementation of musculoskeletal injury-prevention exercise programmes in team ball sports: a systematic review employing the RE-AIM framework. *Sports Med* 2014;44:1305-18.

10 Finch CF, White P, Twomey D, Ullah S. Implementing an exercise-training programme to prevent lower-limb injuries: considerations for the development of a randomised controlled trial intervention delivery plan. *Br J Sports Med* 2011;45:791-6.

11 Finch CF, Donaldson A. A sports setting matrix for understanding the implementation context for community sport. *Br J Sports Med* 2010;44:973-8.

12 Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport* 2006;9:3-9.

13 Donaldson A, Finch CF. Planning for implementation and translation: seek first to understand the end-users' perspectives. *Br J Sports Med* 2012;46:306-7.

14 Almeida GP, Silveira PF, Rosseto NP, Barbosa G, Ejnisman B, Cohen M. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *J Shoulder Elbow Surg* 2013;22:602-7.

15 Edouard P, Degache F, Oullion R, Plessis JY, Gleizes-Cervera S, Calmels P. Shoulder strength imbalances as injury risk in handball. *Int J Sports Med* 2013;34:654-60.

16 Bahr R, Thorborg K, Ekstrand J. Evidence-based hamstring injury prevention is not adopted by the majority of Champions League or Norwegian Premier League football teams: the Nordic Hamstring survey. *Br J Sports Med* 2015;49:1466-71.

17 Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M, Junge A, Dvorak J, Bahr R, Andersen TE. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ* 2008;337:a2469.

18 Kiani A, Hellquist E, Ahlqvist K, Gedeborg R, Michaelsson K, Byberg L. Prevention of soccer-related knee injuries in teenaged girls. *Arch Intern Med* 2010;170:43-9.

19 Longo UG, Loppini M, Berton A, Marinozzi A, Maffulli N, Denaro V. The FIFA 11+ program is effective in preventing injuries in elite male basketball players: a cluster randomized controlled trial. *Am J Sports Med* 2012;40:996-1005.

20 Cumps E, Verhagen E, Meeusen R. Efficacy of a sports specific balance training programme on the incidence of ankle sprains in basketball. *Journal of sports science & medicine* 2007;6:212-9.

21 Kraemer R, Knobloch K. A soccer-specific balance training program for hamstring muscle and patellar and achilles tendon injuries: an intervention study in premier league female soccer. *Am J Sports Med* 2009;37:1384-93.

22 Finch CF, Doyle TL, Dempsey AR, Elliott BC, Twomey DM, White PE, Diamantopoulou K, Young W, Lloyd DG. What do community football players think about different exercise-training programmes? Implications for the delivery of lower limb injury prevention programmes. *Br J Sports Med* 2014;48:702-7.

23 Engebretsen AH, Myklebust G, Holme I, Engebretsen L, Bahr R. Prevention of injuries among male soccer players: a prospective, randomized intervention study targeting players with previous injuries or reduced function. *Am J Sports Med* 2008;36:1052-60.

24 Petersen W, Braun C, Bock W, Schmidt K, Weimann A, Drescher W, Eiling E, Stange R, Fuchs T, Hedderich J, Zantop T. A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Archives of orthopaedic and trauma surgery* 2005;125:614-21.

25 Soligard T, Nilstad A, Steffen K, Myklebust G, Holme I, Dvorak J, Bahr R, Andersen TE. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. *Br J Sports Med* 2010;44:787-93.

26 Van Tiggelen D, Wickes S, Stevens V, Roosen P, Witvrouw E. Effective prevention of sports injuries: a model integrating efficacy, efficiency, compliance and risk-taking behaviour. *Br J Sports Med* 2008;42:648-52.

WHAT ARE THE NEW FINDINGS?

- Coaches and captains in elite handball believe that players are at high risk of shoulder injuries and that an exercise programme targeting risk factors will reduce the risk.
- The OSTRC Shoulder Injury Prevention Programme was reported to be well suited as a part of the handball warm-up and the majority of coaches and captains were satisfied with the variation and progression in the programme.
- Only a minority of the surveyed coaches and captains agreed that they would continue to use the complete programme, with time consumption and lack of player motivation reported as the main barriers.

HOW MIGHT IT IMPACT ON CLINICAL PRACTICE IN THE NEAR FUTURE?

- Coaches and captains in elite handball seem primed for implementation of the OSTRC Shoulder Injury Prevention Programme. However, prior to widespread dissemination, initiatives to reduce the length of the programme are essential.

Table 1 Attitudes, beliefs and current behaviour towards risk factors and prevention of shoulder injuries among coaches (n=44) and captains (n=44) in intervention (n=21) and control teams (n=23).

		Intervention teams				Control teams			
		Coaches (n=21)		Captains (n=21)		Coaches (n=23)		Captains (n=23)	
Question/statement	**Response**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**
To which degree do you think handball players are at risk for shoulder injuries?	High risk	20	(95.2)	19	(90.5)	17	(73.9)	20	(87.0)
	Medium risk	1	(4.8)	2	(9.5)	6	(26.1)	3	(13.0)
	Low risk	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
	No risk	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
What are the most important risk factors for shoulder injuries among handball players? (MR)	Poor fitness in general	19	(90.5)	17	(81.0)	18	(78.3)	20	(87.0)
	Low training load	2	(9.5)	3	(14.3)	8	(34.8)	5	(21.7)
	High exposure to match time	3	(14.3)	1	(4.8)	7	(30.4)	1	(4.3)
	Tackles	7	(33.3)	10	(47.6)	11	(47.8)	12	(52.2)
	Length of career	10	(23.8)	4	(19.0)	5	(21.7)	3	(13.0)
	Throwing load	17	(42.9)	14	(66.7)	8	(34.8)	10	(43.5)
	Other	10	(23.8)	2	(9.5)	5	(21.7)	4	(17.4)
Do you think an injury-prevention exercise programme designed to improve strength, mobility and stability in the shoulder will reduce the risk for shoulder injuries?	Yes, definitely	12	(57.1)	11	(52.4)	14	(60.9)	11	(73.9)
	Yes, to some degree	8	(38.1)	8	(38.1)	9	(39.1)	8	(13.0)
	No, it won’t make any difference	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
	No, it will increase the risk	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
	I don´t know	1	(4.8)	2	(9.5)	0	(0.0)	2	(13.0)
Have your team previously performed prevention training to reduce the risk for shoulder injuries?	Yes, to a large degree	5	(23.8)	1	(4.8)	12	(52.2)	2	(8.7)
	Yes, to some degree	10	(47.6)	11	(52.4)	8	(34.8)	15	(65.2)
	Rarely	4	(19.0)	8	(38.1)	0	(0.0)	5	(21.7)
	No, never	1	(4.8)	1	(4.8)	0	(0.0)	1	(4.3)
	I´m new to the team and don´t know	1	(4.8)	0	(0.0)	3	(13.0)	0	(0.0)
It is more important to spend time on specific handball training than prevention (LOA)	Strongly agree	0	(0.0)	4	(19.0)	1	(4.3)	5	(21.7)
	Agree	7	(33.3)	5	(23.8)	4	(17.4)	8	(34.8)
	Unsure	3	(14.3)	5	(23.8)	3	(13.0)	2	(8.7)
	Disagree	9	(42.9)	7	(33.3)	14	(60.9)	7	(30.4)
	Strongly disagree	2	(9.5)	0	(0.0)	1	(4.3)	1	(4.3)
Motivation among coaches has no influence on player motivation to perform prevention training (LOA)	Strongly agree	0	(0.0)	0	(0.0)	0	(0.0)	1	(4.3)
	Agree	1	(4.8)	5	(23.8)	2	(8.7)	2	(8.7)
	Unsure	2	(9.5)	2	(9.5)	0	(0.0)	3	(13.0)
	Disagree	17	(81.0)	11	(52.4)	14	(60.9)	14	(60.9)
	Strongly disagree	1	(4.8)	3	(14.3)	7	(30.4)	3	(13.0)

MR, multiple responses possible; LOA, level of agreement. The shaded cells denote the most frequent response for each respondent group.

Table 2 Attitudes towards shoulder injury prevention among coaches, players, medical staff and administration according to coaches (n=44) and captains (n=44) in intervention (n=21) and control teams (n=23).

How will you best describe attitudes towards shoulder injury prevention in the following groups?	Intervention teams				Control teams			
	Coaches (n=21)		Captains (n=21)		Coaches (n=23)		Captains (n=23)	
	n	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**
Coaching staff								
Strongly positive	12	(57.1)	4	(19.0)	13	(56.5)	3	(13.0)
Positive	8	(38.1)	12	(57.1)	10	(43.5)	17	(73.9)
Neutral	1	(4.8)	5	(23.8)	0	(0.0)	3	(13.0)
Negative	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Strongly negative	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
I don't know	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Players								
Strongly positive	3	(14.3)	0	(0.0)	4	(17.4)	2	(8.7)
Positive	15	(71.4)	11	(52.4)	13	(56.5)	15	(65.2)
Neutral	2	(9.5)	7	(33.3)	6	(26.1)	3	(13.0)
Negative	1	(4.8)	1	(4.8)	0	(0.0)	2	(8.7)
Strongly negative	0	(0.0)	2	(9.5)	0	(0.0)	0	(0.0)
I don't know	0	(0.0)	0	(0.0)	0	(0.0)	1	(4.3)
Medical staff								
Strongly positive	19	(90.5)	9	(42.9)	16	(69.6)	12	(52.2)
Positive	2	(9.5)	8	(38.1)	6	(26.1)	10	(43.5)
Neutral	0	(0.0)	3	(14.4)	0	(0.0)	1	(4.3)
Negative	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Strongly negative	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
I don't know	0	(0.0)	1	(4.8)	1	(4.3)	0	(0.0)
Administration								
Strongly positive	1	(4.8)	4	(19.0)	3	(13.0)	1	(4.3)
Positive	6	(28.6)	5	(23.8)	5	(21.7)	5	(21.7)
Neutral	6	(28.6)	2	(9.5)	7	(30.4)	3	(13.0)
Negative	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Strongly negative	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
I don't know	8	(38.1)	10	(47.6)	8	(34.8)	14	(60.9)

The shaded cells denote the most frequent response for each respondent group.

Table 3 Experiences with completion of the OSTRC Shoulder Injury Prevention Programme among coaches and captains in intervention teams (n=21).

		Coaches (n=21)		Captains (n=21)	
Question/statement	**Response**	**n**	**(%)**	**n**	**(%)**
Which players have mainly performed the programme?	All players	20	(95.2)	17	(81.0)
	Players with a previous shoulder problem	0	(0.0)	1	(4.8)
	Players with a current shoulder problem	1	(4.8)	1	(4.8)
	None of the players	0	(0.0)	0	(0.0)
	I don´t know	0	(0.0)	2	(9.5)
Have your performed the programme three times per week as recommended?	Yes, three times per week or more	6	(28.6)	3	(14.3)
	No, between one to three times per week	14	(66.7)	14	(66.7)
	No, less than once per week	1	(4.8)	4	(19.0)
	I don´t know	0	(0.0)	0	(0.0)
In which context has the programme been performed? (MR)	Before organised handball training	12	(57.1)	14	(66.7)
	As a part of the handball warm-up	10	(47.6)	7	(33.3)
	During handball training	2	(9.5)	0	(0.0)
	During other organised training	4	(19.0)	6	(28.6)
	During individual training	5	(23.8)	5	(23.8)
	Other	0	(0.0)	1	(4.8)
Have you usually performed the programme as a whole?	Yes, always	7	(33.3)	4	(19.0)
	Yes, most of the time	10	(47.6)	11	(52.4)
	Sometimes	4	(19.0)	5	(23.8)
	No, never	0	(0.0)	1	(4.8)
Have you followed the planned progression and variation of the exercises in the programme?	Yes, absolutely	8	(38.1)	8	(38.1)
	Yes, to some degree	11	(52.4)	10	(47.6)
	No, we use a random selection	1	(4.8)	2	(9.5)
	I don´t know	1	(4.8)	1	(4.8)
What do you think about the progression and variation of the exercises in the programme?	Very good	2	(9.5)	1	(4.8)
	Good	15	(71.4)	16	(76.2)
	Not very good	1	(4.8)	3	(14.3)
	Poor	1	(4.8)	0	(0.0)
	I don´t know	2	(9.5)	1	(4.8)
Who has had the main responsibility for implementing the programme?	The head coach	6	(28.6)	9	(42.9)
	The physical trainer	2	(9.5)	3	(14.3)
	The medical staff (e.g. physiotherapist)	10	(47.6)	6	(28.6)
	The team captain	2	(9.5)	1	(4.8)
	Other player(s)	0	(0.0)	0	(0.0)
	All players in general	1	(4.8)	2	(9.5)
Who has had the main responsibility for the quality of the exercises?	Main coach	1	(4.8)	1	(4.8)
	Physical trainer	1	(4.8)	1	(4.8)
	Medical staff (e.g. physiotherapist)	5	(23.8)	4	(19.0)
	Team captain	2	(9.5)	1	(4.8)
	Other player	0	(0.0)	1	(4.8)
	All players in general	12	(57.1)	13	(61.9)
The education and follow-up we have received regarding the programme has been sufficient (LOA)	Strongly agree	5	(23.8)	3	(14.3)
	Agree	8	(38.1)	11	(52.4)
	Unsure	6	(28.6)	3	(14.3)
	Disagree	2	(9.5)	3	(14.3)
	Strongly disagree	0	(0.0)	1	(4.8)
The programme is well suited as a part of the handball warm-up (LOA)	Strongly agree	5	(23.8)	3	(14.3)
	Agree	8	(38.1)	13	(61.9)
	Unsure	7	(33.3)	3	(14.3)
	Disagree	1	(4.8)	1	(4.8)
	Strongly disagree	0	(0.0)	1	(4.8)

MR, multiple responses possible; LOA, level of agreement. The shaded cells denote the most frequent response for each respondent group.

