

No Added Benefit of 8 Weeks of Shoulder External Rotation Strength Training for Youth Handball Players Over Usual Handball Training Alone: A Randomized Controlled Trial

The prevalence of shoulder problems in handball is high (23%–41%), both among senior and adolescent players.^{1,2,4,7,11,28,31} The problems often persist, and players continue to play despite shoulder pain.^{7,31} Overuse shoulder problems are the most common overuse injury in handball.^{1,4,17,21}

It is possible to prevent shoulder injuries in handball. There was a 28% reduction in the prevalence of shoulder problems after implementing the Oslo Sports Trauma Research Center

(OSTRC) shoulder injury prevention program.⁴ However, adherence to the program was low. Players and coaches reported that program length and poor motivation were the main barriers

to completing the OSTRC program.⁶ Our Norwegian colleagues encouraged research to evaluate the effect of the exercises in the OSTRC program on the specific risk factors their exercises targeted, to identify plausible ways to shorten the program.⁶ External rotation (ER) strength is a modifiable risk factor for shoulder injuries in handball.^{2,5,8,15,30} Although effective in preventing shoulder injuries, the OSTRC shoulder injury prevention program did not affect ER strength.¹⁸

To find the most effective ER strength exercises handball players would likely adhere to, we conducted a Delphi consensus study involving 16 international experts in shoulder research, shoulder rehabilitation, handball, or strength training.¹⁹ We developed a short shoulder ER strength program for handball players based on the opinions of the shoulder experts. The purpose of our trial was to assess whether the program was effective in adolescent handball players. We hypothesized that adding a short shoulder ER strength program, using elastic bands, would increase shoulder ER strength in

● **OBJECTIVE:** To assess the effectiveness of a short (5–10 minutes) shoulder external rotation (ER) strength program, using elastic bands, in adolescent handball players.

● **DESIGN:** Randomized controlled trial.

● **METHODS:** The sample included 6 adolescent handball teams (3 female, 3 male) with a total of 92 players and a mean age of 16.6 years. Players were randomized within teams to an intervention group, which completed a shoulder ER strengthening program of 2 exercises performed 3 times per week after handball training for 8 weeks, or a control group of no treatment. The primary outcome was the between-group difference in shoulder ER strength change, measured as isometric strength using a handheld dynamometer from preintervention to postintervention (8 weeks). Secondary out-

comes were between-group differences in internal rotation (IR) strength and the ER/IR strength ratio from preintervention to postintervention.

● **RESULTS:** The estimated between-group difference in dominant-shoulder ER strength was 0.06 N/kg (95% confidence interval [CI]: –0.01, 0.14) in favor of the intervention group. The estimated between-group differences in the ER/IR ratio and IR strength were 0.03 (95% CI: –0.02, 0.08) and 0.02 (95% CI: –0.08, 0.13), respectively.

● **CONCLUSION:** The ER strength program improved neither the ER strength nor the ER:IR ratio. *J Orthop Sports Phys Ther* 2021;51(4):174–187. doi:10.2519/jospt.2021.9957

● **KEY WORDS:** external rotation strength, handball, shoulder

¹Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway. ²Department of Rehabilitation Sciences and Physiotherapy, Ghent University, Ghent, Belgium. The South-Eastern Norway Regional Committee for Medical and Health Research Ethics (2019/28912/REK sør-øst) approved this study. The trial was registered in the International Standard Randomized Controlled Trial Number registry (ISRCTN19694168). 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 and Confederation of Sport, and Norsk Tipping AS. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Hilde Fredriksen, Sognsveien 220, 0863 Oslo, Norway. E-mail: hilde.fredriksen@nih.no • Copyright ©2021 JOSPT®, Inc

adolescent handball players compared to usual training.

METHODS

THIS RANDOMIZED CONTROLLED TRIAL was registered in the International Standard Randomized Controlled Trial Number registry (ISRCTN19694168) and was reported according to the Consolidated Standards for Reporting Trials (CONSORT) statement.²⁷ The 8-week intervention took place from October to December 2019. The main investigator was blinded to group allocation until data collection was complete. Given the nature of the intervention, it was impossible to blind the players, coaches, or physical therapists who provided the intervention program.

Participants

During May to June 2019, we invited all handball teams ($n = 48$ teams; age range of players, 16-18 years) within or close to Oslo, Norway to participate in our trial. To be included, each team had to have at least 12 players. Of the 48 invited teams, 25 teams were eligible (11 male teams, 14 female teams). A person not otherwise involved in the project randomly selected 3 male and 3 female teams using opaque, sealed envelopes containing the name of each team. After the inclusion, coaches from 1 male and 1 female team reported that several players had quit after the team had agreed to participate in the study, which resulted in fewer than 12 players on the team. These teams were excluded and were replaced by another male and female team, randomly selected as described (FIGURE 1).

There were 14 to 21 players on the included teams. All players on the teams were eligible, irrespective of previous or current shoulder pain. The players received verbal and written information and signed a written consent form. A statistician performed a computer-generated randomization of players into an intervention or a control group within each team. We chose within-team ran-

domization to ensure the intervention and control groups were balanced. The teams received the group assignment from the statistician on the first day of intervention. The study was approved by the South-Eastern Norway Regional Committee for Medical and Health Research Ethics (2019/28912/REK sør-øst).

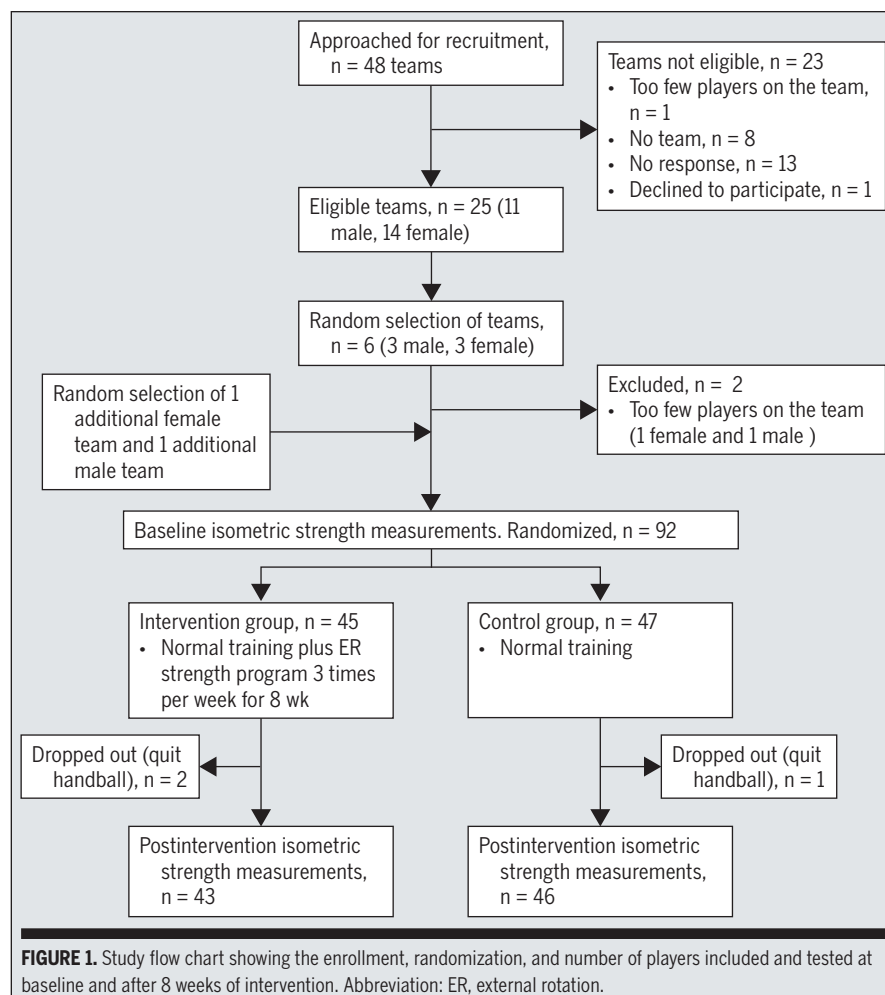
Intervention

The intervention group completed an 8-week (3 times per week) progressive shoulder-strengthening program with AlfaCare fitness bands (AlfaCare AS, Notodden, Norway) after handball training. AlfaCare fitness bands are elastic bands with different resistance, represented by different colors. We used yellow (X-Light) to black (X-Hard).