Table 4 Views on and beliefs towards the OSTRC Shoulder Injury Prevention Programme and factors affecting adoption and implementation according to coaches and captains in intervention teams (n=21)

		Coaches (n=21)		Captains (n=21)	
Question/statement	**Response**	**n**	**(%)**	**n**	**(%)**
Which factors have influenced the motivation to perform the programme? (MR)	Belief that the programme will prevent shoulder injuries	21	(100.0)	13	(61.9)
	Belief that the programme will increase performance	12	(57.1)	7	(33.3)
	Sense of duty	6	(28.6)	11	(52.4)
	Influence from other players	6	(28.6)	2	(9.5)
	Influence from the medical team	7	(33.3)	11	52,4)
	Other	1	(4.8)	0	(0.0)
The programme will prevent shoulder injuries when used systematically (LOA)	Strongly agree	8	(38.1)	6	(28.6)
	Agree	11	(52.4)	11	(52.4)
	Unsure	2	(9.5)	4	(19.0)
	Disagree	0	(0.0)	0	(0.0)
	Strongly disagree	0	(0.0)	0	(0.0)
Have you experienced reduced amount of shoulder injuries?	Yes, we have less shoulder problems	4	(19.0)	2	(9.5)
	No, the situation is unchanged	10	(47.6)	12	(57.1)
	No, we have more shoulder problems	3	(14.3)	0	(0.0)
	I don´t know	4	(19.0)	7	(33.3)
Have you experienced any positive effect on handball performance?	Yes, player performance has improved	0	(0.0)	3	(14.3)
	No, the performance is unchanged	10	(47.6)	8	(38.1)
	No, player performance is reduced	0	(0.0)	1	(4.8)
	I don´t know	11	(52.4)	9	(42.9)
I will continue to use the complete programme next season (LOA)	Strongly agree	1	(4.8)	1	(4.8)
	Agree	5	(23.8)	4	(19.0)
	Unsure	11	(52.4)	9	(42.9)
	Disagree	4	(19.0)	4	(19.0)
	Strongly disagree	0	(0.0)	3	(14.3)
I will continue to use parts of the programme next season (LOA)	Strongly agree	4	(19.0)	2	(9.5)
	Agree	11	(52.4)	10	(47.6)
	Unsure	4	(19.0)	6	(28.6)
	Disagree	1	(4.8)	1	(4.8)
	Strongly disagree	1	(4.8)	2	(9.5)
What are the main reasons why your team did not comply with the programme as recommended? (MR)	The players lack motivation	16	(76.2)	13	(61.9)
	Too few exercises with handball	1	(4.8)	4	(19.0)
	The exercises are to challenging	0	(0.0)	0	(0.0)
	The programme is to time consuming	14	(66.7)	17	(81.0)
	The programme is difficult to organise	0	(0.0)	0	(0.0)
	The programme is not relevant	3	(14.3)	0	(0.0)
	Lack of equipment	0	(0.0)	2	(9.5)
	The head coach doesn´t prioritise the programme	3	(14.3)	8	(38.1)

MR, multiple responses possible; LOA, level of agreement. The shaded cells denote the most frequent response for each respondent group.

Table 5 Prevention of shoulder injuries and knowledge with the OSTRC Shoulder Injury Prevention Programme according to coaches and captains in control teams (n=23)

		Coaches (n=23)		**Captains (n=23)**	
Question	**Response**	**n**	**(%)**	**n**	**(%)**
Do your team perform prevention training to reduce the risk for shoulder injuries?	Yes	20	(87.0)	8	(34.8)
	No	3	(13.0)	9	(39.1)
	I don´t know	0	(0.0)	6	(26.1)
Is the coaching staff familiar with the prevention programme used by the intervention teams?	Yes, they´re familiar with programme details	12	(52.2)	17	(73.9)
	Yes, they have heard about it	10	(43.5)	3	(13.0)
	No, they´re unaware of it	0	(0.0)	0	(0.0)
	I don´t know	1	(4.3)	3	(13.0)
Are players familiar with the prevention programme used by the intervention teams?	Yes, they´re familiar with programme details	14	(60.9)	15	(65.2)
	Yes, they have heard about it	6	(26.1)	5	(21.7)
	No, they´re unaware of it	1	(4.3)	2	(8.7)
	I don´t know	2	(8.7)	1	(4.3)
Is the medical team familiar with the prevention programme used by the intervention teams?	Yes, they´re familiar with programme details	13	(56.5)	16	(69.6)
	Yes, they have heard about it	8	(34.8)	4	(17.4)
	No, they´re unaware of it	0	(0.0)	0	(0.0)
	I don´t know	2	(8.7)	3	(13.0)
Is the administration familiar with the prevention programme used by the intervention teams?	Yes, they´re familiar with programme details	1	(4.3)	4	(17.4)
	Yes, they have heard about it	11	(47.8)	6	(26.1)
	No, they´re unaware of it	1	(4.3)	0	(0.0)
	I don´t know	10	(43.5)	13	(56.5)
Has knowledge of the programme affected your team's efforts towards shoulder injury prevention?	Yes, our effort have increased	5	(21.7)	2	(8.7)
	No, our effort is unchanged	18	(78.3)	21	(91.3)

The shaded cells denote the most frequent response for each respondent group.

Table 6 Completion of specific exercises in the OSTRC Shoulder Injury Prevention Programme or similar according to coaches and captains in control teams (n=23)

		Coaches (n=21)		**Captains (n=21)**	
Question	**Response**	**n**	**(%)**	**n**	**(%)**
Have you performed the *Push-up plus back slide* during the season?	Yes, this exercise has been performed	18	(78.3)	17	(73.9)
	No, not this exercise specifically, but similar	4	(17.4)	5	(21.7)
	No	1	(4.3)	1	(4.3)
How often has this exercise or similar been performed per week?	Three times or more per week	2	(8.7)	1	(4.3)
	Two times or more per week	6	(26.1)	2	(8.7)
	One time per week	7	(30.4)	9	(39.1)
	Only sporadically	7	(30.4)	10	(43.5)
	Not relevant	1	(4.3)	1	(4.3)
Have you performed the *Bow and arrow* during the season?	Yes, this exercise has been performed	4	(17.4)	4	(17.4)
	No, not this exercise specifically, but similar	15	(65.2)	7	(30.4)
	No	4	(17.4)	12	(52.2)
How often has this exercise or similar been performed per week?	Three times or more per week	2	(8.7)	0	(0.0)
	Two times or more per week	6	(26.1)	1	(4.3)
	One time per week	7	(30.4)	2	(8.7)
	Only sporadically	4	(17.4)	8	(34.8)
	Not relevant	4	(17.4)	12	(52.2)
Have you performed the *Dynamic W-stretch* during the season?	Yes, this exercise has been performed	6	(26.1)	6	(26.1)
	No, not this exercise specifically, but similar	7	(30.4)	4	(17.4)
	No	10	(43.5)	13	(56.5)
How often has this exercise or similar been performed per week?	Three times or more per week	1	(4.3)	2	(8.7)
	Two times or more per week	4	(17.4)	2	(8.7)
	One time per week	4	(17.4)	2	(8.7)
	Only sporadically	4	(17.4)	4	(17.4)
	Not relevant	10	(43.5)	13	(56.5)
Have you performed the *Sleeper stretch* during the season?	Yes, this exercise has been performed	9	(39.1)	14	(60.9)
	No, not this exercise specifically, but similar	7	(30.4)	1	(4.3)
	No	7	(30.4)	8	(34.8)
How often has this exercise or similar been performed per week?	Three times or more per week	2	(8.7)	1	(4.3)
	Two times or more per week	3	(13.0)	0	(0.0)
	One time per week	3	(13.0)	2	(8.7)
	Only sporadically	8	(34.8)	12	(52.2)
	Not relevant	7	(30.4)	8	(34.8)
Have you performed the *Backwards throw* during the season?	Yes, this exercise has been performed	2	(8.7)	3	(13.0)
	No, not this exercise specifically, but similar	6	(26.1)	5	(21.7)
	No	15	(65.2)	15	(65.2)
How often have this exercise or similar been performed per week?	Three times or more per week	1	(4.3)	0	(0.0)
	Two times or more per week	0	(0.0)	1	(4.3)
	One time per week	5	(21.7)	1	(4.3)
	Only sporadically	2	(8.7)	6	(26.1)
	Not relevant	15	(65.2)	15	(65.2)

The shaded cells denote the most frequent response for each respondent group.

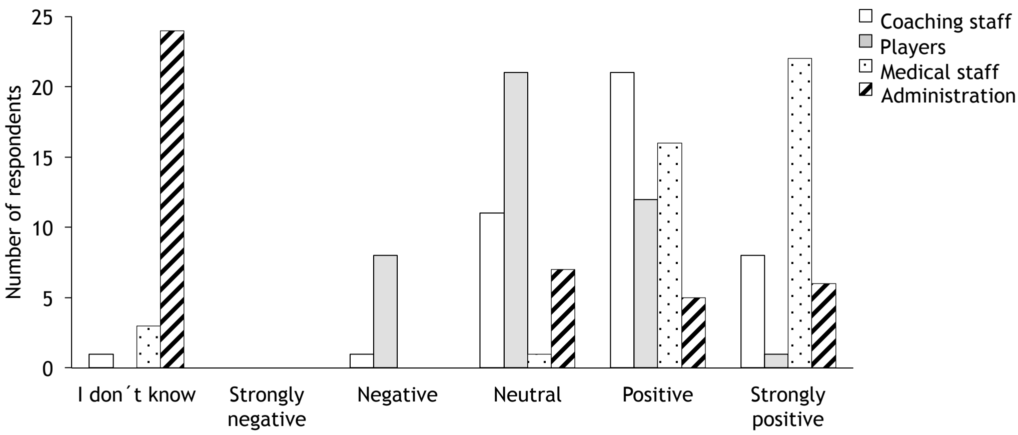


Figure 1 Attitudes towards the OSTRC Shoulder Injury Prevention Programme among coaches, players, medical staff and administration according to all respondents in the intervention teams (n=42, 21 coaches, 21 captains)

Paper IV

VIDEO ANALYSIS OF ACUTE INJURIES AND REFEREE DECISIONS DURING THE 24TH MEN´S HANDBALL WORLD CHAMPIONSHIP 2015 IN QATAR

Stig Haugsboe Andersson, Marco Cardinale, Rod Whiteley, Nebojsa Popovic, Clint Hansen, Fernando Sanz Lopez, Tone Bere, Roald Bahr, Grethe Myklebust

Corresponding Author
Stig Haugsboe Andersson
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences
PB 4014 Ullevål Stadion
0806 Oslo, Norway
Tel: +4790065819
Fax: +4723262307
Email: s.h.andersson@nih.no

Co-authors
Marco Cardinale
Aspire Academy, Department of Sports Science, Doha, Qatar
University of St. Mark and St. John, Faculty of Sport and Health Sciences, Plymouth, UK
University College London, Department of Computer Science and ISEH, London, UK

Rod Whiteley
Aspetar Orthopaedic and Sports Medicine Hospital
Doha, Qatar

Nebojsa Popovic
Aspetar Orthopaedic and Sports Medicine Hospital
Doha, Qatar

Clint Hansen
Aspetar Orthopaedic and Sports Medicine Hospital
Doha, Qatar

Fernando Sanz Lopez
Aspetar Orthopaedic and Sports Medicine Hospital
Qatar Handball Association. Physical Therapy Department.
Doha, Qatar.

Tone Bere
Division of Orthopaedic Surgery
Oslo University Hospital
Oslo, Norway

Roald Bahr
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences, Oslo, Norway

Grethe Myklebust
Oslo Sports Trauma Research Center
Department of Sports Medicine
Norwegian School of Sport Sciences, Oslo, Norway

Word count: 4971

ABSTRACT

Although handball is a contact sport with a high risk of acute match injuries, their mechanisms have not yet been investigated. We aimed to describe the mechanisms of acute match injuries in elite male handball and evaluate referee performance in injury situations. Based on injury surveillance from the 24th Men´s Handball World Championship 2015 in Qatar, injury situations and the referee decisions were identified on video footage.

A total of 55 injury situations and 37 referee decisions were included for analysis. The injury situations were analysed individually by five handball experts, followed by a consensus meeting. An expert referee panel performed individual blinded evaluation of the referee decisions, followed by an online consensus meeting. Injuries were evenly distributed among attackers (n=29) and defenders (n=26). The most frequent injury cause was contact trauma due to a tackle (n=27). At the time of injury, attackers were most frequently performing a jump shot (n=9), while defenders were completing a tackle (n=10). Defenders most commonly tackled the throwing arm (n=7) or towards the head/face region (n=6) of injured attackers, while attackers most frequently hit injured defenders with the knee during jump shots (n=5). Agreement between the referees and the expert panel was weak (kappa: 0.22, 95% CI 0.07 to 0.36), with substantially more lenient rule interpretation by the referees. Our results suggest that stricter refereeing and rule amendments should be considered to prevent acute match injuries in elite handball, especially in relation to tackling episodes when an attacker is performing a jump shot.

KEY WORDS

Injury mechanisms, referee performance, referee decisions, risk factor, handball

INTRODUCTION

Handball is a team throwing sport characterised by frequent and rapid changes of movement, high intensity running efforts, cutting and jumping, as well as frequent physical contact between opponents and teammates during tackles and collisions.[1] Compared to other Olympic team sports, the risk of acute injuries in handball is high.[2,3] During the 24th Men´s Handball World Championship 2015 in Qatar, a total incidence of 104.5 match injuries per 1000 player-hour was reported, with about half leading to time-loss.[4] Despite existing rules attempting to make the sport safe and fair,[5,6] the majority of injuries occurred during matches (92%) and 61% were reported as the result of contact between players, with only a few cases arising from foul play.[4]

When planning preventative measures aiming to reduce the rate of sports injuries it is crucial to understand their causes.[7] This encompasses information regarding the risk factors present for a particular player in a given situation and the specific mechanisms of injury. Bahr & Krosshaug,[8] expanding on previous epidemiological and biomechanical models, suggested that the description of the injury mechanisms should not only include details of the whole body and joint biomechanics at the time of injury, but also needs to account for the events leading to the injury situation, i.e. the playing situation, as well as player and opponent behaviour.[8-10]

The majority of intervention studies in sport injury prevention research have used such data to develop and assess the effect of programmes on the risk of injuries, with only a minority investigating the effect of amendments and/or stricter interpretation of rules.[11] Despite these studies showing a great potential to reduce the rate of acute injuries through reduction of foul play, this remains unexplored in several sports and research efforts are warranted.[12]

To successfully intervene through the rules and regulations governing sports, information on the events leading to injury is needed, including referee performance.[8] As there is no data on the events leading to injury in handball and no previous studies have investigated referee decisions, the aims of this study were to describe the mechanisms of acute match injuries in elite male handball and evaluate referee performance in injury situations.

METHODS

Study design and video material

This was a prospective video analysis including acute injuries during the 24th Men´s Handball World Championship 2015 in Qatar. Throughout the event (15 January to 1 February 2015), 122 match injuries were recorded by team medical staff, using the IOC injury and illness surveillance protocol. Detailed information regarding these injuries and the methods used is described in a previous publication.[4] Based on the injury reports, which also included the approximate timing of the match injuries, three operators accessed the videos of each game and identified the specific injury situations using video analysis software (ProzoneHANDBALL v.1.0.0.0.14, ProzoneSports, Leed, UK). All events involving entry of medical team and playing situations leading to two-minute suspension and red cards were coded to easily retrieve such events linked to injuries. In addition, players sustaining injuries were tracked over the course of the specific match reported to identify the key situation leading to injury. All videos were saved with a minimum of 5 s preceding and following the injury situation. A total of 55 videos, with visible acute injury situations, were identified and included in an individual analysis performed by a panel of handball experts June 2016, followed by a consensus meeting in July 2016 (figure 1).

[Figure 1 near here]

Following the injury consensus meeting, the operators re-accessed the videos to identify the decisions made by the referees in each injury situation (September to October 2016). Videos including non-contact traumas (n=4) and videos not showing the referees and their decisions (n=14) were excluded (figure 1). The referee decisions in the remaining 37 videos were recorded according to the rules of the game.[5,6] An expert referee panel performed individual blinded evaluation of the same videos using the same evaluation criteria (November 2016), followed by an online consensus meeting.

Analysis of acute injuries

An expert panel consisting of a handball coach employed by the Norwegian Handball Federation and four clinicians (two physicians and two physiotherapists) working with handball players nationally and internationally analysed the 55 injury videos. A specific form, developed by the expert panel to describe the situation and mechanism leading to injury, was used for the analyses and included variables such as ball possession, playing position, court position, injury cause, action of attacker and defender and localisation of tackle or hit, with additional specific sections on injuries to the head/face, knee and ankle (Appendix 1).

If the team had ball possession, injuries were classified as an acute injury to an attacking player, whereas if the opposing team had ball possession, injuries were classified as an injury to a defending player. The cause of injury was divided into contact trauma, landing trauma following contact and non-contact trauma. Contact trauma was defined as injuries due to direct contact with opponent (tackle), teammate (collision), static object (e.g. post) or moving object (e.g. handball). Landing trauma following contact was defined as injuries occurring during landing after contact with opponent (tackle) or teammate (collision). Non-contact trauma was defined as injuries occurring during running, cutting, jumping or landing without any involvement from opponents or teammates.

At the time of injury, the action of both the attacking and defending player was analysed. The action of the attacking player was divided into: cutting movement; shot on target from the ground, or while jumping; running towards the goal; receiving pass from teammate; passing to teammate from the ground or while jumping; or other. The action of the defending player was divided into: blocking or tackling, with specified body region of the tackle, e.g. head/face, shoulder, throwing arm, ball, abdomen, hip, thigh, or other. In addition, whenever an attacking player sustained an injury due to contact with a defending player, the main body region used by the defender to tackle was noted: head, shoulder, arm(s) flexed or extended, elbow, hand(s), abdomen, hip, knee, leg, or foot. Whenever a defending player sustained an injury due to contact with an attacking player, the body region used by the attacker to hit the defender was noted: head, shoulder, throwing arm, elbow, hand, ball, abdomen, hip, thigh, knee, or foot.

Following the individual analysis of the acute injuries, a consensus meeting including the five handball experts and a moderator, was performed at the Oslo Sports Trauma Research Center. A consensus was reached in all cases, defined as three of the five handball experts in the panel agreeing on all the variables related to an injury.

Evaluation of referee performance

Three referees employed by the Norwegian Handball Federation, with extensive refereeing experience from international handball at the club and national team level, performed individual blinded evaluation of 37 videos of playing situations leading to injury. Blinding was accomplished by editing the video so that the decision of referees could not be seen. The evaluation criteria were identical to the ones used by the referees, i.e. no foul, free throw in favour of attacking (defensive foul) or defending team (offensive foul) and penalty throw in favour of attacking team (defensive foul). In addition, it was evaluated whether foul play led to the use of sanctions, i.e. a two-minute suspension, a yellow card (warning) or a red card (disqualification). In 25 of the 37 videos a consensus could be reached, as at least two of three in the referee expert panel agreed. The 12 remaining videos were discussed in an online consensus meeting (Skype, Skype Communications SARL, Luxembourg city, Luxembourg) to ensure a majority agreement in all cases.

Statistics

Descriptive statistics were used to present the results from the video analysis of acute injury situations and referee decisions. Kappa correlation coefficients were calculated to assess the agreement between the decisions made by the referees and the expert referee panel. All analyses were performed using SPSS statistical software (SPSS V.24, IBM Corporation, New York, USA).

RESULTS

The acute injuries (n=55) were evenly distributed between attackers (n=29) and defenders (n=26), but time-loss injuries (n=22) were more common among attackers (n=15). Of the 22 time-loss injuries, ten were reported as less severe injuries (estimated absence 1-2 days), ten were moderate injuries (estimated absence 3-4 days) and two were severe injuries (estimated absence >4 weeks). Injuries occurred most frequently between the 6 and 9-meter line on the handball court (n=37), with back position as the most common playing position at the time of injury for attackers (n=19) and mid defence for defenders (n=15).

As shown in table 1, the most frequent acute injury cause was contact trauma (n=42) due to direct contact with an opponent (n=27) and landing trauma following contact (n=9) with an opponent (n=8). Irrespective of injury cause, a tackling episode between opponents was observed in the majority of injury situations (n=35).

[Table 1 near here]

Injury situations to the attacking players

Attacking players sustaining an acute injury (n=29) were most frequently performing a shot on target (n=11), while jumping (n=9) or standing (n=2). The defending opponent(s) most commonly tackled the attacker's throwing arm (n=7) or towards the head/face region (n=6), with arms extended (n=6), while moving towards the attacker from the side (n=11). Most often, one defender was involved in the injury situation (n=13), followed by two defenders or more (n=9).

Injury situations to the defending players

When defending players sustained an acute injury (n=26), they most commonly tackled the throwing arm of an attacker (n=10) or performed a blocking attempt (n=3), while moving directly towards the attacking player (n=7) or from the side (n=6). Most frequently, they were hit to the head/face region (n=10), followed by the abdominal and thoracic region (n=4). In the majority of the situations, the attacking player was performing a jump shot on target (n=15) and hit the defender with the knee (n=5), the elbow (n=2) or the hand (n=2). In five of the situations, the defending player was hit by the handball.

Head/face injuries

All the acute injuries to the head/face region (n=17) were classified as contact trauma. The most common injury situation was a tackling episode (n=12), where six attacking players and six defending players sustained an injury. A straight blow to the front of the head/face was the most common injury mechanism (n=10), followed by a blow to the side of the head/face (n=5), resulting in nine contusions, four lacerations and two concussions. A total of 11 head/face injuries required medical attention on the court. Four players had to leave the court, two on their own (one contusion and one laceration) and two with assistance from the medical team (concussions). The majority of the head/face injuries resulted in no absence from training and match play (n=8), while one was classified as a less severe injury (contusion) and two as injuries with moderate severity (concussions).

Ankle injuries

The six acute ankle injuries were evenly distributed between contact trauma, landing trauma following contact, and non-contact trauma. The two injuries classified as due to contact trauma were both less severe injuries (sprains) and occurred in relation to a direct blow to the ankle from the anterior side, one during collision with teammate and one during a tackle. Landing on the ground and on the opponent's foot were the two situations observed for the landing traumas following contact with opponent (tackle), both less severe injuries (sprains). The two non-contact traumas occurred during running without interception from teammates or opponents and were both moderately severe injuries (one sprain and one ligament tear). For the non-contact traumas and landing traumas following contact (n=4), the injured ankle was observed to be in an inverted position at initial contact with either the ground or foot of an opponent in all cases. At initial contact, the ankle was also in plantar flexion in two cases and in relatively neutral flexion in two cases. Subsequently, the ankle moved towards dorsal flexion and inversion in all cases.

Knee injuries

Of the four acute knee injuries, two were classified as contact trauma, one as landing trauma following contact and one as non-contact trauma. A direct blow to the anterior knee and from the lateral side was observed as the injury mechanisms for the two contact traumas, both occurring during a tackle. The anterior blow resulted in a less severe injury (contusion), while the lateral blow resulted in an injury with moderate severity (sprain). The landing trauma following contact (n=1) was classified as a less severe injury (sprain) and occurred during a landing situation on the ground subsequent to a tackle, where the knee was flexed at initial contact and subsequently moved towards flexion and valgus. The non-contact trauma (n=1) was classified as a less severe injury (sprain) and observed to occur during a cutting movement, with the knee flexed and in relatively valgus at initial contact with the ground, and subsequently moving towards flexion and valgus.

Referee decisions

The overall decisions made by the referees and in relation to possession of the injured player are presented in table 2. When assessing videos in relation to tackling episodes leading to an acute injury (n=30), irrespective of possession, no foul was called in eight episodes, free throw in favour of the defending team (offensive foul) in two and free throw in favour of the attacking team (defensive foul) in 20, with eight two-minute suspensions of defenders. In situations where the attacker performed a shot on target (n=10), the most common action when attackers sustained an injury, the referees called no foul in three cases, free throw against (offensive foul) in one and free throw in favour (defensive foul) in six, with a two-minute suspension against the defender in two situations. In situations where the defender tackled the throwing arm of the attacker (n=7), the most common action when an injury occurred to defenders, the referees called no foul in four situations and free throw against (defensive foul) in three, with a two-minute suspension against the injured defender in two episodes. When examining videos in relation to situations leading to an acute injury, with any degree of absence (n=13), no foul was called in six situations, free throw in favour of the attacking player (defensive foul) in five and free throw in favour of the defending players (offensive foul) in two. Only one of the situations qualified for the use of sanction, a two-minute suspension of the defending player.

[Table 2 near here]

Evaluation of referee performance

As shown in table 3, there was agreement between the referees and the expert panel in only 14 of the 37 acute injury situations (kappa: 0.22, 95% CI 0.07 to 0.36). The expert panel awarded two yellow cards and three two-minute suspensions in relation to three free throws and two penalties, all in in favour of the attacking team (defensive foul), in five situations in which the referees called no foul. In addition, the expert panel awarded a red card to an attacking player perpetrating an offensive foul (free throw defending team) in one situation in which the referees called no foul. When examining the overall use of sanctions, the expert panel awarded five yellow cards, 11 two-minute suspensions and one red card in 17 situations in which the referees awarded no sanctions.

[Table 3 near here]

Assessment of decisions in relation to tackling episodes (n=30) revealed that the expert panel called three free throws and one penalty in favour of the attacking team (defensive foul) in four situations in which the referees called no foul. Regarding use of sanctions, the expert panel awarded five yellow cards and 11 two-minute suspensions in 16 tackling episodes in which the referees awarded no sanction. In addition, the expert panel awarded three red cards in episodes in which the referees only awarded two-minute suspension.

When assessing decisions in the most frequent injury situations for attackers (performing a jump shot, n=8) and defenders (tackling towards the throwing arm, n=7), the expert panel called eleven free throws in favour of the attacking team (defensive foul), including seven two-minute suspensions and one yellow card, in situations where the referees called no foul.

When examining decisions in situations leading to an injury with any degree of absence (n=13), the expert panel called four free throws in favour of the attacking team (defensive foul) in four situations in which the referees called no foul. In addition, the expert panel awarded three yellow cards and five two-minute suspensions, all to the defending player, in eight situations leading to a time-loss injury in which the referees refrained from the use of sanctions.

DISCUSSION

This is the first prospective video analysis describing the mechanisms of acute injuries and evaluating referee performance in injury situations in elite handball. A tackle was the most frequent injury situation, with contact trauma and landing trauma after opponent contact as the main injury causes. The referees were substantially more lenient than the expert referee panel in their interpretation of rules and use of sanctions.

Cause of acute injuries

Handball is considered a contact sport, where tackles and collisions are a natural part of the game.[1] Consequently, this puts players at risk of sustaining an injury, with contact highlighted as the main cause of injuries in epidemiological studies.[4,13-16] In fact, between 60 to 90% of all injuries has been reported as contact injuries during international male championships.[4,17,18] Based on player and medical reporting, contact injuries typically occur during high-speed movement, often involve several players and can be caused by a direct blow to the body during a tackle or collision, or indirectly during landing, following a tackle, or a collision.[4] However, the causes of injury can be challenging to capture with data collection based on recall. Based on the current video analysis, we found that contact trauma due to a tackling episode between opponents was the most common acute injury cause, followed by landing trauma subsequent to a tackling episode. In fact, a tackling episode was the most frequent event observed preceding an acute injury situation.

Possession and playing position

According to previous epidemiological studies in handball, the majority of injuries occur during attacking while having ball possession,[13-15] with back players in the most vulnerable playing position.[19,20] However, when adjusting for match exposure during an international tournament, players in the line position had the highest risk of injury.[4] In the current study, acute injuries were evenly distributed between attackers and defenders. At the time of injury, the back position was the most common playing position for attackers and mid-defence for defenders, with the majority of injuries occurring between the 6- and 9-m lines. A previous study conducted on the time motion analysis of the same event highlighted that majority of goals were scored from the back and line position.[21] Therefore, to reduce scoring chances, it is expected that the likelihood of collisions and contact is high between opponents in these positions. When comparing our results with previous studies, methodological differences should be kept in mind, as epidemiological studies are solely based on player and medical reporting, and may vary from observation of actual injury situations, i.e. the playing position at the time of injury may vary from player's ordinary position and may be dependent on playing possession.

Action of injured player and opponent

To our knowledge, no previous study has reported information regarding the action of the injured player and the opponent at the time of injury in handball. In the current study, we found that attacking players most often were performing a jump shot when sustaining an acute injury, while the defending opponent tackled towards the throwing arm or the head/face region of the attacker with arms extended, which is a violation of the rules.[5] Interestingly, the majority of injuries to defenders occurred in the same playing situation, i.e.

while defenders tackled towards the throwing arm of an attacker performing a jump shot and were hit by the attackers knee, elbow or hand. This indicates that tackling episodes occurring when attackers perform a jump shot should be targeted to prevent acute injuries among both attackers and defenders through development and appropriate interpretation of the rules of the games.

Referee decisions and performance

We found that the referees called foul play in 62% of situations leading to injuries, with only a minority leading to the use of sanctions. All situations leading to foul play resulted in free throws, with the majority in favour of the attacking team (defensive foul), despite injuries being evenly distributed among attackers and defenders. None of the situations qualified for a penalty throw and no yellow or red cards were awarded.

In a previous epidemiological study, including match injuries from six international handball tournaments, 54% of the contact injuries were caused by foul play according to the medical team and the injured player. In contrast, only 32% of these injuries qualified for the use of sanctions by the referees.[18] These data are solely based on an injury-reporting system and vulnerable to both recall and information bias. In the current study, we found that the overall agreement between the referees and the expert panel in regard to calling foul play was weak, with substantially stricter interpretation of the rules in the expert panel. The referees were found to be substantially more lenient in their use of sanctions and calling foul play during tackling episodes and situations leading to time-loss injuries. Based on these results, we suggest that stricter refereeing and potentially also rule amendment should be considered to protect handball players from acute injuries, as previous studies have reported a preventative effect of such efforts in other sports.[22-25]

Injury mechanisms of specific body regions

The analysis form used in the current study included specific sections regarding head/face, knee and ankle, and aimed to describe the acute injury mechanisms to these body regions in detail. However, due to a limited number of cases, these results must be interpreted with caution.

All acute injuries to the head/face region were classified as contact trauma. The majority occurred during tackling episodes and was evenly distributed among attackers and defenders and should be targeted when aiming to prevent head/face injuries through referee´s interpretation of rules. A blow straight to the head/face or from the side was the most common injury mechanism. Interestingly, majority of players continued to play, despite more than half of the injuries requiring medical attention on the court. Only four players were withdrawn from play and only two were classified as moderate injuries. Due to the high intensity in handball, it could be questioned if the severity of head/face injuries in handball is underestimated. Are the medical teams capturing the true extent of the problem? Do they use the sport concussion assessment tool when evaluating if a player should be withdrawn from play after a blow to the head/face? In July 2016, subsequent to the championship in Qatar, the International Handball Federation updated the rules regarding injured players during matches. In case of an injury, the referees may give permission to the medical team to enter the court to assist an injured player. However, if the preceding event does not involve foul play, the injured player must leave the court immediately after receiving medical attention and can only return following the third attack of his team.[26] This may provide the medical team with additional time to evaluate an injury. However, in situations where the referees are uncertain if the player requires medical attention on the court, the players should decide themselves.[26] This may stimulate players to neglect medical attention to avoid leaving the court. Consequently, this may inhibit the medical team in capturing a player with a concussion that should be withdrawn from play, and the new rules should be debated in a medical perspective. Rule amendments to consider include a three-minute full stop in play whenever the referees suspect a serious injury to the head, allowing a thorough assessment of the injured player on the court, with mandatory confirmation from the medical team before the player is allowed back in play, similar to the procedure introduced by the Union of European Football Associations Executive Committee in 2014, dealing with suspected concussions in football.[27]

According to previous kinematic case studies,[28-30] ankle inversion traumas occur in a neutral or dorsal flexed position. Recently, a systematic video analysis of ankle injuries in volleyball supported this, as landing-related injuries were reported to mostly result from inversion in neutral flexion without any substantial plantar flexion.[31] In the current study, we observed similar mechanisms for acute ankle injuries occurring whilst running or during landing situations on the ground or on an opponent's foot. However, when interpreting our results, it should be noted that we only included four ankle injuries classified as non-contact trauma or landing trauma following contact. A previous prevention study in handball,[19] including exercises to improve awareness and control of ankles during running, cutting, jumping and landing has reported a reduction in acute ankle injuries, and such exercises should be preferred when aiming to prevent ankle injuries. Regarding the ankle injuries due to contact trauma, there is no obvious aim for prevention, as this study only included two cases that both occurred during an involuntary blow to the ankle.