Eight exercises were selected by the

Delphi group.¹⁹ We prescribed pairs of 1 single-plane exercise and 1 combined exercise for each training session, and changed the pair of exercises every second week. Exercise pairs and order were determined a priori (APPENDIX A). Unilateral exercises were conducted with the dominant (throwing) arm only.

Participants completed 3 sets of each exercise during every training session (total program time, 5-10 minutes). The level of resistance was defined by the target number of repetitions (8-repetition maximum with 2 repetitions in reserve [2RIR], corresponding to 8 on the resistance exercise-specific rating of perceived exertion scale).³⁸ The players were instructed, on an individual basis, to select a resistance band according to this principle, and to increase the resistance



if they were able to perform more than 12 repetitions with 2RIR.

Prior to the trial, we pilot tested the exercise program with 1 handball team. The players felt that the strength program was inappropriate to perform before handball training, because muscle fatigue impaired their throwing precision. Research supports the players' assertions.²⁵ We decided to ask participants to complete the program after handball training.

One physical therapist for each team received standardized instructions and training on the execution of the exercises prior to intervention. Once or twice per week, the physical therapist directed the program and monitored how well the exercises were performed. We also provided the players and coaches with online instructional videos. The control group was instructed to train as usual and refrain from any additional shoulder strength training during the trial period.

Outcome Measures

The primary outcome measure was the between-group difference in shoulder ER strength change, measured as isometric strength in Newtons per kilogram. The secondary outcomes were between-group differences in internal rotation (IR) strength and the ER/IR ratio from baseline until postintervention. We forgot to prespecify IR strength and the ER/IR ratio as outcome measures in the ISRCTN trial registration protocol, but we measured them as part of our trial.

Testing Procedures

All testing was conducted in the afternoon in a physical therapy clinic. The players were instructed to refrain from training on the same day as they were tested. An experienced physical therapist, familiar with the testing equipment and procedures, conducted all the testing, assisted by another therapist. Prior to testing, the players performed a standardized warm-up consisting of multiplanar shoulder movements.

Isometric Strength Testing Maximal isometric ER was measured using a

handheld dynamometer (microFET; Hoggan Scientific, LLC, Salt Lake City, UT). The players were supine, with the shoulder abducted to 90° in the frontal plane and in neutral rotation. The examiner placed the dynamometer 2 cm proximal to the player's ulnar styloid process, on the dorsal side of the wrist. The examiner's medial hand was placed against the bench on the caudal side of the player's elbow to restrict shoulder adduction during the test (**FIGURE 2**). After standardized instruction on the testing procedure and 1 familiarization trial, 3 maximal isometric tests were conducted.³⁵ The participants were asked to gradually build their force to maximum effort over a 2-second period and continue the maximal effort for 3 seconds. The best of 3 attempts was used for analysis. A detailed test protocol is presented in **APPENDIX B**.

We have previously assessed the reliability of isometric shoulder tests ($n = 30$ shoulders) in healthy handball players with a mean $\pm$ SD age of 17.4 ± 1.3 years. The intraclass correlation coefficient was 0.94, standard error of measurement was 0.12 N/kg, and minimal detectable change was 0.33 N/kg.

Baseline Questionnaires

At baseline, we registered demographic data, hand dominance, years playing handball, shoulder problems in the previous year, and whether the players were playing with or without shoulder pain.

Weekly Questionnaires

A questionnaire was sent to the participants each Sunday during the intervention period, 8 times in total, using online survey software (Briteback; Briteback AB, Norrköping, Sweden).

The players reported how many times they had completed the exercise program. The total number of times completed was divided by the number of respondents to calculate the weekly adherence to the program.

Players reported their exposure to handball training and matches and additional shoulder training. The total number of minutes completed was divided by the number of respondents to calculate the weekly exposure in each group.

Prevalence of shoulder problems, other injuries, and illnesses was recorded using the OSTRC injury and illness questionnaire¹² to monitor whether these



FIGURE 2. Glenohumeral isometric external rotation strength measurement in 90° of abduction, using a handheld dynamometer.

factors influenced the players' adherence to the program.

Data Analysis

The sample-size calculation was based on a previous study examining the effects of an elastic-band shoulder training program on shoulder ER strength²⁶ and on values from our reliability testing of ER using a handheld dynamometer. For a 15% increase in ER strength from baseline to the end of the study, the expected between-group difference was set at 0.30 N/kg, with an SD of 0.34 N/kg. With a power of 90%, a significance level of .05, and a dropout rate of 15%, we needed 36 players per group.

Analyses were based on the intention-to-treat principle, where all randomized participants were included in the analyses according to their group assignment.

Repeated-measures, linear mixed-effect models with random intercepts were used to assess the between-group differences for each outcome variable. Time was defined as a categorical variable with 2 levels (baseline and postintervention). Group (intervention and control), time, and the group-by-time interaction were fixed variables. Team and shoulder pain at baseline were defined as covariates.

RESULTS

WE ENROLLED 92 PLAYERS (MEAN $\pm$ SD age, 16.6 ± 0.7 years): 45 players in the intervention group (24 male, 21 female) and 47 players in the control group (25 male, 22 female). The flow of participants is presented in **FIGURE 1**. There were no important differences between the intervention and control groups in demographic data, handball experience, shoulder pain at baseline, shoulder pain during the previous year (**TABLE 1**), or baseline shoulder isometric strength (**TABLE 2**).

Outcomes

The estimated between-group difference in mean dominant-shoulder ER strength change from baseline to postintervention was 0.06 N/kg (95% CI: -0.01, 0.14) in favor of the intervention group. The intervention had no effect on the secondary outcome variables (**TABLE 2**).

Response Rate, Adherence, and Exposure

The mean weekly response rate to the questionnaire was 95% in the intervention group and 88% in the control group. On average, the shoulder strength program was completed 2.5 times a week (range, 2.3-2.8). The average weekly ex-

posure to handball training, match play, and additional shoulder training was not different between groups (**TABLE 3**).

DISCUSSION

EIGHT WEEKS OF SHOULDER ER strength training had no effect (0.06 N/kg; 95% CI: -0.01, 0.14) on shoulder ER strength in a cohort of adolescent handball players. The intervention had no effect on the secondary outcome variables. Our results contradict 2 previous studies.^{20,26} A different study design²⁰ or higher strength gain potential in players with weaker muscles²⁶ might explain the difference.

Exercise Selection

We worked with experts to design the training program,¹⁹ aiming to find the most effective exercises handball players would adhere to. It is possible that a different exercise program might have yielded different results. The 2 exercises with the highest efficacy scores (prone ER and prone plyometric ER in 90° of abduction) scored very low on adherence, and we did not include them in the final program. Isolated exercises with the upper arm supported may facilitate muscle recruitment and strength gains of the muscles in question.^{9,37} Although the single-plane exercises in our study aimed to achieve isolated ER, there was no stabilization, and compensatory movements could have happened.