Two of the acute knee injuries were classified as contact trauma occurring during a tackle, with a direct blow anterior to the knee and from the lateral side as the observed injury mechanisms. Potentially, injury preventative measures should focus on referee's interpretation of rules in such situations. However, as there are only two cases in the current study, this remains unclear. The remaining two acute knee injuries in the video material were classified as one non-contact trauma and one landing trauma. In both injuries, the knee was flexed at initial contact with the ground and subsequently moving towards increased flexion and valgus, similar to acute knee injury mechanisms previously reported in handball.[32] Prevention programs including balance exercises focusing on neuromuscular control, planting and landing skills, and lower extremity strength have been reported to reduce the risk of acute knee injuries in handball,[19,33] and should be preferred when aiming to prevent such injuries.

Methodological considerations

A major strength of this study was that we included a sample of real time acute match injuries in elite handball, which were individually analysed by five handball experts, before completing a consensus meeting. We also recruited an expert referee panel, with extensive referee experience from international handball, to perform individual blinded evaluation of the injury situations in regard to foul play, and compared this with the referee decisions. However, this study also has several limitations that need to be addressed.

When interpreting our results, it should be kept in mind that the time of injury was determined subjectively and may differ from real life, but was in most cases obvious according to the expert panel. As the video material consisted of limited camera angles and only included a minimum of 5 s preceding and following the injury situations, our ability to describe the injury mechanisms may have been affected. In addition, the external validity is limited due to a homogenous population and the low number of cases, especially for ankle and knee injuries.

Videos not showing the referees and their decisions were excluded, but it seems reasonable to assume that these would be random cases. When evaluating referee performance, the decisions made by the expert panel were used as the gold standard. However, we cannot be certain that their evaluations were correct. There are several differences between evaluating the situations live compared to on video. In ice hockey, it is reported that situational factors, such as crowd noise, influence from the coaches and stress can influence the refereeing.[34,35] These factors will also be present during international handball matches and may have influenced the referee's decision-making. In contrast, the expert panel will not have been exposed to these factors. Regarding visual view, the expert panel had access to two camera angles in most cases, i.e. an overview of the situation, followed by a close up during the replay. Naturally, these angles will differ from the referees live viewing of the situations and may have lead to different observations. In addition, the expert panel had the opportunity to watch unlimited slow-motion replays, providing them with an advantage when evaluation the situations. It is also reported that hockey referees tend to use a stricter interpretation of rules when refereeing based on video compared to live.[36] This may be explained by the "advantage" rule, allowing referees not to interfere if they consider that the attacker is not obstructed and will benefit from continued play.[5] As the expert panel only had access to the specific injury situation with a limited timeframe, this may have affected their ability to take this rule into account. It should also be noted that the culture of handball and tradition of referring and adherence to existing rules might differ between the Norwegian referees in the expert panel and championship referees with an extensive international background. This may have affected our results and challenges the external validity of our findings.

PERSPECTIVES

Rules and referee performance are important external risk factors to consider when planning injury preventative measures in sports and previous studies intervening on these factors have reported to successfully reduce the rate of injuries.[8,12,22-25] Based on our results, we recommend that rule amendments and stricter rule enforcement should be considered to prevent acute match injuries in elite male handball, especially in relation to tackling episodes when an attacker is performing a jump shot, as this was the most common playing situation observed when attackers and defenders sustained an acute injury. Measures to consider are delayed video review of matches with the possibility to retrospectively sanction players violating the rules,[37] as well as extensive referee education focusing on playing situations with injury potential, i.e. defender use of extended arms during tackles and attacker use of knee, elbow and hand during jump shots. These measures to reduce foul play should be communicated to the handball community on an organisational level and be addressed by future research to assess the effects on acute injury rates.

ACKNOWLEDGEMENTS

We would like to thank Tom Morten Svendsen for contributing to the video analysis of the acute injury situations and the referees in the expert panel; Øyvind Togstad, Øystein Pettersen and Per Morten Sødal, for evaluating the playing situations leading to injury. Aspetar hospital, the International Handball Federation, the Aspire Zone Foundation Research committee, the Medical and Scientific Commission and the organising committee of the Qatar 2015 World Championships which provided the approval and support for the project and the funding to conduct the analyses of the games. The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic and Paralympic Committee & Confederation of Sport, and Norsk Tipping AS.

CONTRIBUTORS

All authors contributed to the study design and data recording preparation. MC was responsible for developing the video software in collaboration with ProzoneSports. MC, CH and FSL were responsible for preparation of the video material. SA, MC, NP and GM performed the video analysis and TB was responsible for the injury consensus meeting. SA was responsible for the referee consensus meeting. SA interpreted the data and wrote the first draft of the paper. All authors reviewed and approved the manuscript. SA and the main supervisor, GM, are responsible for the overall content as guarantors.

FUNDING

Qatar 2015 Organising Committee funded the video analysis of all the games of the World Championship.

ETHICAL APPROVAL

The injury surveillance study was reviewed and approved by the Anti-Doping Lab Qatar (ADLQ), Doha, Qatar. The video analysis of the games was reviewed and approved by the Medical and Scientific Commission of the Qatar 2015 World Championships and by the Aspire Zone Foundation Research Committee.

TRANSPARENCY

The lead author (the manuscript´s guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported and that no important aspects of the study have been omitted.

DATA SHARING

All data are available upon request.

REFERENCES

1. Karcher C, Buchheit M. On-court demands of elite handball, with special reference to playing positions. *Sports Med.* 2014;44:797-814.
2. Engebretsen L, Soligard T, Steffen K, et al. Sports injuries and illnesses during the London Summer Olympic Games 2012. *Br J Sports Med.* 2013;47:407-414.
3. Soligard T, Steffen K, Palmer D, et al. Sports injury and illness incidence in the Rio de Janeiro 2016 Olympic Summer Games: A prospective study of 11274 athletes from 207 countries. *Br J Sports Med.* 2017;51:1265-1271.

4. Bere T, Alonso JM, Wangensteen A, et al. Injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar. *Br J Sports Med.* 2015;49:1151-1156.

5. International Handball Federation. Rules of the Game. 2005. http://www.ihf.info/upload/Manual/IHF_STATUTS_CHAP_9A_GB.pdf

6. International Handball Federation. Changes to the Rules of the Game. 2010. http://www.ihf.info/files/Uploads/NewsAttachments/0_Overview%202010_GB.pdf

7. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med.* 1992;14:82-99.

8. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. *Br J Sports Med.* 2005;39:324-329.

9. Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med.* 1994;4:166-170.

10. McIntosh AS. Risk compensation, motivation, injuries, and biomechanics in competitive sport. *Br J Sports Med.* 2005;39:2-3.

11. Klugl M, Shrier I, McBain K, et al. The prevention of sport injury: an analysis of 12,000 published manuscripts. *Clin J Sport Med.* 2010;20:407-412.

12. Matheson GO, Mohtadi NG, Safran M, Meeuwisse WH. Sport injury prevention: time for an intervention? *Clin J Sport Med.* 2010;20:399-401.

13. Moller M, Attermann J, Myklebust G, Wedderkopp N. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. *Br J Sports Med.* 2012;46:531-537.

14. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury pattern in youth team handball: a comparison of two prospective registration methods. *Scand J Med Sci Sports.* 2006;16:426-432.

15. Seil R, Rupp S, Tempelhof S, Kohn D. Sports injuries in team handball. A one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. *Am J Sports Med.* 1998;26:681-687.

16. Nielsen AB, Yde J. An epidemiologic and traumatologic study of injuries in handball. *Int J Sports Med.* 1988;9:341-344.

17. Junge A, Langevoort G, Pipe A, et al. Injuries in team sport tournaments during the 2004 Olympic Games. *Am J Sports Med.* 2006;34:565-576.

18. Langevoort G, Myklebust G, Dvorak J, Junge A. Handball injuries during major international tournaments. *Scand J Med Sci Sports.* 2007;17:400-407.

19. Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ.* 2005;330:449.

20. Piry H, Fallahi A, Kordi R, Rajabi R, Rahimi M, Yosefi M. Handball injuries in elite asian players. *World Appl Sci J.* 2011;10:1559-1564.

21. Cardinale M, Whiteley R, Hosny AA, Popovic N. Activity Profiles and Positional Differences of Handball Players During the World Championships in Qatar 2015. *Int J Sports Physiol Perform.* 2017;12:908-915.

22. Orchard JW, Seward H. Decreased incidence of knee posterior cruciate ligament injury in Australian Football League after ruck rule change. *Br J Sports Med.* 2009;43:1026-1030.

23. Bjorneboe J, Bahr R, Dvorak J, Andersen TE. Lower incidence of arm-to-head contact incidents with stricter interpretation of the Laws of the Game in Norwegian male professional football. *Br J Sports Med.* 2013;47:508-514.

24. Wennberg RA, Tator CH. Concussion incidence and time lost from play in the NHL during the past ten years. *Can J Neurol Sci.* 2008;35:647-651.

25. Macan J, Bundalo-Vrbanac D, Romic G. Effects of the new karate rules on the incidence and distribution of injuries. *Br J Sports Med.* 2006;40:326-330.

26. International Handball Federation. Rules of the Game. 2016 http://www.ihf.info/files/Uploads/NewsAttachments/0_New-Rules%20of%20the%20Game_GB.pdf

27. The Union of European Football Associations Executive Committee. New concussion procedure. 2014. http://www.uefa.com/insideuefa/protecting-the-game/medical/news/newsid=2154076.html

28. Fong DT, Ha SC, Mok KM, Chan CW, Chan KM. Kinematics analysis of ankle inversion ligamentous sprain injuries in sports: five cases from televised tennis competitions. *Am J Sports Med.* 2012;40:2627-2632.

29. Mok KM, Fong DT, Krosshaug T, et al. Kinematics analysis of ankle inversion ligamentous sprain injuries in sports: 2 cases during the 2008 Beijing Olympics. *Am J Sports Med.* 2011;39:1548-1552.

30. Kristianslund E, Bahr R, Krosshaug T. Kinematics and kinetics of an accidental lateral ankle sprain. *J Biomech.* 2011;44:2576-2578.

31. Skazalski C, Kruczynski J, Bahr M, Bere T, Whiteley R, Bahr R. Landing-related ankle injuries do not occur in plantarflexion as once thought: A systematic video analysis of ankle injuries in world-class volleyball. *Br J Sports Med* Published Online First: 27 June 2017.doi:10.1136/bjsports-2016-097155

32. Koga H, Nakamae A, Shima Y, et al. Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *Am J Sports Med.* 2010;38:2218-2225.

33. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med.* 2003;13:71-78.

34. Nevill AM, Balmer NJ, Williams AM. The influence of crowd noise and experience upon refereeing decisions in football. *Psychology of Sport and Exercise.* 2002;3:261-272.

35. Wilkins HA, Petersen SR, Quinney HA. Time-motion analysis of and heart rate responses to amateur ice hockey officiating. *Can J Sport Sci.* 1991;16:302-307.

36. Trudel P, Dionne JP, Bernard D. Differences between assessments of penalties in ice hockey by referees, coaches, players and parents. Safety in Ice Hockey; 2000; St. Louis, Missouri.

37. The Football Association. Player Essentials 2017-18 Season Guide. 2017. http://www.thefa.com/-/media/files/thefaportal/governance-docs/player-essentials/2017-18/english---steps-2-4---player-essentials-2017-18.ashx

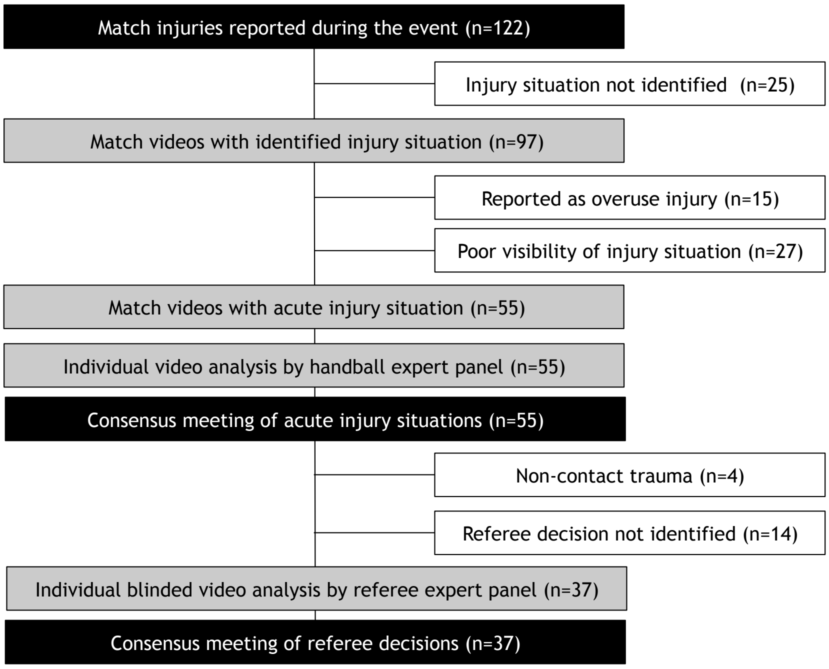


Figure 1 Study flow chart showing the number of match videos included in the analysis by the handball expert panel and by the referee expert panel.

Table 1 Causes observed for acute injuries (n=55)

Acute injury cause	Description	n (%)
Contact trauma	With opponent (tackle)	27 (49.1)
	With opponent (collision)	6 (10.9)
	With teammate (collision)	2 (3.6)
	With static object	1 (1.8)
	With moving object	6 (10.9)
Landing trauma following contact	With opponent (tackle)	8 (14.5)
	With opponent (collision)	1 (1.8)
Non-contact trauma	During running	3 (5.5)
	During landing	1 (1.8)

Table 2 Overall decisions made by the referees and in relation to possession of injured players (n=37)

Referees decisions	Attacker injured (n=22)		Defender injured (n=15)		Total (n=37)	
No foul	6	(27.3)	8	(53.3)	14	(37.8)
Free throw in favour	10	(45.5)[a]	2	(13.3)[b]	12	(32.4)
Free throw against	1	(4.5)[b]	2	(13.3)[a]	3	(8.1)
Penalty throw	-	-	-	-	-	-
Yellow card	-	-	-	-	-	-
Two-minute suspension[c]	5	(22.7)	3	(20.0)	8	(21.6)
Red card	-	-	-	-	-	-

Results are shown as n (%)

[a]defensive foul, [b]offensive foul, [c]all two-minute suspensions resulted in a free throw in favour of the attacking team (defensive foul)

Table 3 The decisions made by the referees versus the decisions made by the expert referee panel for acute injury situations (n=37)

	Referees					
Expert panel	No foul	Free throw[a]	Free throw[b]	Yellow card	Two-min suspension	Red card
No foul	8	1	1	-	-	-
Free throw[a]	-	2	-	-	-	-
Free throw[b]	-	-	-	-	-	-
Yellow card	2	3	-	-	1	-
Two-min suspension	3	6	2	-	4	-
Red card	1	0	-	-	3	-

[a]In favour of attacking team (defensive foul), [b]In favour of defending team (offensive foul)
The shaded cells denote agreement between the match referees and the expert panel

Appendix I

Literature searches performed to identify studies reporting on:

1. Injuries, risk factors and injury prevention in handball

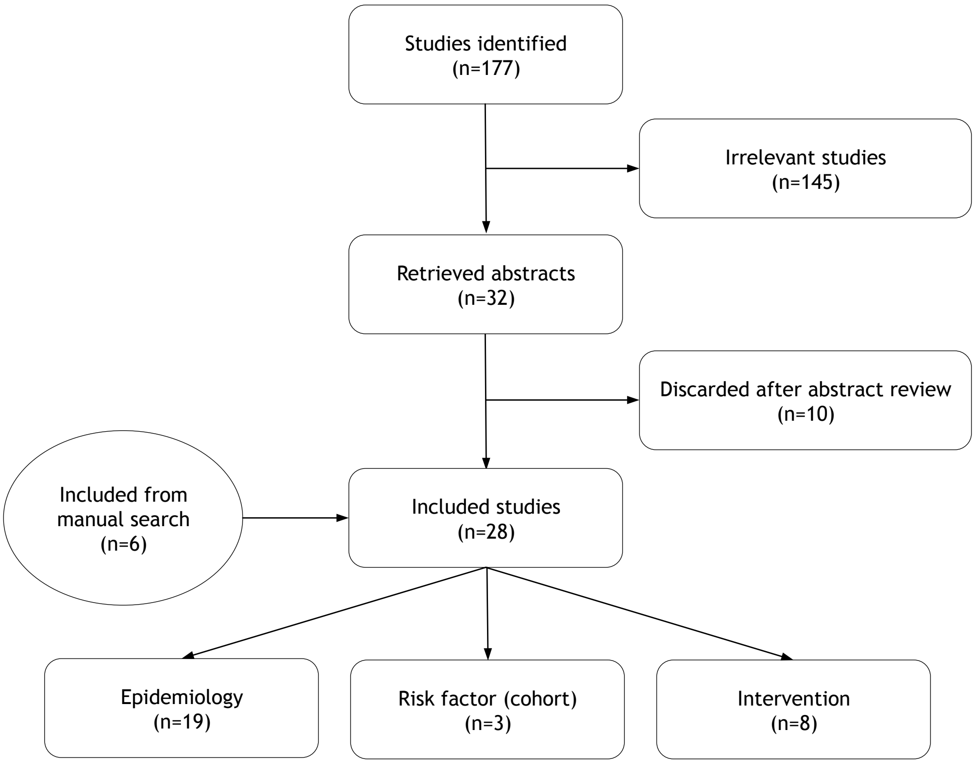
2. Modifiable risk factors for shoulder injuries in overhead sport

3. Exercises aiming to modify risk factors for shoulder injuries

Literature search 1

Injuries, risk factors and injury prevention in handball

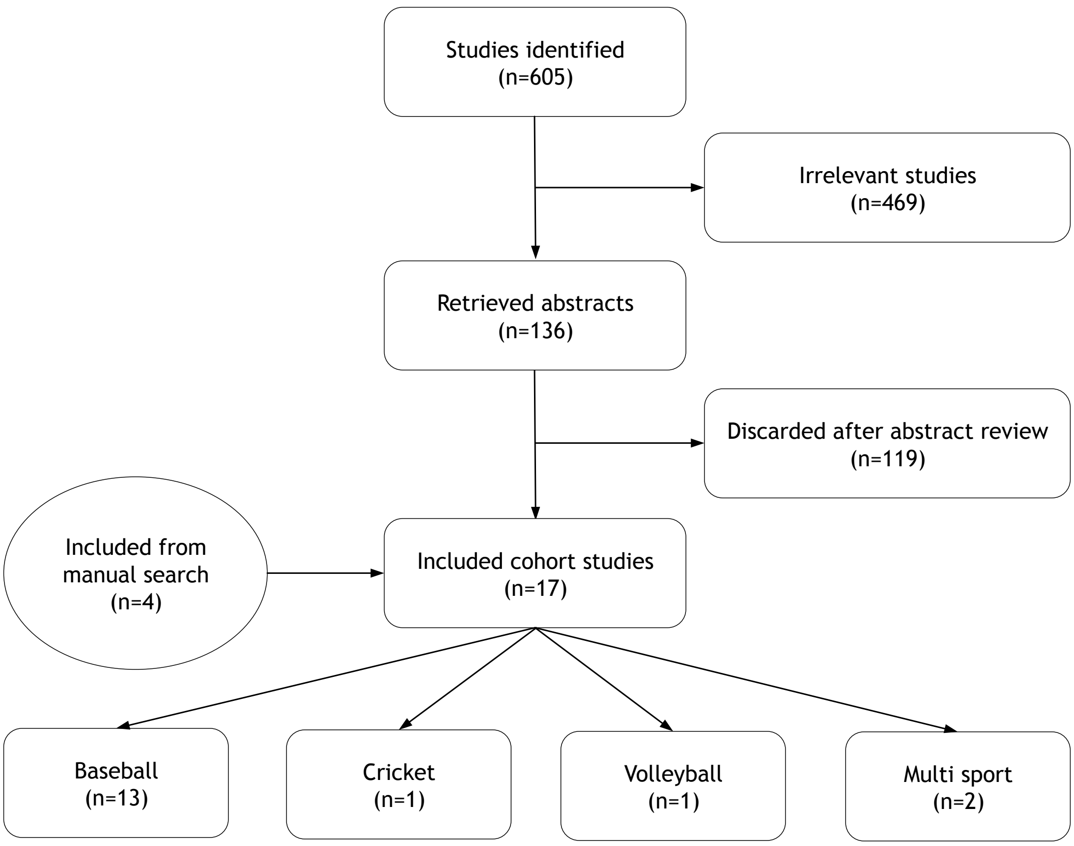
Search #1 (terms combined with OR)	Search #2 (terms combined with OR)
"handball"[Text]	"athletic injuries"[MeSH]
"handball players"[Text]	"athletic injuries"[Text]
Items found: 854	Items found: 24 393
Search #1 AND Search #2 AND "English"[lang] = 177	



Literature search 2

Modifiable risk factors for shoulder injuries in overhead sport

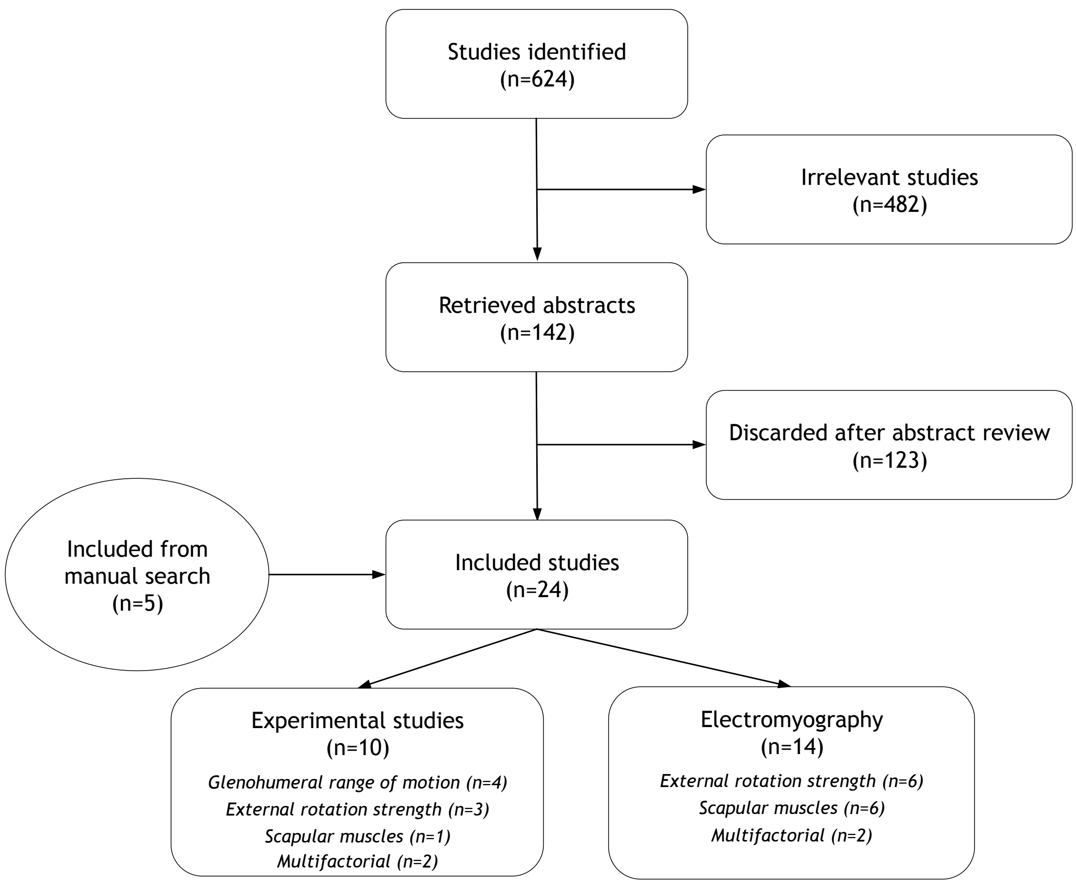
Search #1 (terms combined with OR)	**Search #2** (terms combined with OR)	**#Search 3** (terms combined with OR)
“shoulder”[MeSH]	“athletic injuries/epidemiology”[MeSH]	“badminton”[Text]
“shoulder joint”[MesH]	“baseball/injuries”[MeSH]	“baseball”[Text]
“shoulder”[Text]	“shoulder pain”[MeSH]	“cricket”[Text]
“glenohumeral joint”[Text]	“risk factors”[MeSH]	“lacrosse”[Text]
	“injury risk”	“softball”[Text]
		“tennis”[Text]
		“volleyball”[Text]
		“water polo”[Text]
Items found: 66 400	Items found: 732 838	Items found: 12 023
Search #1 AND Search #2 AND Search #3 AND “English”[lang] = 605		



Literature search 3 (performed 31.05.14)

Exercises aiming to modify risk factors for shoulder injuries

Search #1 (terms combined with OR)	**Search #2** (terms combined with OR)	**Search #3** (terms combined with OR	**Search #4** (terms combined with OR
“shoulder”[MeSH]	“external rotation”	“exercise therapy”[MeSH]	“muscle strength”[MeSH]
“shoulder joint”[MesH]	“external rotator muscles”	“exercise”	“muscle strength”
“shoulder”	“infraspinatus”	“training”	“strength increase”
“glenohumeral joint”	“internal rotation”	“stretching”	“muscle balance”
“posterior capsular”	“scapular muscle”		“strength ratio”
“scapula”[MeSH]	“serratus anterior”		“range of motion” [MeSH]
“scapula”	“trapezius”		“range of motion”
	“rotator cuff”		“dyskinesis”
			“electromyography”[MeSH]
Items found: 51 208	Items found: 17 430	Items found: 482 077	Items found: 168 522
Search #1 AND Search #2 AND Search #3 AND Search #4 AND “English”[lang] = 624			



Appendix II

Informed consent forms and decision letters from the Regional Committee for Medical and Health Research Ethics, the Norwegian Social Science Data Services, the Anti- Doping Lab Qatar Institutional Review Board, and the Aspire Zone Foundation Research Committee

FORESPØRSEL OM DELTAKELSE I PROSJEKTET:
"Forebygging av skulderproblemer blant elitehåndballspillere "

Kjære …………..,

Senter for idrettsskadeforskning ved Norges idrettshøgskole jobber med et nytt prosjekt for å redusere omfanget av skulderproblemer blant elitehåndballspillere.

Dette prosjektet vil være en videreføring av resultatene fra studien som ble gjennomført i Postenligaen for menn i løpet av 2011-2012 sesongen. Det ble her avdekket at skulderproblemer er et utbredt problem, og tiltak for å forebygge skulderproblemer bør iverksettes. I løpet av sesongen hadde gjennomsnittlig 30% av spillerne symptomer fra skulderen. De oppgav at de måtte redusere treningsmengden og opplevde at de ikke presterte optimalt. Det ble i tillegg gjennomført tester i forkant av sesongen for å undersøke hvilke faktorer som er assosiert med skulderproblemer. Vi ønsker å følge opp disse resultatene og undersøke effekten av et forebyggingsprogram på utbredelsen av skulderproblemer blant elite håndballspillere. Resultatene fra dette prosjektet vil være til stor nytte for norsk håndball, da skulderplager er et utbredt problem i håndball, i alle aldersklasser og hos begge kjønn.

Vi vil invitere dine utøvere til å delta i en studie hvor vi i løpet av en vanlig trening undersøker spillernes skulderstyrke, bevegelighet og koordinasjon. I tillegg vil vi måle spillernes skuddhastighet med laser. Spillerne vil bli testet av to erfarne fysioterapeuter fra Senter for Idrettsskadeforskning. Deretter vil vi registrere alle skulderplager de opplever i løpet av sesongen 2014-15, med hjelp av regelmessige spørreskjemaer. Halvparten av lagene som deltar i prosjektet vil bli instruert i et 8-10 minutters forebyggingsprogram som skal gjennomføres som en fast del av oppvarming til trening. De resterende lagene fortsetter aktivitet som normalt.

Spillerne får tilsendt en link til et spørreskjema på e-post annenhver uke, der vil utøveren få noen korte spørsmål om belastningsskader i skuldrene. Alle må fylle ut spørreskjemaene, uansett om de er skadet eller ikke. Det vil ta om lag 2 minutter å fylle ut skjemaet hver gang. Utøverne vil i spørreskjemaet også registrere hvor mye de trener og spiller håndball.

Dersom utøveren har fravær fra trening på grunn av skade eller sykdom vil en av oss ta kontakt med den skadde utøveren pr telefon for å gjennomføre et kort intervju.

Om du bestemmer deg for å delta i studien, skal ditt lags deltagelse være konfidensiell. Alle personlige data vil bli anonymisert etter at innsamlingen er over, og det skal ikke være mulig å identifisere verken individer eller lag i rapporter fra studien.

Angrer du på ditt lags deltagelse på noe som helst tidspunkt, kan du selvfølgelig trekke laget fra studien uten å måtte oppgi noen grunn, og uten konsekvenser. Alle data som er samlet inn til da vil i så fall bli anonymisert.

Vi håper du og laget ønsker å delta.

Hvis du vil ha mer informasjon om studien, kan vi kontaktes på telefonnummer 23 26 23 70 eventuelt på e-post grethe.myklebust@nih.no.