Training Principles and Exercise Dosage

We aimed to follow the training principles for strength training: specificity, intensity, progression, variation, and individualization. We used 6 sets per muscle group during each training session, with an average of 2.5 training sessions per week, and aimed for high intensity (8 repetitions with 2RIR). This is within the recommended dosage to obtain strength gains in the upper extremities. Participants had lengthy training experience (8.8 years) and were strong at the time of inclusion. At baseline, their ER isometric

TABLE 1

BASILINE CHARACTERISTICS OF THE PARTICIPANTS^a

	Intervention (n = 45)	Control (n = 47)
Age, y	17 $\pm$ 0.7	17 $\pm$ 0.7
Height, cm	177 $\pm$ 19	177 $\pm$ 10
Body mass, kg	73 $\pm$ 11	71 $\pm$ 11
Hand dominance (right), n (%)	40 (89)	41 (87)
Handball experience, y	8.8 $\pm$ 2.2	8.5 $\pm$ 2.7
Sex (female), n (%)	21 (47)	22 (47)
Shoulder pain in the last year (yes), n (%)	11 (24)	18 (38) ^b
Shoulder status at baseline, n (%)		
Playing without shoulder pain	36 (80)	42 (89)
Playing with shoulder pain	6 (13)	4 (9)
Not playing due to shoulder pain	0 (0)	0 (0)
Not playing due to other injury or illness	3 (7)	1 (2)

^aValues are mean $\pm$ SD unless otherwise indicated.

^bMissing value, n = 1.

TABLE 2

ISOMETRIC SHOULDER STRENGTH MEASUREMENTS AT BASELINE AND POSTINTERVENTION, AND RESULTS OF REPEATED-MEASURES MIXED-MODEL ANALYSES OF OUTCOMES BETWEEN THE INTERVENTION AND CONTROL GROUPS

Measure/Side	Raw Data ^a				Point Estimates ^b				Estimated Between-Group Difference ^{bc}
	Baseline		Postintervention		Baseline		Postintervention		
	Intervention (n = 45)	Control (n = 47)	Intervention (n = 43)	Control (n = 46)	Intervention	Control	Intervention	Control	
ER strength, N/kg									
Dominant	197 ± 0.33	195 ± 0.31	2.07 ± 0.38	198 ± 0.36	197 (1.88, 2.07)	195 (1.85, 2.05)	2.06 (1.96, 2.17)	198 (1.88, 2.08)	0.06 (−0.01, 0.14)
Nondominant	196 ± 0.36	197 ± 0.40	2.00 ± 0.39	199 ± 0.39	196 (1.84, 2.07)	197 (1.86, 2.08)	1.98 (1.87, 2.10)	199 (1.97, 2.10)	0.01 (−0.07, 0.08)
IR strength, N/kg									
Dominant	2.19 ± 0.42	2.22 ± 0.41	2.18 ± 0.51	2.18 ± 0.46	2.19 (2.06, 2.33)	2.22 (2.09, 2.35)	2.17 (2.04, 2.30)	2.18 (2.05, 2.31)	0.02 (−0.08, 0.13)
Nondominant	2.16 ± 0.42	2.10 ± 0.42	2.13 ± 0.46	2.13 ± 0.48	2.15 (2.02, 2.29)	2.10 (1.97, 2.23)	2.12 (1.99, 2.26)	2.12 (1.97, 2.25)	−0.05 (−0.14, 0.04)
ER/IR ratio									
Dominant	0.91 ± 0.12	0.89 ± 0.12	0.97 ± 0.17	0.92 ± 0.15	0.91 (0.87, 0.95)	0.89 (0.85, 0.93)	0.97 (0.93, 1.02)	0.93 (0.89, 0.97)	0.03 (−0.02, 0.08)
Nondominant	0.92 ± 0.12	0.95 ± 0.13	0.95 ± 0.12	0.95 ± 0.14	0.92 (0.88, 0.96)	0.95 (0.91, 0.98)	0.94 (0.90, 0.98)	0.95 (0.91, 0.99)	0.02 (−0.03, 0.07)

Abbreviations: ER, external rotation; IR, internal rotation.

^aValues are mean ± SD.

^bValues in parentheses are 95% confidence interval.

^cChange from baseline to postintervention.

TABLE 3

WEEKLY EXPOSURE TO HANDBALL TRAINING, MATCH PLAY, AND ADDITIONAL SHOULDER TRAINING IN THE INTERVENTION AND CONTROL GROUPS^a

Activity Type	Intervention	Control
Handball training	251 ± 10	262 ± 17
Match play	37 ± 12	35 ± 11
Additional shoulder training	22 ± 2	24 ± 2

^aValues are mean ± SD minutes.

strength values were comparable to reference values for adult handball players,¹³ and were greater than reported for adolescent players.^{20,29} The dose-response relationship for muscular strength development is dependent on the population's training status and experience.³² More advanced athletes need higher doses for strength gains. It is possible that our 8-week intervention was too short to achieve an effect, although previous studies have reported strength gains after 6 weeks.²⁶ We changed the exercises every second week, which might be too short a period to ensure appropriate progression. However, the supervising physical ther-

apists reported satisfactory performance and resistance progression through the 2-week periods.

Timing of the Exercises

Based on feedback from athletes, we designed a program that was completed after handball training. The timing of strength training might have impaired the effect of strength training—players who were already fatigued may have completed insufficient load for strength gains. However, strength improvement is dependent on both load magnitude and metabolic stress.³⁴ If the players were fatigued when they started the strength

training, it could increase the metabolic stress and have a positive effect on strength improvement.

Elastic Bands as Resistance

When using elastic bands as resistance, it is difficult to quantify the precise resistance. With increasing extension of the band, resistance increases; the moment arm changes through the range of motion and is highest when the band-to-arm angle is 90°. ²⁴ We tried to control resistance in 3 ways. (1) We aimed for an angle of 45° between the player's forearm and the elastic band at end range. In this way, an increase in elastic-band resistance and a reduction of the moment arm occurred simultaneously toward the end range of motion. (2) The targeted resistance was tailored by aiming for 8 repetitions with 2RIR to target muscle strength. (3) Players were instructed to increase resistance if they were able to do more than 12 repetitions with 2RIR.

Strengths of Our Trial

A randomized controlled trial with single randomization within teams ensured that

the intervention and control groups were as equal as possible. Our experience is that different teams often have very different training regimens and match schedules. Therefore, within-team randomization was chosen. We used a Delphi consensus method to find the most effective ER strength exercises handball players would adhere to. We provided a detailed description of the exercises, in both written and video formats, and a physical therapist was present with each team once or twice a week to instruct and supervise the players. An experienced physical therapist conducted all the manual tests, which had good to excellent test-retest reliability in a pilot study. The measurement error of our manual muscle testing was comparable to isokinetic shoulder measurements.^{16,23} There were no between-group differences in weekly training and match exposure during the intervention, the dropout rate was 3%, and the adherence to the program was 83%.

We included both healthy players and players with current or a history of shoulder pain, because a majority of players with chronic shoulder pain continue playing handball despite their pain.^{4,7} Only 11% of the players had shoulder pain at baseline, and outcomes were similar between those with and without shoulder pain at baseline. We included adolescent players (16-18 years of age) because the prevalence of shoulder pain is comparable between adolescents and adults^{1,2,7,30} and because ER weakness is a risk factor; targeting this factor at a young age could prevent future shoulder problems.