Med vennlig hilsen

Grethe Myklebust	Roald Bahr	Stig Haugsbø Andersson
Førsteamanuensis, Fysioterapeut dr. scient.	Professor dr. med.	Fysioterapeut, stipendiat

FORESPØRSEL OM DELTAKELSE I PROSJEKTET:
"Forebygging av skulderproblemer blant elitehåndballspillere – En randomisert kontrollert studie"

Bakgrunn for undersøkelsen
Belastningsskader i skulderleddet hos håndballspillere har i det siste vært et svært aktuelt tema, både i media og i forskningssammenheng. I en kartleggingsstudie vi gjennomførte i Postenligaen for menn i løpet av 2011-2012 sesongen fikk vi bekreftet at skulderproblemer er et utbredt problem, og at forebyggende tiltak er nødvendig. I løpet av sesongen hadde gjennomsnittlig 30% av spillerne symptomer fra skulderen. De oppgav at de måtte redusere treningsmengden og opplevde at de ikke presterte optimalt. Det ble i tillegg gjennomført tester i forkant av sesongen for å undersøke hvilke faktorer som er assosiert med skulderproblemer. Formålet med det kommende prosjektet vil være å følge opp disse resultatene og undersøke effekten av et forebyggingsprogram på utbredelsen av skulderproblemer blant elitehåndballspillere. Resultatene fra denne undersøkelsen vil være til stor nytte for norsk håndball, da skulderplager er et utbredt problem i håndball, i alle aldersklasser og hos begge kjønn.

Senter for idrettsskadeforskning er en forskningsgruppe bestående av fysioterapeuter, kirurger og biomekanikere med kunnskap innen idrettsmedisin. Vår hovedmålsetting er å forebygge skader i norsk idrett, med spesiell satsning på håndball, fotball, ski og snowboard. Denne studien er en viktig brikke i arbeidet med å redusere omfanget av skulderproblemer. Vi ønsker nå å undersøke effekten av et forebyggingsprogram som har til hensikt å redusere utbredelsen av skulderproblemer i de to øverste divisjonene for både menn og kvinner.

Gjennomføring av undersøkelsen
Vi ønsker at du som elitespiller deltar i denne studien, og deltakelsen er frivillig. Testingen vil finne sted på en vanlig trening høsten 2014. I løpet av en trening vil vi gjennomføre ulike styrke- og bevegelighetstester i skulderleddet, samt gjennomføre en bevegelsesanalyse av hvordan du kontrollerer skuldrene dine når du løfter armene. I tillegg vil vi måle hvor hardt du skyter med laser.

Testingen vil ta ca. 30 minutter. I tillegg til disse testene vil du få utdelt et skjema, der vi spør om treningserfaring og spilleposisjon, tidligere skader, og skulderfunksjon. Spørreskjemaet besvares på testdagen, og det vil ta ca. 10 min.

Behandling av testresultatene
Vi vil den neste sesongen følge opp alle lag og spillere som har deltatt på testingen, for å registrere alle skulderskader som oppstår. Dataene vil bli behandlet konfidensielt, og kun i forskningsøyemed. Alle som utfører testingen og forskere som benytter dataene er underlagt taushetsplikt.

Vi vil underveis i testingen ta bilder og video av dere som vi senere kan ønske å bruke i undervisnings- og formidlingssammenheng. Bildene og videoopptakene inkluderer situasjoner der herrespillerne kun har på shorts, mens kvinnespillerne har shorts og sports bh. Dersom dere ikke vil at deres videoopptak og bilder skal brukes krysser dere av for det i samtykkeerklæringen.

Hva får du ut av det?
Du vil få kopi av dine resultater fra styrketestene og lasermålingene som gjennomføres i løpet av testingen.

Angrer du?
Du kan selvfølgelig trekke deg fra forsøket når som helst uten å måtte oppgi noen grunn. Alle data som angår deg vil uansett bli anonymisert.

Spørsmål?
Ring gjerne til Grethe Myklebust, tlf.: 23 26 23 70 hvis du har spørsmål om prosjektet, eller send e-post til grethe.myklebust@nih.no

"Forebygging av skulderproblemer blant elitehåndballspillere – En randomisert kontrollert studie"

SAMTYKKEERKLÆRING

Jeg har mottatt skriftlig og muntlig informasjon om studien *"Forebygging av skulderproblemer blant elitehåndballspillere – En randomisert kontrollert studie"*. Jeg er klar over at jeg kan trekke meg fra undersøkelsen på et hvilket som helst tidspunkt.

☐ Jeg ønsker ikke at bilder og videoopptak av meg skal brukes i undervisningssammenheng

Sted ……………………….. Dato ………………………..

....
Underskrift

....
Navn med blokkbokstaver

....
Adresse

....
Mobiltelefon

....
E-postadresse

……………………………………………………
Eventuelt navn foresatt med blokkbokstaver

……………………………………………………
Underskrift foresatt

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK sør-øst	Anne S. Kavli	22845512	23.05.2014	2014/653/REK sør-øst A
			Deres dato:	**Deres referanse:**
			08.04.2014	

Vår referanse må oppgis ved alle henvendelser

Stig Haugsbø Andersson
Norges Idrettshøgskole

2014/653 Forebygging av skulderproblemer blant elitehåndballspillere

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst) i møtet 08.05.2014. Vurderingen er gjort med hjemmel i helseforskningsloven § 10, jf. forskningsetikklovens § 4.

Forskningsansvarlig: Norges Idrettshøgskole
Prosjektleder: Stig Haugsbø Andersson

Prosjektbeskrivelse

Formålet med prosjektet er å undersøke effekten av et forebyggende program på utbredelse av skulderproblemer blant elitehåndballspillere.

Skulderproblemer er utbredt hos denne gruppen idrettsutøvere. Det er tidligere vist at inntil 30 prosent av spillerne har måttet redusere treningsmengden og ikke har prestert optimalt på grunn av problemer med skuldre.

Det er utviklet et treningsprogram som skal utføres som en del av oppvarming, og man ønsker å undersøke effekten av dette forebyggingsprogrammet på forekomsten av skulderskader.

Det planlegges å inkludere 800 håndballspillere i de to øverste divisjonene for både kvinner og menn. Rekruttering skjer ved at trenerne i elite og første divisjon får tilsendt informasjon om prosjektet og en invitasjon til laget for å bli med i studien. Hvis treneren gir et positivt svar vil det informeres om prosjektet på trening og spillerne vil få utlevert informasjonsskriv med samtykkeerklæring.

Halvparten av lagene i utvalget gjennomfører et forebyggingsprogram som en fast del av oppvarmingen til trening, mens de resterende lagene fortsetter aktivitet som normalt. Skader vil registreres i begge gruppene.

Deltakere i studien skal gjennomgå en klinisk undersøkelse som innebærer måling av bevegelsesutslag i skulderleddet ved hjelp av digitalt inklinometer, måling av isometrisk styrke i skuldermuskulaturen ved bruk av dynamometer, måling av skuddhastighet ved hjelp av håndholdt lasermåler og vurdering av kontroll omkring skulderbladet ved observasjon og subjektiv vurdering.

I tillegg skal det det innsamles opplysninger ved hjelp av spørreskjema, film og bilder.

Komiteens vurdering

Formålet med prosjektet er å få mer kunnskap om skadeforebygging hos håndballspillere og tilrettelegge oppfølgingen av utøverne slik at de presterer best mulig. Deltakerne får god informasjon om hvorfor opplysningene hentes inn, hva de skal brukes til og at det er frivillig å delta.

Målet er ikke å oppnå ny kunnskap om diagnose eller behandling av sykdom, og deltakerne utsettes ikke for risiko eller belastning ved å delta i prosjektet.

Etter REKs vurdering faller dermed prosjektet, slik det er beskrevet, utenfor virkeområdet til helseforskningsloven. Helseforskningsloven gjelder for medisinsk og helsefaglig forskning på norsk territorium eller når forskningen skjer i regi av en forsknings-ansvarlig som er etablert i Norge.

Hva som er medisinsk og helsefaglig forskning fremgår av helseforskningsloven § 4 bokstav a hvor medisinsk og helsefaglig forskning er definert slik: "virksomhet som utføres med vitenskapelig metodikk for å skaffe til veie ny kunnskap om helse og sykdom", jf. helseforskningsloven §§ 2 og 4a. Formålet er avgjørende, ikke om forskningen utføres av helsepersonell, på pasienter eller benytter helseopplysninger.

Vedtak

Prosjektet faller utenfor helseforskningslovens virkeområde, jf. § 2, og kan derfor gjennomføres uten godkjenning av REK. Det er institusjonens ansvar på å sørge for at prosjektet gjennomføres på en forsvarlig måte med hensyn til for eksempel regler for taushetsplikt og personvern.

Komiteens vedtak kan påklages til Den nasjonale forskningsetiske komité for medisin og helsefag, jf. helseforskningsloven § 10, 3 ledd og forvaltningsloven § 28. En eventuell klage sendes til REK Sørøst A. Klagefristen er tre uker fra mottak av dette brevet, jf. forvaltningsloven § 29.

Med vennlig hilsen

Knut Engedal
Professor dr. med.
Leder

Anne S. Kavli
Førstekonsulent

Kopi til: grethe.myklebust@nih.no; postmottak@nih.no

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Harald Hårfagres gate 29
N-5007 Bergen
Norway
Tel: +47-55 58 21 17
Fax: +47-55 58 96 50
nsd@nsd.uib.no
www.nsd.uib.no
Org.nr. 985 321 884

Stig Haugsbø Andersson
Seksjon for idrettsmedisinske fag Norges idrettshøgskole
Postboks 4014 Ullevål Stadion
0806 OSLO

Vår dato: 24.03.2014 Vår ref: 38187 / 3 / LT Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 17.03.2014. Meldingen gjelder prosjektet:

38187	*Forebygging av skulderproblemer blant elitehåndballspillere*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Stig Haugsbø Andersson*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.08.2018, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Lis Tenold

Kontaktperson: Lis Tenold tlf: 55 58 33 77
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 38187

Dette prosjektet vil være en videreføring av resultatene fra studien som ble gjennomført i Postenligaen for menn i løpet av 2011-2012 sesongen. Det ble her avdekket at skulderproblemer er et utbredt problem, og tiltak for å forebygge skulderproblemer bør iverksettes. Det ble i tillegg gjennomført tester i forkant av sesongen for å undersøke hvilke faktorer som er assosiert med skulderproblemer. En ønsker å følge opp disse resultatene og undersøke effekten av et forebyggingsprogram på utbredelsen av skulderproblemer blant både mannlige og kvinnelige elitehåndballspillere i de to øverste divisjonene. Resultatene fra dette prosjektet vil være til stor nytte for norsk håndball, da skulderplager er et utbredt problem på tvers av alder og kjønn..

Utvalget informeres skriftlig og muntlig om prosjektet og samtykker til deltakelse. Informasjonsskrivet er godt utformet.

Personvernombudet finner i utgangspunktet iformasjonsskriv og samtykkeerklæring godt utformet, men forutsetter at det også opplyses om dato for anonymisering av innsamled opplysninger, her 01.08.2018. Revidert informasjonsskriv skal sendes til personvernombudet@nsd.uib.no før utvalget kontaktes.

Det behandles sensitive personopplysninger om helseforhold, .

Det benyttes Questback for innsamling av opplysninger via elektronisk spørreskjema. Personvernombudet legger til grunn at det foreligger en avtale mellom NIH og Questback som regulerer oppdraget, og om at kopi av avtalen ettersendes for arkivering (personvernombudet@nsd.uib.no). Personvernombudet legger til grunn at forsker etterfølger Norges idrettshøgskole sine interne rutiner for datasikkerhet. Dersom personopplysninger skal sendes elektronisk, bør opplysningene krypteres tilstrekkelig.

Forventet prosjektslutt er 01.08.2018. Ifølge prosjektmeldingen skal innsamlede opplysninger da anonymiseres. Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan gjenkjennes. Det gjøres ved å slette direkte personopplysninger (som navn/koblingsnøkkel) og slette/omskrive indirekte personopplysninger (identifiserende sammenstilling av bakgrunnsopplysninger som f.eks. bosted/arbeidssted, alder og kjønn),samt slette lyd- og videoopptak. Vi gjør oppmerksom på at også databehandler Questback må slette personopplysninger tilknyttet prosjektet i sine systemer. Dette inkluderer eventuelle logger og koblinger mellom IP-/epostadresser og besvarelser.

Anti- Doping Lab Qatar Institutional Review Board

Tel: 44132988
Fax: 44132997
Email: ADLQ-RO@adlqatar.com

IRB SCH Registration: SCH-ADL-070
SCH Assurance: SCH-ADL-A-071

APPROVAL NOTICE

Date	03/03/2015
Lead Principal Investigator	**Dr. Tone Bere**
IRB Application #	X2014000054
Protocol Title	**Injury & Illness Surveillance during the Handball World Championship**
Submission Type	**Re- Submission [after withdrawing initially]**
Review Type	**Expedited Review**
Approval Period	03/03/2015– 02/03/2016

The Anti-Doping Lab Qatar Institutional Review Board has reviewed and approved the above referenced protocol.

As the Principal Investigator of this research project, you are responsible for:

- Ethical Compliance and protection of the rights, safety and welfare of human subjects involved in this research project.
- To follow the policies and procedures as set by ADLQ-IRB in any matters related to the project, following the ADLQ-IRB approval (i.e., with regards to obtaining prior approval of any deviation of protocol, reporting of unanticipated events, and submission of progress reports).
- To inform the ADLQ-RO of the date of commencement of the research*.

مختبر مكافحة المنشطات قطر
Anti Doping Lab Qatar

Director – ORS/ADLQ (Office of Research Support)
Ms. Noor AlMotawa

** For Commencement of Research, Protocol Deviation Reporting, Unanticipated Problem Reporting & Research Progress Annual Report, please contact - Education & Research Office, Anti-Doping Lab Qatar.*

Subject: RE: EXTERNAL: Revision of the video analysis in elite male handball for the SJMSS
Date: Tuesday 21 November 2017 09 h 16 min 46 s Central European Standard Time
From: Marco Cardinale
To: Stig Haugsbø Andersson, Rodney Whiteley, Nebojsa Popovic, hansen.clint@gmail.com, fsanz79@yahoo.es, Tone Bere
CC: Roald Bahr, Grethe Myklebust

Here is the AZF Approval

From: Pitre Bourdon
Sent: Sunday, December 13, 2015 5:28 PM
To: Marco Cardinale
Cc: Farah Abughaida
Subject: Research Committee Decision - M Cardinale

Dear Marco,

To follow is a summary of the ASPIRE Research Committee's decision on the research project you presented at their last meeting:

Proposal Title: "Time-Motion characteristics of elite handball players competing in the World Championships in Qatar 2015"

Principal Investigator: Dr Marco Cardinale

Research Committee Recommendation: Accepted with no modifications
Comments for your consideration:
•Data such as this ideally must inform practice. It is suggested that the Researchers from Aspire/Aspetar should speak with the QHA to discuss application of these data for preparing for Rio

If you have any questions about this decision or the process from here please feel free to contact me.

Kind regards,

Pitre

Pitre Bourdon PhD
Head of Research and Quality Assurance
ASPIRE Academy
PO Box 22287, Doha, Qatar
www.aspire.qa
Phone: (+974) 4413 6694
Mobile: (+974) 3345 2435
Fax: (+974) 4413 6190
Email: pitre.bourdon@aspire.qa
Skype: pitre.bourdon

الدكتور ماركو كاردينال

Appendix III

Baseline questionnaire including a modified version of the Fahlström questionnaire and the Oslo Sports Trauma Research Center Overuse Injury Questionnaire

Skulderstudien 2014-2015(1)

1) Navn?

2) Fødselsdato?

3) Mobil nummer?

4) Mail adresse?

5) Klubb?

6) Drakt nummer?

7) Høyde?

8) Vekt?

9) Dominant arm/skuddarm?

- Høyre
- Venstre

10) År som håndballspiller?

11) Ar som spiller i eliteserien?

12) År som spiller i 1.divisjon?

13) Landslagsspiller?

- Ja
- Nei

14) År som landslagsspiller?

15) Spillerposisjon?

- Målvakt
- Venstre kant
- Venstre bak
- Midt bak
- Høyre bak
- Høyre kant
- Linje

16) Har du gjennomgått skulder- og/eller nakkeoperasjon i løpet av de siste 12 månedene?

- Ja
- Nei

17) Vennligst spesifiser eventuell operasjon siste 12 måneder

18) Har du hatt en eller flere av følgende akutte skader i løpet av siste 6 måneder?

- SLAP lesjon (labrumskade/leddleppe skade)
- Luksasjon av skulder (ute av ledd)
- Luksasjon av albue (ute av ledd)
- Fraktur/brudd i albue, overarm eller skulder
- Prolaps i nakken

19) Hadde du vondt/smerter i din dominante skulder/skuddarm i løpet av forrige sesong (2013-2014)?

- Ja
- Nei

20) Har du vondt/smerter i din dominante skulder (skuddarm) akkurat nå?

- Ja
- Nei

Vi ønsker at du skal besvare alle spørsmålene uavhengig av om du har problemer med eller smerter i skuldrene. Svar ved å velge det svaralternativet som du synes passer best. Om du er usikker på hva du skal svare, forsøk likevel å svare så godt du kan.

Med skulderproblemer menes smerter, verking, stivhet, slark eller andre plager i en eller begge skuldre.

Her vil vi spørre om din dominante skulder (den du pleier å kaster/skyte med). Tenk på hvordan den skulderen som plager deg mest har vært de siste 7 dagene når du svarer.

24) Har du vansker med å spille håndball (vanlig trening/konkurranse) på grunn av problemer med din dominante skulder (skuddarm)?

- Deltatt for fullt uten skulderproblemer
- Deltatt for fullt, men med skulderproblemer
- Redusert deltakelse, på grunn av skulderproblemer
- Har ikke kunnet delta på grunn av skulderproblemer

25) I hvilken grad har du redusert treningsmengden på grunn av problemer med din dominante skulder?

- Ingen reduksjon
- I liten grad
- I moderat grad
- I stor grad
- Har ikke kunnet delta

26) I hvilken grad opplever du at problemer med din dominante skulder påvirker prestasjonsevnen i håndball (kamp/trening)?

- Ingen påvirkning

- I liten grad
- I moderat grad
- I stor grad
- Har ikke kunnet delta

27) I hvilken grad opplever du smerte i din dominante skulder i forbindelse med håndball deltagelse?

- Ingen smerte
- I liten grad
- I moderat grad
- I stor grad

Appendix IV

The Oslo Sports Trauma Research Center
Shoulder Injury Prevention Programme

The OSTRC Shoulder Injury Prevention Programme

The programme consist of five exercises completed three times per week during the warm-up, prior to throwing activity. The five exercises change every six weeks.

At start-up, follow the recommended load and number of repetitions.
Progress by increasing the number of repetitions, change to a stiffer elastic band or use a small weight or weight ball as external resistance.

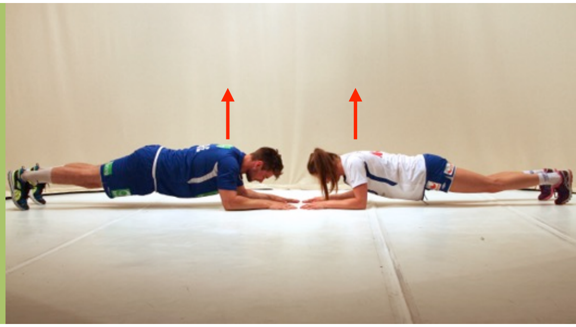
Reduce load and seek medical attention if you experience shoulder pain during the exercises.

Oslo Sports Trauma
RESEARCH CENTER

Oslo Sports Trauma
RESEARCH CENTER

EXERCISE 1

Week 1-6

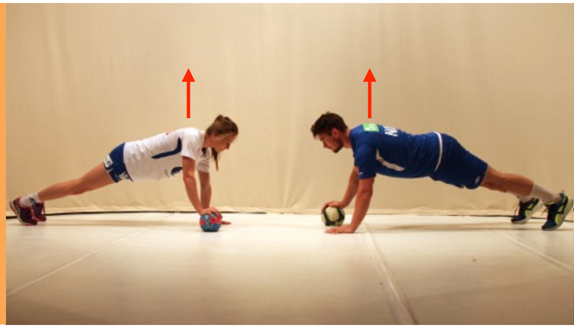


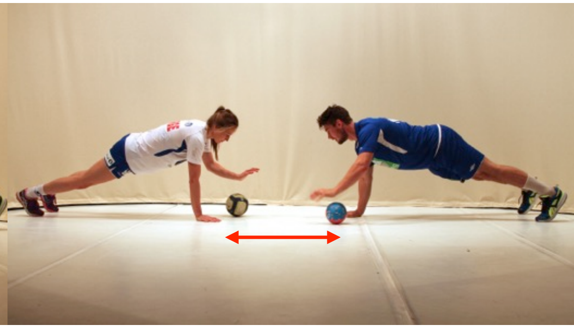
__Trunk rotation__

Push-up plus position* on elbows
Alternating trunk rotation

3 x 8-16 reps

Week 7-12



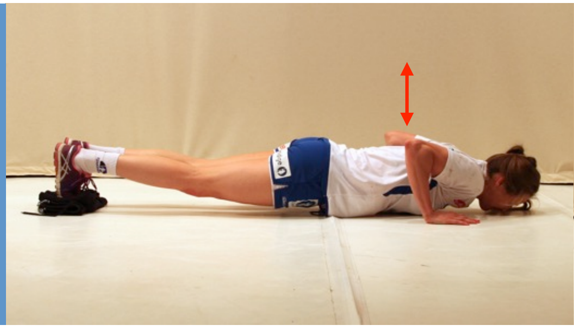


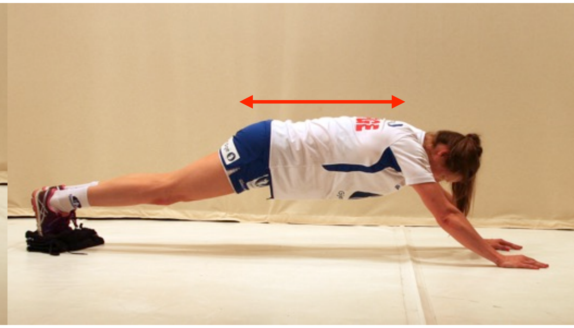
__Plank with passing__

Pair exercise
Push-up plus position*
Players roll ball to each other
Alternating hands

3 x 8-16 reps

Week 13-18





__Push-up plus with backward slide__

Push-up plus*
Slide backwards
Maintain neutral spine
Return to start position

3 x 8-16 reps

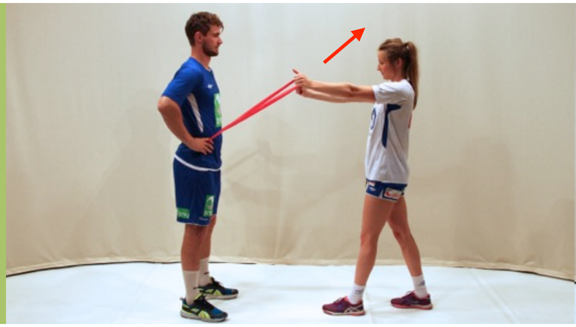
After week 18: choose between the different variations

** The push-up plus position is achieved by pushing hands/elbows towards the floor by pushing your shoulder blades forward and out.*

Oslo Sports Trauma
RESEARCH CENTER

EXERCISE 2

Week 1-6



Standing Y-flies*

Pair exercise
Lift chest, draw shoulders back/down
Pull the elastic with straight arms towards the ceiling in a Y-position

3 x 8-16 reps

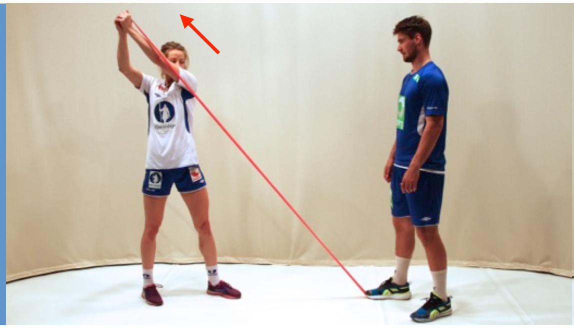
Week 7-12

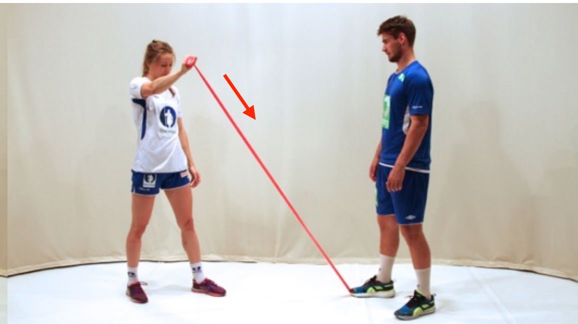
Bow and arrow*

Pair exercise
Start by drawing shoulder back/down
Follow through with arm and trunk rotation

3 x 8-16 reps

Week 13-18





Slow arm lowering*

Pair exercise
Tighten elastic with 2 hands to maximum throwing position
Return slowly with one hand (3 seconds)

3 x 8-16 reps

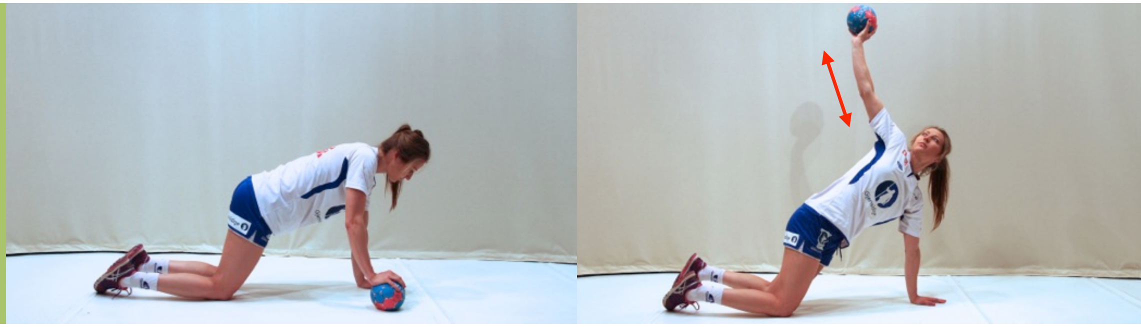
After week 18: choose between the different variations

** Pre-position your shoulders before starting the exercise by lifting your chest and pulling your shoulder blades slightly back and down*

Oslo Sports Trauma
RESEARCH CENTER

EXERCISE 3

Week 1-6



__Trunk rotation__

Alternating trunk rotation
Point hand towards ceiling

3 x 8-16 reps

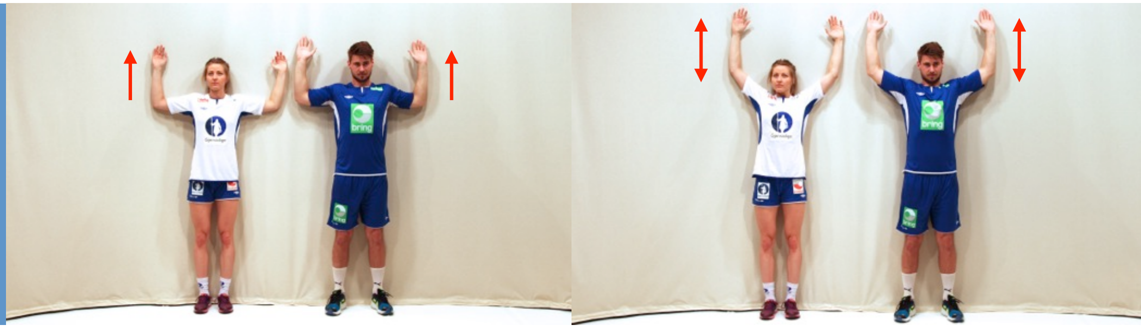
Week 7-12

__Dynamic latissimus dorsi stretch__

Stand with elbows against wall
Slide arms upwards
Keep forearms vertical
Maintain neutral spine

3 x 8-16 reps

Week 13-18



__Dynamic W-stretch__

Slide arms upwards
Keep forearms, head and spine against wall

3 x 8-16 reps

After week 18: choose between the different variations

Oslo Sports Trauma
RESEARCH CENTER

EXERCISE 4

Week 1-6 / 13-18

Sleeper stretch

Lie on your shoulder blade to stabilise it
Keep shoulder slightly under 90°
Push hand downwards towards floor
(internal rotation)

3 x 30 seconds

Week 7-12 / 18-24

Cross-body stretch

Pair exercise
Keep shoulder slightly under 90°
Partner stretch the elbow across body and prevents shoulder blade from moving

3 x 30 seconds

After week 24: choose between the two variations

Oslo Sports Trauma
RESEARCH CENTER

EXERCISE 5

Week 1-6

*External rotation**

Keep the elbow and shoulder in 90°
Use a ball or small weight as resistance

3 x 10-20 reps

Week 7-12

*Drop and catch**

Keep the elbow and shoulder in 90°
Drop the ball and catch it quickly
Return to start position
Use a ball or small weight as resistance

3 x 10-20 reps

Week 13-18

*Backwards throw**

Pair exercise
Partner throws a ball from behind
Catch the ball and throw it back using backwards rotation of the shoulder
Progress by using a weighted ball

3 x 10-20 reps

After week 18: choose between the different variations

** Pre-position your shoulders before starting the exercise by lifting your chest and pulling your shoulder blades slightly back and down*

Appendix V

The Oslo Sports Trauma Research Center

Overuse Injury Questionnaire

(Two versions: Intervention and control group)

Norges Håndballforbund | SENTER FOR Idrettsskadeforskning KLOKE AV SKADE

Skulderstudien 2014-2015 - SISTE 7 DAGER (I)

Vi ønsker at du skal besvare alle spørsmålene uavhengig av om du har problemer eller smerter i din dominante skulder (skuddarm). Med skulderproblemer menes smerter, verking, stivhet, slark eller andre plager i din dominante skulder.

Her vil vi spørre om din dominante skulder (den du pleier å kaste/skyte med). Tenk på hvordan din dominante skulder har vært den siste uken (7 dagene) når du svarer.

Navn:

Klubb:

Dato:

Har du hatt vansker med å spille håndball (vanlig trening/konkurranse) på grunn av problemer med din dominante skulder (skuddarm)?