Limitations

Lack of blinding to group assignment is a limitation, but given the nature of the intervention, blinding was impossible. There is a possibility of contamination with simple randomization within teams. Every attempt was made to decrease contamination between the treatment and control groups by supervising the treatment group during their exercise intervention, without the control group present. Additionally, the

players in the control group did not report doing any part of the intervention exercises, and the exposure to additional shoulder training was similar in the 2 groups. However, we cannot guarantee that contamination did not occur in the control group. During our long experience working with handball players, as physical therapists and coaches, we have experienced that handball players mainly want to play handball, not to do additional training like strength or preventive training. The risk of low adherence is probably higher than the risk of contamination or the confounding effect. The players were well instructed on progression of the exercises, but the progression was not recorded. Our results in adolescent handball players cannot be generalized to adults, but, to our knowledge, no difference in response to strength training between adolescents and young adults has been reported.

Because throwing is a plyometric action with high angular velocities, isokinetic measurements, particularly at high angular velocities, and eccentric contractions might be more valid than isometric measurements. However, measurement error is higher when testing at higher angular velocities and during eccentric contractions than at slow concentric contractions,^{16,23} and also higher than our measurement error when testing isometric strength with a handheld dynamometer. Additionally, we chose isometric strength testing because it can be carried out in the field without expensive equipment.

We described the exercises in terms of load magnitude, number of repetitions and sets, training sessions per week, and training period. However, describing contraction modes per repetition, time under tension for each repetition, and rest between sets and between sessions is also recommended to define the exercise dosage.³⁶ Longer time under tension can increase myofibrillar protein synthesis after a single bout of strength training,¹⁰ and is therefore an important determinant of strength training.

Rest periods of 2 to 5 minutes between sets have been recommended to improve maximal strength.^{3,14,22} To complete the strength training program within 10 minutes, participants had rest periods of less than 90 seconds. This could have reduced the training effect of our intervention. An adaptive effect of strength training is dependent on a balance between degenerative and regenerative processes. If there is insufficient time for recovery between training sessions, degenerative processes will dominate and muscle mass will be lost.³⁶ We did not have control over the duration of rest between sessions.

Although we had high self-reported adherence to the program, previous studies have shown that self-reported adherence to exercises is overestimated.³³ We assumed that having a physical therapist present with each team 1 to 2 times per week, combined with high reported adherence, would contribute to high performance quality of the exercises. However, the physical therapists reported that on average about two thirds of the intervention group was present during the supervised training sessions. We therefore do not know the quality of one third of the training sessions.

The listed limitations reflect that, although the study was performed in a controlled setting, this was not a strict efficacy study that would have been able to determine whether the intervention would produce the expected results under ideal conditions. It seems difficult to achieve an adaptive response, that is, a strength gain, in already strong players within a time frame of 5 to 10 minutes. To achieve a strength gain, one may need to conduct the strength training as separate training sessions, with better control of the loads and progression, higher dosages, and longer rest periods between trials than those in our trial.

CONCLUSION

WHEN AN ELASTIC-BAND STRENGTHENING program of 2 exercises for shoulder external rotators, per-

formed 3 times per week for 8 weeks in handball players, was compared to a non-treatment control group, there were no differences in isometric strength. ●

KEY POINTS

FINDINGS: Eight weeks of a short shoulder external rotation (ER) strength program, conducted after handball training, had no effect on shoulder ER strength among adolescent handball players.

IMPLICATIONS: To achieve a strength gain, one may need to conduct the strength training as separate training sessions, with better control of the loads and progressions, higher doses, and longer rest periods between sets than those in our study.

CAUTION: This was not an efficacy study, because we did not have full control over load and progression. There was a possible risk of contamination across groups, due to within-team randomization and not blinding players to group allocation. Our results among already strong adolescent handball players cannot be generalized to adults or to players with ER weakness.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors made substantial contributions to the conception or design of the work, or the acquisition, analysis, or interpretation of data for the work; drafted the work or revised it critically; and approved the final version of this manuscript.

DATA SHARING: Summary data relevant to this study are included in this article, with full data available on request from the corresponding author. Please include how proposed data will be used.

PATIENT AND PUBLIC INVOLVEMENT: Prior to the study, we pilot tested the exercise program in a handball team. The players' responses were important when we decided on the implementation of the study.

ACKNOWLEDGMENTS: *We thank all the players for their kind participation, as well as the clubs and coaches involved. Thanks to Kaja*

Funnemark, Charlotte Kristine Hansen, Guro Holth, Ingrid H. Kollevold, Bettina Nævestad, and Jørn Erik Strand for help with collecting data and administering the intervention.

REFERENCES

1. Aasheim C, Stavenes H, Andersson SH, Engbretsen L, Clarsen B. Prevalence and burden of overuse injuries in elite junior handball. *BMJ Open Sport Exerc Med*. 2018;4:e000391. <https://doi.org/10.1136/bmjsem-2018-000391>
2. Achenbach L, Laver L, Walter SS, Zeman F, Kuhr M, Kruttsch W. Decreased external rotation strength is a risk factor for overuse shoulder injury in youth elite handball athletes. *Knee Surg Sports Traumatol Arthrosc*. 2020;28:1202-1211. <https://doi.org/10.1007/s00167-019-05493-4>
3. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2009;41:687-708. <https://doi.org/10.1249/MSS.0b013e3181915670>
4. 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. <https://doi.org/10.1136/bjsports-2016-096226>
5. 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*. 2018;52:1191-1198. <https://doi.org/10.1136/bjsports-2017-097648>
6. Andersson SH, Bahr R, Olsen MJ, Myklebust G. Attitudes, beliefs, and behavior toward shoulder injury prevention in elite handball: fertile ground for implementation. *Scand J Med Sci Sports*. 2019;29:1996-2009. <https://doi.org/10.1111/sms.13522>
7. Asker M, Holm LW, Källberg H, Waldén M, Skillgate E. Female adolescent elite handball players are more susceptible to shoulder problems than their male counterparts. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:1892-1900. <https://doi.org/10.1007/s00167-018-4857-y>
8. Asker M, Waldén M, Källberg H, Holm LW, Skillgate E. Preseason clinical shoulder test results and shoulder injury rate in adolescent elite handball players: a prospective study. *J Orthop Sports Phys Ther*. 2020;50:67-74. <https://doi.org/10.2519/jospt.2020.9044>
9. Broström LA, Kronberg M, Németh G, Oxelbäck U. The effect of shoulder muscle training in patients with recurrent shoulder dislocations. *Scand J Rehabil Med*. 1992;24:11-15.
10. Burd NA, Andrews RJ, West DW, et al. Muscle time under tension during resistance exercise stimulates differential muscle protein sub-fractional synthetic responses in men. *J Physiol*. 2012;590:351-362. <https://doi.org/10.1113/jphysiol.2011.221200>
11. 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;48:1327-1333. <https://doi.org/10.1136/bjsports-2014-093702>
12. 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. <https://doi.org/10.1136/bjsports-2012-091524>
13. Cools AM, Vanderstucken F, Vereecken F, et al. Eccentric and isometric shoulder rotator cuff strength testing using a hand-held dynamometer: reference values for overhead athletes. *Knee Surg Sports Traumatol Arthrosc*. 2016;24:3838-3847. <https://doi.org/10.1007/s00167-015-3755-9>
14. de Salles BF, Simão R, Miranda F, da Silva Novaes J, Lemos A, Willardson JM. Rest interval between sets in strength training. *Sports Med*. 2009;39:765-777. <https://doi.org/10.2165/11315230-000000000-00000>
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;34:654-660. <https://doi.org/10.1055/s-0032-1312587>
16. Edouard P, Samozino P, Julia M, et al. Reliability of isokinetic assessment of shoulder-rotator strength: a systematic review of the effect of position. *J Sport Rehabil*. 2011;20:367-383. <https://doi.org/10.1123/jsr.20.3.367>
17. Forthomme B, Croisier JL, Delvaux F, Kaux JF, Crielaard JM, Gleizes-Cervera S. Preseason strength assessment of the rotator muscles and shoulder injury in handball players. *J Athl Train*. 2018;53:174-180. <https://doi.org/10.4085/1062-6050-216-16>
18. Fredriksen H, Cools A, Bahr R, Myklebust G. Does an effective shoulder injury prevention program affect risk factors in handball? A randomized controlled study. *Scand J Med Sci Sports*. 2020;30:1423-1433. <https://doi.org/10.1111/sms.13674>
19. Fredriksen H, Cools A, Myklebust G. Development of a short and effective shoulder external rotation strength program in handball: a Delphi study. *Phys Ther Sport*. 2020;44:92-98. <https://doi.org/10.1016/j.pts.2020.05.005>
20. Genevois C, Berthier P, Guidou V, Muller F, Thiebault B, Rogowski I. Effects of 6-week sling-based training of the external-rotator muscles on the shoulder profile in elite female high school handball players. *J Sport Rehabil*. 2014;23:286-295. <https://doi.org/10.1123/jsr.2012-0108>
21. 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. <https://doi.org/10.1111/sms.12636>

22. Grgic J, Schoenfeld BJ, Skrepiak M, Davies TB, Mikulic P. Effects of rest interval duration in resistance training on measures of muscular strength: a systematic review. *Sports Med*. 2018;48:137-151. <https://doi.org/10.1007/s40279-017-0788-x>
23. Habets B, Staal JB, Tijssen M, van Cingel R. Intrarater reliability of the Humac NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles. *BMC Res Notes*. 2018;11:15. <https://doi.org/10.1186/s13104-018-3128-9>
24. Hughes CJ, Hurd K, Jones A, Sprigle S. Resistance properties of Thera-Band® tubing during shoulder abduction exercise. *J Orthop Sports Phys Ther*. 1999;29:413-420. <https://doi.org/10.2519/jospt.1999.29.7.413>
25. Lauersen JB, Andersen TE, Andersen LB. Strength training as superior, dose-dependent and safe prevention of acute and overuse sports injuries: a systematic review, qualitative analysis and meta-analysis. *Br J Sports Med*. 2018;52:1557-1563. <https://doi.org/10.1136/bjsports-2018-099078>
26. Mascarin NC, de Lira CAB, Vancini RL, da Silva AC, Andrade MS. The effects of preventive rubber band training on shoulder joint imbalance and throwing performance in handball players: a randomized and prospective study. *J Bodyw Mov Ther*. 2017;21:1017-1023. <https://doi.org/10.1016/j.jbmt.2017.01.003>
27. Moher D, Hopewell S, Schulz KF, et al. CONSORT

2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *Int J Surg*. 2012;10:28-55. <https://doi.org/10.1016/j.ijsu.2011.10.001>

28. 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. <https://doi.org/10.1016/j.jmpt.2012.07.011>
29. Møller M, Attermann J, Myklebust G, et al. The inter- and intrarater reliability and agreement for field-based assessment of scapular control, shoulder range of motion, and shoulder isometric strength in elite adolescent athletes. *Phys Ther Sport*. 2018;32:212-220. <https://doi.org/10.1016/j.ptspt.2018.04.005>
30. 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;51:231-237. <https://doi.org/10.1136/bjsports-2016-096927>
31. 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;23:288-294. <https://doi.org/10.1111/j.1600-0838.2011.01398.x>
32. Peterson MD, Rhea MR, Alvar BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription. *J Strength Cond Res*. 2005;19:950-958.
33. Rathleff MS, Bandholm T, McGirr KA, Harring SI, Sørensen AS, Thorborg K. New exercise-integrated technology can monitor the dosage and

quality of exercise performed against an elastic resistance band by adolescents with patellofemoral pain: an observational study. *J Physiother*. 2016;62:159-163. <https://doi.org/10.1016/j.jphys.2016.05.016>

34. Schoenfeld BJ. Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training. *Sports Med*. 2013;43:179-194. <https://doi.org/10.1007/s40279-013-0017-1>
35. Stratford PW, Balsor BE. A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. *J Orthop Sports Phys Ther*. 1994;19:28-32. <https://doi.org/10.2519/jospt.1994.19.1.28>
36. Toigo M, Boutellier U. New fundamental resistance exercise determinants of molecular and cellular muscle adaptations. *Eur J Appl Physiol*. 2006;97:643-663. <https://doi.org/10.1007/s00421-006-0238-1>
37. Yu IY, Lee DK, Kang MJ, Oh JS. Effects of 3 infraspinatus muscle strengthening exercises on isokinetic peak torque and muscle activity. *J Sport Rehabil*. 2019;28:229-235. <https://doi.org/10.1123/jsr.2017-0110>
38. Zourdos MC, Klemp A, Dolan C, et al. Novel resistance training-specific rating of perceived exertion scale measuring repetitions in reserve. *J Strength Cond Res*. 2016;30:267-275. <https://doi.org/10.1519/JSC.0000000000001049>



MORE INFORMATION
WWW.JOSPT.ORG

CHECK Your References With the JOSPT Reference Library

JOSPT has created an **EndNote reference library** for authors to use in conjunction with PubMed/MEDLINE when assembling their manuscript references, as well as an EndNote style template. The style template is available in the **Author and Reviewer Tools** section of the JOSPT website in the Author and Reviewer centers. The reference library offers a compilation of all article reference sections published in the *JOSPT*, as well as complete references for all articles published in the *JOSPT* since 1979—a total of approximately **32,000 unique references**. The reference library is available on request from coreyparker@jospt.org. The library is **updated twice a year**.

The JOSPT EndNote style template can be found at: http://www.jospt.org/page/authors/author_reviewer_tools

APPENDIX A

SHOULDER EXTERNAL ROTATION STRENGTH EXERCISES FOR HANDBALL PLAYERS

Two shoulder external rotation exercises are performed after regular handball training 3 times per week.

The 2 exercises are changed every other week.