- ○ Deltat for fullt uten skulderproblemer
- ○ Deltat for fullt, men med skulderproblemer
- ○ Redusert deltakelse, på grunn av skulderproblemer
- ○ Har ikke kunnet delta på grunn av skulderproblemer

I hvilken grad har du redusert treningsmengden på grunn av problemer med din dominante skulder?

- ○ Ingen reduksjon
- ○ I liten grad
- ○ I moderat grad
- ○ I stor grad
- ○ Har ikke kunnet delta

I hvilken grad har du opplevd at problemer med din dominante skulder har påvirket prestasjonsevnen i håndball (kamp/trening)?

- ○ Ingen påvirkning
- ○ I liten grad
- ○ I moderat grad
- ○ I stor grad
- ○ Har ikke kunnet delta

I hvilken grad har du opplevd smerte i din dominante skulder i forbindelse med håndball deltagelse?

- Ingen smerte
- I liten grad
- I moderat grad
- I stor grad

Har du hatt en akutt skade (skade som oppstod som følge av en enkelt skadesituasjon, f.eks: takling) i din dominante skulder (skuddarm) den siste uken?

- Yes
- No

Krevde den akutte skaden medisinsk tilsyn fra lege/fysioterapeut eller annet helsepersonell?

- Ja
- Nei

Oppstod den akutte skaden under håndballaktivitet (trening/kamp)?

- Ja
- Nei

Hvor mange timer har du trent håndball med laget den siste uken?

Hvor mange kampminutter (håndball) har du spilt den siste uken?

Hvor mange minutter styrke- og/eller stabilitetstrening som involverer skulder og arm har du gjennomført den siste uken?

Hvor mange ganger har du gjennomført skulderprogrammet <u>sammen med laget</u> den siste uken?

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

Hvor mange ganger har du gjennomført skulderprogrammet <u>på egenhånd</u> den siste uken?

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

Norges Håndballforbund | SENTER FOR Idrettsskadeforskning KLOKE AV SKADE

Skulderstudien 2014-2015 - SISTE 7 DAGER (C)

Vi ønsker at du skal besvare alle spørsmålene uavhengig om du har problemer eller smerter i din dominante skulder (skuddarm). Med skulderproblemer menes smerter, verking, stivhet, slark eller andre plager i din dominante skulder.

Her vil vi spørre om din dominante skulder (den du pleier å kaste/skyte med). Tenk på hvordan din dominante skulder har vært den siste uken (7 dagene) når du svarer.

Navn:

____

Klubb:

____

Dato:

____

Har du hatt vansker med å spille håndball (vanlig trening/konkurranse) på grunn av problemer med din dominante skulder (skuddarm)?

- ◯ Deltat for fullt uten skulderproblemer
- ◯ Deltat for fullt, men med skulderproblemer
- ◯ Redusert deltakelse, på grunn av skulderproblemer
- ◯ Har ikke kunnet delta på grunn av skulderproblemer

I hvilken grad har du redusert treningsmengden på grunn av problemer med din dominante skulder?

- ◯ Ingen reduksjon
- ◯ I liten grad
- ◯ I moderat grad
- ◯ I stor grad
- ◯ Har ikke kunnet delta

I hvilken grad har du opplevd at problemer med din dominante skulder har påvirket prestasjonsevnen i håndball (kamp/trening)?

- ◯ Ingen påvirkning
- ◯ I liten grad
- ◯ I moderat grad
- ◯ I stor grad
- ◯ Har ikke kunnet delta

I hvilken grad har du opplevd smerte i din dominante skulder i forbindelse med håndball deltagelse?

- Ingen smerte
- I liten grad
- I moderat grad
- I stor grad

Har du hatt en akutt skade (skade som oppstod som følge av en enkelt skadesituasjon, f.eks: takling) i din dominante skulder (skuddarm) den siste uken?

- Yes
- No

Krevde den akutte skaden medisinsk tilsyn fra lege/fysioterapeut eller annet helsepersonell?

- Ja
- Nei

Oppstod den akutte skaden under håndballaktivitet (trening/kamp)?

- Ja
- Nei

Hvor mange timer har du trent håndball med laget den siste uken?

Hvor mange kampminutter (håndball) har du spilt den siste uken?

Hvor mange minutter styrke- og/eller stabilitetstrening som involverer skulder og arm har du gjennomført den siste uken?

Appendix VI

Video analysis form used in the analysis of acute injuries during the 24th Men's Handball World Championship 2015 in Qatar

Video analysis of acute injuries during the 24th Men´s Handball World Championship 2015 in Qatar

Analyst: Date:

Injury information (pre-filled based on injury registration)

Injury nr:
Team:
Opponent:
Player nr:

Position:
- Back ☐
- Goalkeeper ☐
- Pivot/line ☐
- Wing ☐
- Not available ☐

Match time: ___________________
Video time: ___________________

Notes:

Body part:
- Abdomen ☐
- Ankle ☐
- Elbow ☐
- Face ☐
- Finger ☐
- Foot/toe ☐
- Groin ☐
- Head ☐
- Hip ☐
- Knee ☐
- Lower leg ☐
- Lumbar spine ☐
- Neck ☐
- Pelvis/sacrum ☐
- Shoulder/clavicle ☐
- Sternum/ribs ☐
- Thigh ☐
- Thumb ☐
- Upper arm ☐
- Wrist ☐

Please correct any pre-filled information above you disagree with, or is missing, after analyzing the video!

Fill in for ALL INJURIES - Playing situation and injury type

Possession
- Attack ☐
- Turnover attack ☐
- Defense ☐
- Turnover defense ☐

Injured side
- Right ☐
- Left ☐
- Unsure/not relevant ☐

Playing position
- Back ☐
- Wing ☐
- Pivot/line ☐
- Goalkeeper ☐
- Mid defense ☐

Injury type (tick off only 1 option)

1.Contact trauma
- *With opponent, tackle* ☐
- *With teammate, collision* ☐
- *With static object, e.g. post* ☐
- *With moving object, e.g. handball* ☐

2. Landing trauma with preceding contact
- *Preceding contact with opponent, tackle* ☐
- *Preceding contact with teammate, collision* ☐

3.Non-contact trauma
- *Running* ☐
- *Cutting* ☐
- *Jumping* ☐
- *Landing without preceding contact* ☐
- *Other:*_____________________________ ☐

Court position
- Between center line and the 9m line own side ☐
- Between center line and the 9m line opponents side ☐
- Between the 6m and 9m line own side ☐
- Between the 6m and 9m line opponents side ☐
- Within the 6m line own side ☐
- Within the 6m line opponents side ☐
- Outside playing court ☐

Only fill in if INJURY ATTACKING PLAYER					
Action attacking/injured player			**Movement of main defending opponent**	□	N/R
Cutting movement	□		Directly towards attacking player	□	
Shot on target from the ground	□		From the side towards attacking player	□	
Shot on target while jumping	□		Static in front of attacking player	□	
Run towards target	□		Follows the attacking player	□	
Dribbles towards target	□		Comes from behind the attacking player	□	
Receives pass from teammate	□				
Passes to teammate from the ground	□		**Defending opponent tackles with**	□	N/R
Passes to teammate while jumping	□		Head	□	
Other:____________________________	□		Shoulder	□	
			Arm(s) flexed	□	
Ball possession attacking player			Arm(s) extended	□	
>5 seconds	□		Elbow		
<5 seconds	□		Hand(s)	□	
Receives ball <1 second	□		Abdomen/thorax	□	
No ball possession	□		Hip	□	
			Knee	□	
Action defending opponent	□	N/R	Leg	□	
Tackles to the face/head	□		Foot	□	
Tackles to the neck	□				
Tackles to the shoulder	□		**Evaluation of tackle**	□	N/R
Tackles to the throwing arm - upper	□		Clean	□	
Tackles to the throwing arm - lower	□		Violation of rules	□	
Tackles to the throwing arm - hand	□		Unsure	□	
Tackles to the ball	□				
Tackles to the abdomen	□		**Is attacking player aware of defenders position**	□	N/R
Tackles to the hip	□		Yes	□	
Tackles to the thigh	□		No	□	
Other:_____________________________	□		Unsure	□	
Multiple defenders involved in tackle	□	N/R	**Velocity of tackle**	□	N/R
No, mainly one defender	□		High velocity	□	
Yes, two defenders	□		Low velocity	□	
Yes, >two defenders	□		Unsure	□	

Only if tackled by opponent (contact trauma)		Only if landing trauma after preceding contact	
Is the tackle to the pre-registered injured body part?		**Does the player land on the pre-registered injured body part?**	
Yes, specify:_________________________________	□	Yes, specify:__________________________________	□
No, specify:_________________________________	□	No, specify:___________________________________	□
Unsure	□	Unsure	□

N/R = Not relevant

Only fill in if INJURY DEFENDING PLAYER

Action attacking opponent

Cutting movement □
Shot on target from the ground □
Shot on target while jumping □
Run towards target □
Dribbles towards target □
Receives pass from teammate □
Passes to teammate from the ground □
Passes to teammate while jumping □
Other:_____________________________ □

Ball possession attacking opponent

>5 seconds □
<5 seconds □
Receives ball <1 second □
No ball possession □

Action defending/injured player

Tackles to the face/head □
Tackles to the shoulder □
Tackles to the throwing arm - upper □
Tackles to the throwing arm - lower □
Tackles to the throwing arm - hand □
Tackles to the ball □
Tackles to the abdomen □
Tackles to the hip □
Tackles to the thigh □
Blocking while jumping □
Other:______________________________ □

Multiple defenders involved in tackle

No, mainly one defender □
Yes, two defenders □
Yes, >two defenders □

Movement of main defending opponent

Directly towards attacking player □
From the side towards attacking player □
Static in front of attacking player □
Follows the attacking player □
Comes from behind the attacking player □

Defending/injured player gets hit to the □ N/R

Face/head □
Shoulder □
Upper arm □
Lower arm □
Hand □
Abdomen □
Thorax □
Hip □
Knee □
Leg □
Foot □

Attacking player hits the defender with □ N/R

The face/head □
The shoulder □
The throwing arm □
The elbow □
The hand □
The ball □
The abdomen □
The hip □
The thigh □
The knee □
The foot □

Evaluation of tackle □ N/R

Clean □
Violation of rules □
Unsure □

Is attacking player aware of defenders position □ N/R

Yes □
No □
Unsure □

Velocity of tackle □ N/R

High velocity □
Low velocity □
Unsure □

Only if landing trauma after preceding contact

Does the player land on the pre-registered injured body part?

Yes, specify: ________________________ □
No, specify:_________________________ □
Unsure □

N/R = Not relevant

Only if INJURY TO HEAD/FACE	
Injury situation	
Tackled by defending opponent during attack/turnover attack	☐
Hit by attacking player during defense/turnover defense	☐
Hit by ball during attack/turnover attack	☐
Hit by ball during defense/turnover defense	☐
Hit to head during landing in attack/turnover attack	☐
Hit to head during landing in defense/turnover defense	☐
Other:____	☐
Localization of the hit/tackle/landing	
Straight to the head/face	☐
Left side of the head	☐
Right side of the head	☐
Front of the neck	☐
Back of the head/neck	☐
Top of the head	☐
Other:_______________________________	☐
Visual consequences	
Medical attention on the court is needed	
Yes	☐
No	☐
Unsure	☐
Injured player leaves the court	
Yes, on his own	☐
Yes, with assistance from the medical team	☐
Yes, followed by the medical team	☐
No	☐
Unsure	☐

Only if INJURY TO THE KNEE			

Only if landing trauma after preceding contact or after non-contact trauma			
Landing situation	☐	**Landing on 1 or 2 feet**	
Lands on the ground	☐	Lands primarily on 1 foot (involved)	☐
Lands on opponents foot	☐	Lands relatively on both feet	☐
Lands on teammates foot	☐	Lands primarily on one foot (uninvolved)	☐
Lands on ball	☐	Other:___________________________	☐
Other:___________________________	☐		
Balance during landing			
Relatively balanced	☐		
Relatively unbalanced	☐		
Other:___________________________	☐		

Only if non-contact trauma: running, cutting or jumping (not landing)			
Situation		**Contact with the ground**	
Running	☐	Contact with primarily 1 foot (involved)	☐
Cutting	☐	Contact relatively with both feet	☐
Jumping	☐	Contact with primarily 1 foot (uninvolved)	☐
Other:___________________________	☐	Other:_____________________________	☐

Only if contact trauma (tackled by opponent or collision with teammate)			
Applied forces to the knee			
From the front/anterior	☐		
From the outside/lateral	☐		
From the inside/medial	☐		
From behind/posterior	☐		
Unsure	☐		

All knee injuries - Knee position at initial contact with ground, player or ball			
Flexed/extended		**Rotated?**	
Flexed	☐	Tibia external rotated	☐
Neutral	☐	Tibia internal rotated	☐
Hyperextended	☐	Neutral	☐
Unsure	☐	Unsure	☐
Valgus/varus?			
Relatively in valgus	☐		
Relatively in varus	☐		
Neutral	☐		
Unsure	☐		

All knee injuries - Knee movement from initial contact to time of injury			
Flexion/extension?		**Rotation?**	
Towards flexion	☐	External rotation of tibia	☐
Towards extension	☐	Internal rotation of tibia	☐
Static	☐	Static	☐
Unsure	☐	Unsure	☐
Valgus/varus?			
Towards valgus	☐		
Towards varus	☐		
Static	☐		
Unsure	☐		

Only if INJURY TO THE ANKLE			
Only if landing trauma after preceding contact or after non-contact trauma			
Landing situation	☐	**Landing on 1 or 2 feet**	
Lands on the ground	☐	Lands primarily on 1 foot (involved)	☐
Lands on opponents foot	☐	Lands relatively on both feet	☐
Lands on teammates foot	☐	Lands primarily on one foot (uninvolved)	☐
Lands on ball	☐	Other:____________________________	☐
Other:____________________________	☐		
Balance during landing			
Relatively balanced	☐		
Relatively unbalanced	☐		
Other:____________________________	☐		
Only if non-contact, running, cutting or jumping (not landing)			
Situation		**Contact with the ground**	
Running	☐	Contact with primarily 1 foot (involved)	☐
Cutting	☐	Contact relatively with both feet	☐
Jumping	☐	Contact with primarily 1 foot (uninvolved)	☐
Other:____________________________	☐	Other:______________________________	☐
Only if contact trauma (tackled by opponent or collision with teammate)			
Applied forces to the ankle			
From the front/anterior	☐		
From the outside/lateral	☐		
From the inside/medial	☐		
From behind/posterior	☐		
Unsure	☐		
All ankle injuries - Ankle position at initial contact with ground, player or ball			
Plantar/dorsal flexed?		**Inverted/everted?**	
Plantar flexed	☐	Inverted	☐
Relatively neutral	☐	Relatively neutral	☐
Dorsal flexed	☐	Everted	☐
Unsure	☐	Unsure	☐
All ankle injuries - Ankle movement from initial contact to time of injury			
Plantar/dorsal movement?		**Inversion/eversion movement?**	
Towards dorsal flexion	☐	Toward inversion	☐
Towards plantar flexion	☐	Toward eversion	☐
Static	☐	Static	☐
Unsure	☐	Unsure	☐

Please describe the playing situation preceding the injury in your own words, outlining any factors which may cause the injury situation.

Please describe the injury mechanism in your own words.

Stig Haugsbø Andersson // Injury prevention in elite handball