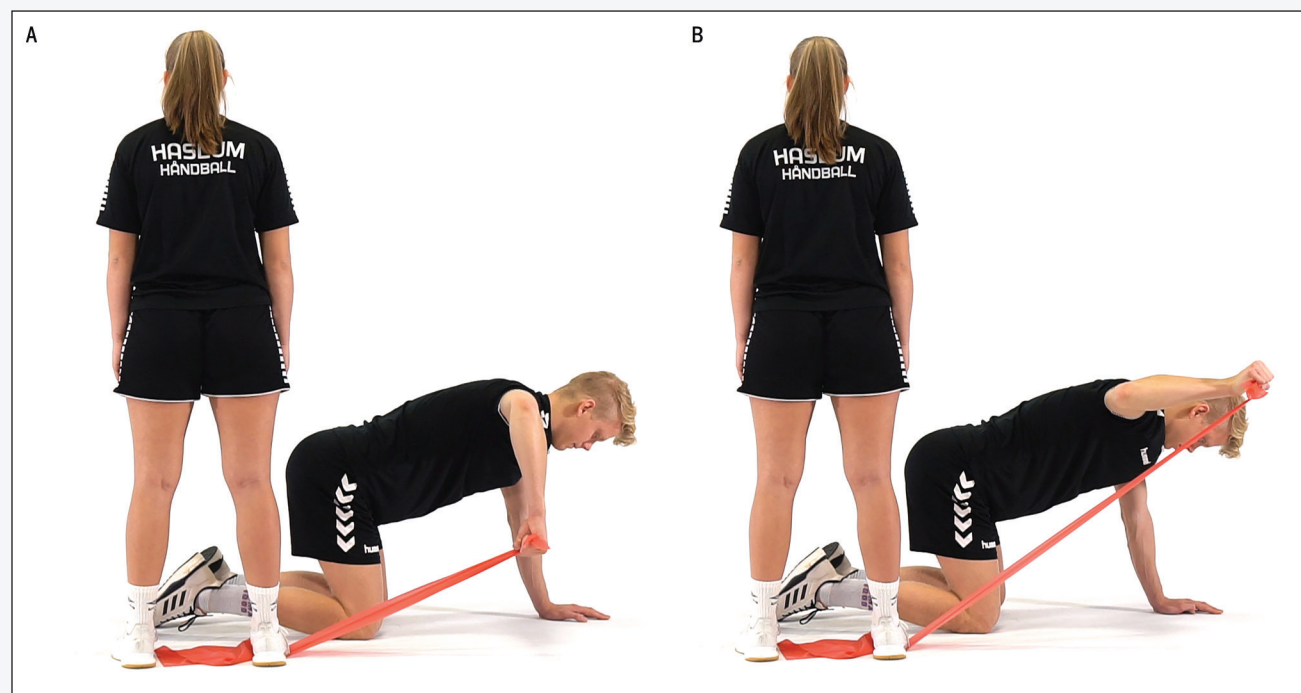
The following applies to all exercises:

- 3 sets of each exercise
- In the starting position, the elastic band is stretched to minimal resistance
- The goal is to use the resistance at which the player is able to perform 8 repetitions with 2 repetitions in reserve (2RIR). The exercises are meant to be heavy
- If the player is able to perform more than 12 repetitions with 2RIR, increase the resistance

The resistance is increased by:

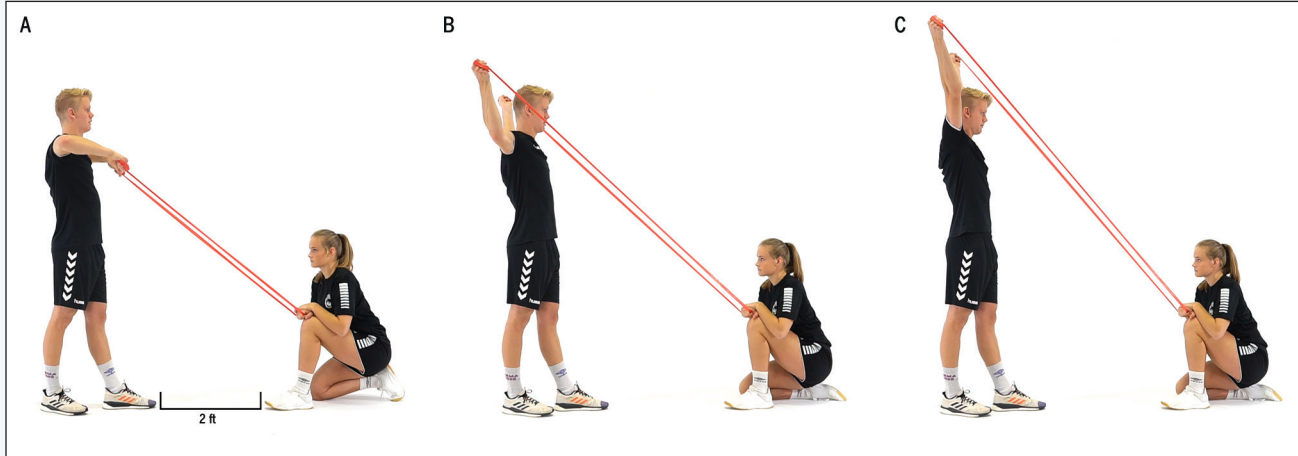
- Using a stronger elastic band (different color)
- Making the elastic band shorter by wrapping it around the hand

There should be no shoulder pain during the exercises, but the muscles are supposed to be tired. The player might also experience muscle soreness afterward due to the strength training.

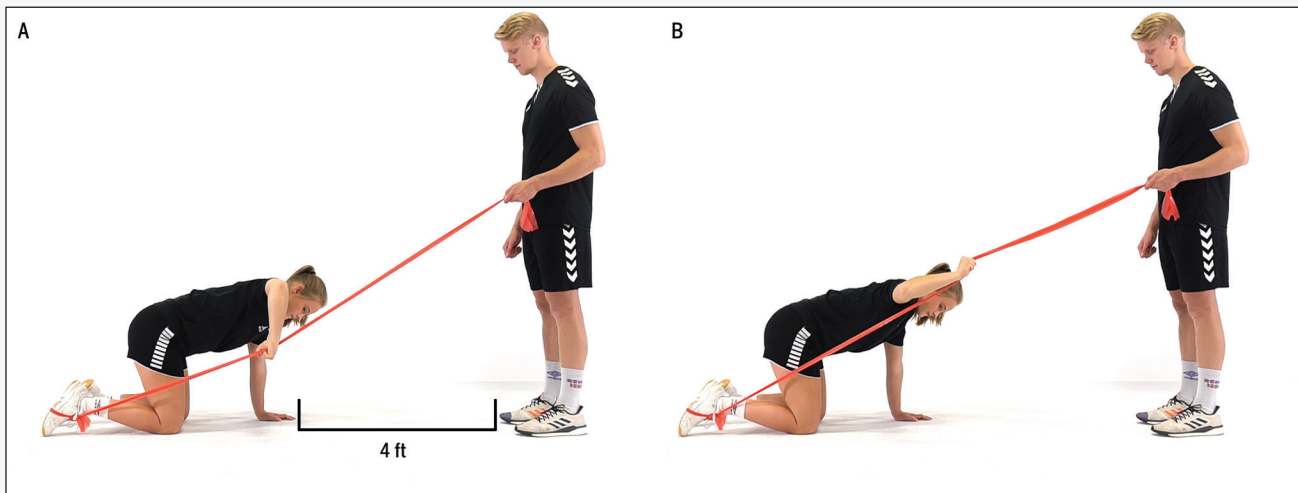


External rotation in 90° of abduction in a 3-point kneeling position (knees straight below hips, supporting hand straight below shoulder), with the shoulder abducted to 90° and the elbow flexed to 90°. The elastic band is anchored by the partner's foot, midway between the player's knee and ankle (same side as dominant arm). Start in full internal rotation (panel A) while the shoulder blade is kept slightly retracted. Rotate through full range of motion, from full internal rotation (panel A) to full external rotation (panel B).

APPENDIX A



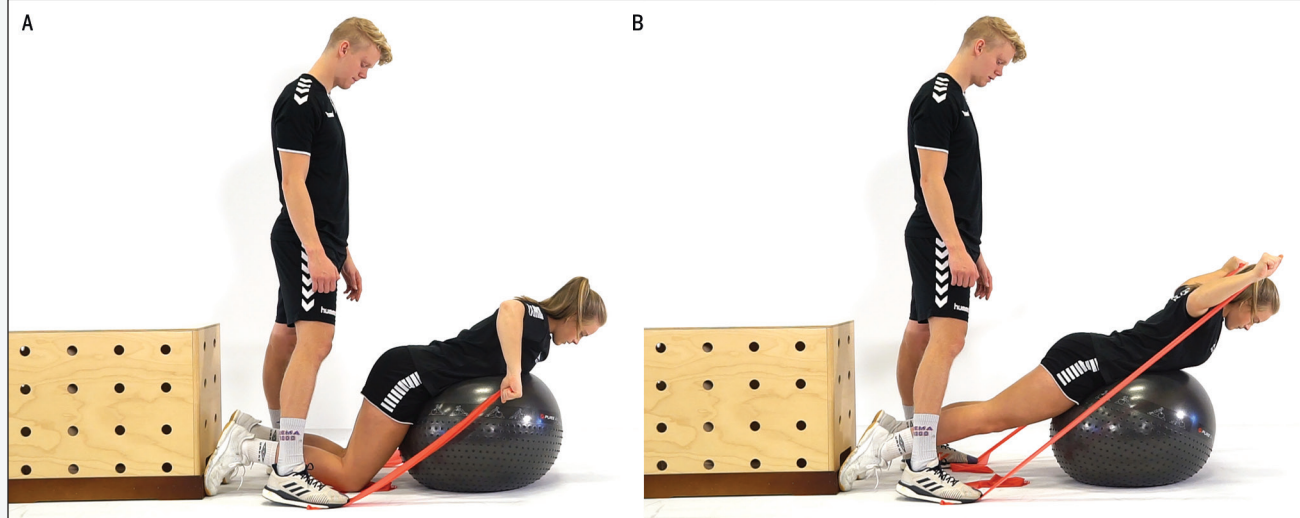
Combined exercise: external rotation with horizontal abduction and elevation (W-Y exercise) in standing. The player and partner are facing each other and the player's feet are in a throwing position. The distance between the player's and the partner's toes is 2 ft (panel A). The player grasps both ends of the elastic band, while the partner anchors the midpoint of the band at the same level as the player's knees. Start with the shoulders in 90° of abduction and full internal rotation, with the shoulder blades slightly retracted and the elbows in 90° of flexion (panel A). Rotate through the full range of motion (W; panel B) and extend the elbows to a Y position (panel C).



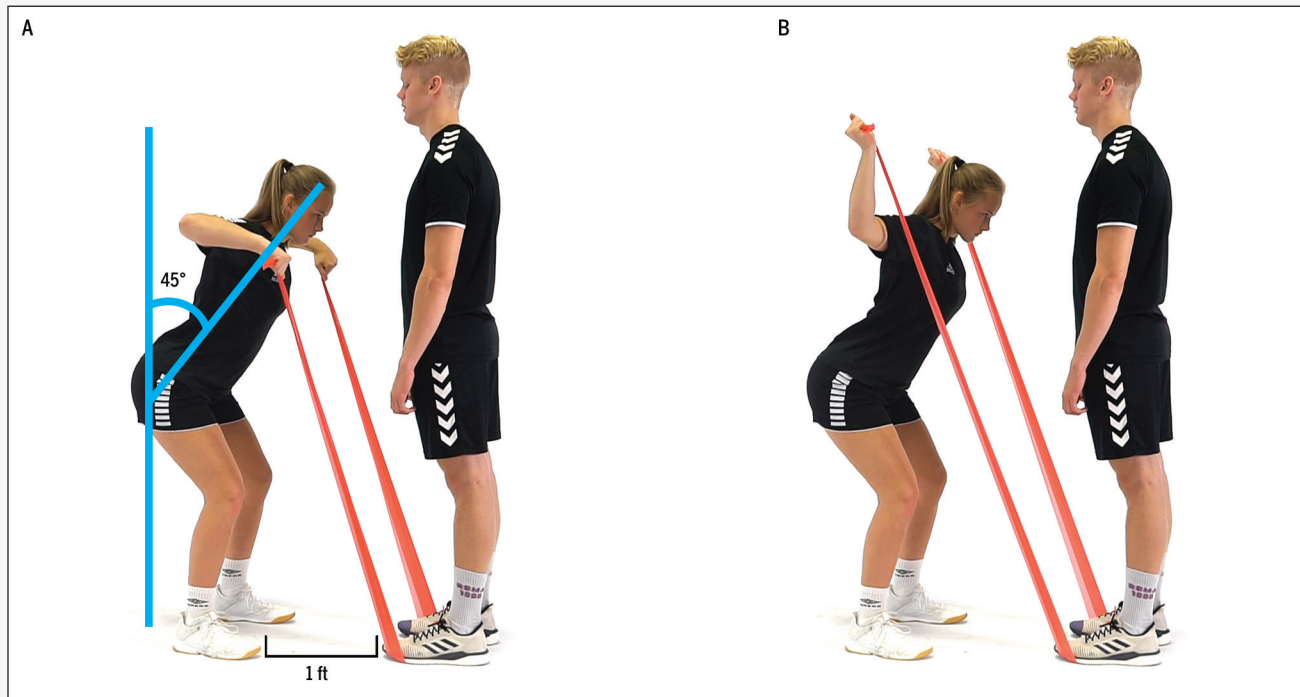
Full rotation in 90° of abduction in a 3-point kneeling position (knees straight below hips, supporting hand straight below shoulder), with the shoulder abducted to 90° and the elbow flexed to 90°. One end of the elastic band is anchored with a loop around the player's foot (same side as dominant arm) and the other end is held by a partner in front of the player, in the same direction as the player's forearm when the shoulder is in maximum external rotation (panel B). The distance from the player's supporting hand to the partner's toes is 4 ft (panel A). Start in full internal rotation (panel A), keeping the shoulder blade slightly retracted. Rotate through full range of motion, from full internal rotation (panel A) to full external rotation (panel B).

[RESEARCH REPORT]

APPENDIX A

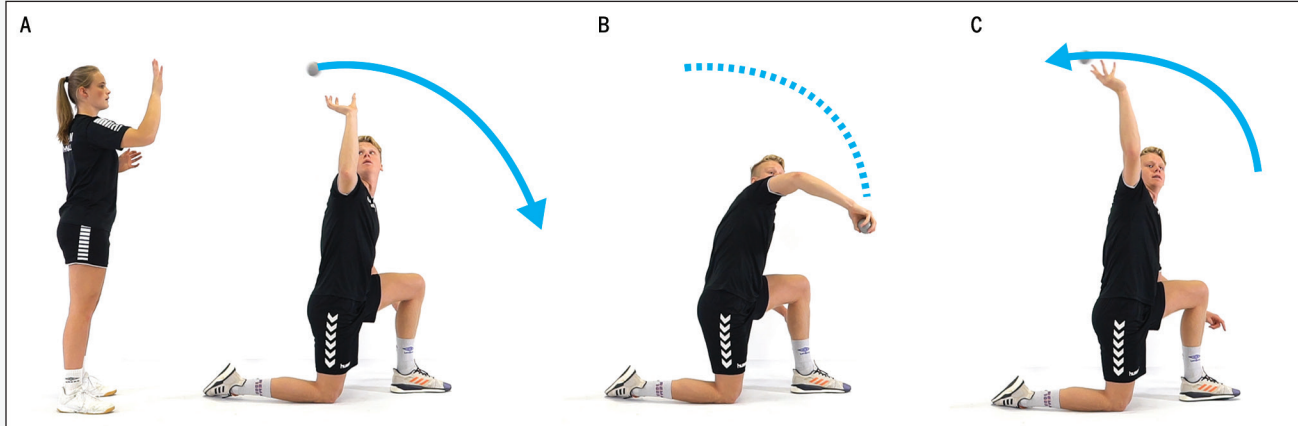


Combined exercise: external rotation with hip extension while lying prone on a Swiss ball. The player is in a kneeling position, with the trunk on a Swiss ball and the feet against a wall. The elastic band is anchored by the partner's feet beside the player's knees. Start with the shoulders in 90° of abduction and full internal rotation, with the shoulder blades slightly retracted and the elbows in 90° of flexion (panel A). Push out (extend hips and knees) while moving into full external rotation (panel B).

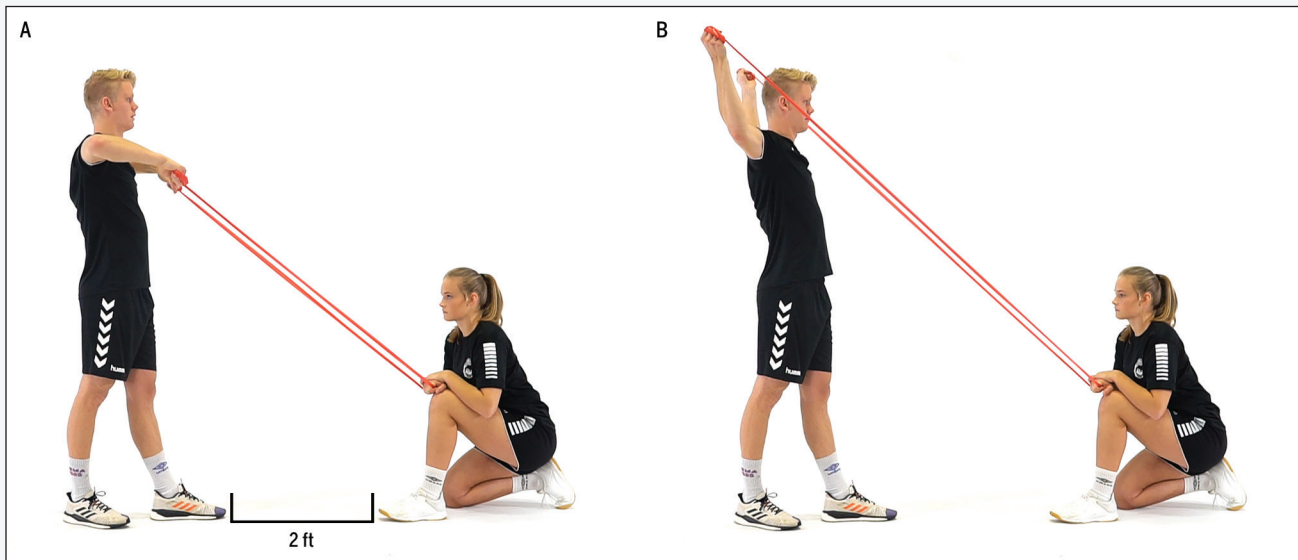


External rotation in 90° of abduction in a bent-over squat position. Reprinted with permission from Fredriksen et al.¹⁹ The player and partner are facing each other. The distance between the player's and partner's toes is 1 ft. The player is standing in a bent-over squat position, with parallel feet and the upper body inclined 45° (panel A). Start with the shoulders in 90° of abduction and in full internal rotation (panel A), with the shoulder blade slightly retracted. Rotate through full range of motion, from full internal rotation (panel A) to full external rotation (panel B).

APPENDIX A

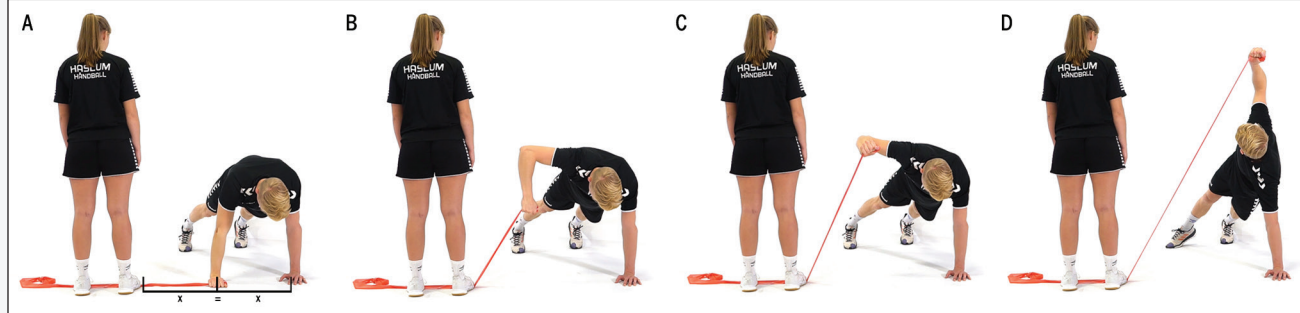


Reverse-catch plyometric exercise. The player is in a half-kneeling position with the nondominant leg in front (panel A). From behind the player, a partner throws a plyoball toward the player, who catches the ball in the 90°/90° position, decelerates the ball, and then rapidly throws the ball back, maintaining the arm in the 90°/90° position (panels A through C).



Standing external rotation in 90° of abduction. The player and partner are facing each other and the player's feet are in a throwing position. The distance between the player's and partner's toes is 2 ft (panel A). The player grasps both ends of the elastic band, while the partner anchors the midpoint of the band at the same level as the player's knees. Start with the shoulders in 90° of abduction and full internal rotation, with the shoulder blades slightly retracted and the elbows in 90° of flexion (panel A). Rotate through the full range of motion (panel B).

APPENDIX A



Combined exercise: external rotation in 90° of abduction, with horizontal abduction and trunk rotation in a push-up position. The player is in a push-up position with the hands shoulder-width apart. The elastic band is attached under the partner's foot, lateral to the player's dominant arm, at the same distance as between the player's hands (panel A). The player lifts the elbow (panel B), rotates the shoulder externally through full range of motion (panel C), pulls the arm backward as in throwing (the hand is leading the movement), and rotates the trunk (panel D).

APPENDIX B

ISOMETRIC ROTATIONAL STRENGTH TESTING

Materials: standard examination table, handheld dynamometer, towel.

Standardized warm-up procedure: Ten repetitions of full-range-of-motion flexion, abduction, and circumduction, all performed at a smooth but rather quick velocity, and 10 repetitions of push-ups against the wall.

The player is positioned supine on the examination table, with the shoulder abducted 90° and the elbow flexed to 90°. The olecranon process should be at the side of the table. If necessary, place a towel underneath the distal humerus. It should be folded sufficiently to ensure frontal plane alignment of the upper arm. The arm not being tested rests on the belly.

The rater is standing in the opposite direction of the movement tested, holding the dynamometer with the lateral hand, while the medial hand stabilizes the player's humerus by pressing the fist against the examination table on the medial side of the humerus.

The rater passively moves the player's arm in internal and external rotation before starting the examination, limiting the movement only to the gleno-humeral joint, and gives a standardized verbal instruction: "I am going to test the strength of your shoulder's internal and external rotation. You should move your arm only in the direction shown. Your upper arm is not supposed to move. Your upper body should stay in contact with the examination table without moving. You will have 1 familiarization trial, followed by 3 maximal trials. Increase the pressure against the dynamometer gradually when I tell you to and press with all your strength for 3 seconds, on my count."

The dynamometer is placed 2 cm proximal to the styloid process of the ulna on the dorsal (external rotation strength measurement) and on the ventral (internal rotation strength measurement) forearm.

Instruct the player to apply and hold maximal pressure for 3 seconds by saying, "Let me know if you experience any pain during the test. Are you ready? Increase the pressure. Press maximum, 1, 2, 3, stop."

Perform 3 repetitions of 3 seconds of maximal voluntary effort using a make test (gradually increasing resistance up to maximum, without breaking the player's contraction) and calculate the mean. Internal rotation strength is measured before external rotation strength.

