ORIGINAL SCIENTIFIC PAPER

The Effect of an Exercise Program on the Biomechanics of the Shoulder Girdle in Overhead Shooting in High-level Handball Players

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Abstract

Handball athletes are subjected to high loads, especially during the process of throwing or shooting overhead. These athletes often complain of pain and report unexplained loss of throwing velocity and throwing control. Shoulder dyskinesia and overuse syndrome have been identified as risk factors among elite handball athletes. Understanding the dynamics and kinematics of the throwing phase is vital for the exercise professional. This study evaluates the effect of an interventional exercise program on shoulder girdle biomechanics and overhead shooting. The sample consisted of 20 high level handball athletes from Greece. The athletes were divided into two groups: 10 in the study group, who were given the exercise program, and 10 in the control group, who only engaged in in-team handball training. Before and after the program, the following measurements were performed: a) angular measurements of abduction, adduction, flexion and extension of the shoulder; b) isokinetic evaluation of abduction flexion and adduction extension of the shoulder joint, at three angular velocities (60°/sec, 180°/sec and 300°/sec). Inferential statistics showed that there was a statistically significant difference in angular measurements with a reduction in range of motion for 10 of the study group. In the isokinetic assessment there was a statistically significant difference, in the 180°/sec velocities in flexion and extension, and in the deficit of flexion of both shoulders. In conclusion, the interventional exercise program had, to some extent, a beneficial effect on muscle strengthening of the shoulder girdle. The results of this study may suggest training guidelines, provide important information to exercise professionals, and provide feedback to handball athletes.

Keywords: *handball, goniometry, isokinetic dynamometry, shoulder girdle, biomechanics, scapular dyskinesia*

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Introduction

The majority of shoulder injuries in handball are caused by repetitive overhead activities leading to overuse injuries rather than a single traumatic mechanism (Landreau, Zumstein, Lubiatowski, &Laver, 2018). Werner and Plancher (1998) report that due to continuous throwing and repetitive wrist flexion and extension and radial and ulnar variations, overuse injuries occur in the upper extremities. The most common symptom in these injuries in athletes is chronic shoulder pain. These athletes, despite developing overuse injuries, continue to participate in the sport. Reckling et al. (2003), in a study of contact sports, observed that 53% of injuries occur during a game and are caused by an opponent, while only 3% are caused by a teammate. The shoulders (44.0%) and knee (26.7%) were the body areas most affected by overuse injuries (Giroto et al, 2017). It was also observed that in backcourt and extreme players, a high percentage of injuries were located in the upper extremities (shoulder or arm), with the majority of these athletes (89%), showing symptoms of overuse injuries in the shoulder (Seil, Rupp, Tempelhof, & Kohn, 1998).

When we raise our arm up to perform any activity, the scapula makes an upward rotational movement, accompanying and supporting the arm in its elevation. In order for this movement of the scapula to take place, several muscles are activated, such as the serratus anterior , upper, middle and lower trapezius (Kapandji, 2021). Many studies report that some of the muscles that move the scapula and stabilize the shoulder are not activated in the correct order (Mascarin, de Lira, Vancini, de CastroPochini, daSilva, & dos Santos Andrade, 2017; Kibler, Stone, Zacharias, Grantham&Sciascia, 2021; Henry, Spigelman, Sabin, &Sciascia2021). Altered patterns of muscle activity, reduced strength levels, and changes in the timing properties of the serratus anterior, upper, middle, and lower trapezius appear to create a problem in the region (Castelein, Cools, Parlevliet, &Cagnie, 2017). In its attempt to ensure normal function of the upper limb, the nervous system, over activates early, the upper trapezius combined with reduced strength of the serratus anterior, reduced activity and delayed activation of the middle and lower trapezius creating a muscular imbalance. When this coordinated movement occurs, certain muscles work harder, causing pain in the shoulder, scapula, and neck area (Ekstrom, Donatelli, &Soderberg, 2003). Inextricably linked to smooth shoulder function is the harmoniously regulated function of the scapula. Dyskinesia of the scapula is also associated with various pathologies of the shoulder, when there is a disturbance in some part of the above mechanism. Rapidly repeated, high mechanical loads of muscle activation are required, which the scapula is called upon to cope with. In the throwing phase, maximum flexion and abduction is ensured by a stabilized scapula (Smith, Dietrich, Kotajarvi, & Kaufman, 2006). This dynamic movement of the scapula, combined with the movement of the humerus, achieves precision movements and positions. The compression mechanism in the scapula cavity is maximized, reducing the internal impact created and thus minimizing stress on the whole joint. All of this miraculous mechanism is essential to the completion and success of the overhead throw (Sheean, Kibler, Conway, & Bradley, 2020). Although changes in scapular motion may be common in athletes throwing overhead, several reports have shown that recognizing and managing the changes can lead to improved recovery and performance outcomes (Tsuruike, Ellenbecker, & Lauffenburger, 2020; Andersson, Bahr, Clarsen, Myclebust 2017; Cools, Dewitte, Lanszweert, Notabaert, Roets, Soetens, Cagnie, Witvrouw 2007; Kibler, Stone, Zacharias, Grantham & Sciascia, 2021). Therefore, assessment and management starting at the scapula may produce improved outcomes related to shoulder pathology in overhead throwing athletes (Kibler, et.al. 2021). This led to the main objective of this study, which was to evaluate the effect of an exercise program designed to reduce the risk of shoulder injuries and problems in handball athletes.

Methods

Subjects

The study included female and male athletes who reported pain or dyskinesia of the shoulder blade. The study was conducted in adult athletes of the A1 handball league in Greece. Specifically, questionnaires were given to the men's teams PAOK, AESX Pylaia, PAS FOIVOS Sykes, GAS Kilkis, Phillipos Veria, AEROPOS Edessa, DRAMA 1986, ZAFEIRAKIS Naoussa. As well as the women's teams, PAOK, AEP Panorama, AESX Pylaia, VEROIA 2017, AO Prosotsani, OFN Ionia. Inclusion criteria: Athletes who had a history of shoulder or scapula pain in the past 6 months. Exclusion criteria: Athletes who had 1) a history of shoulder dislocation, fracture, or shoulder surgery in the past year, 2) intravascular injections in the shoulder in the past 3 months, 3) a history of neck or upper extremity injury in the past month, 4) cervical spine disease or a neurological disorder that may affect shoulder movement; 5) scoliosis or excessive kyphosis and 6) pain during the measurement procedure that may interfere with the measurement procedure.

Variables

Goniometry: the goniometry measurements taken were abduction, adduction in the standing position and extension, flexion of the scapula in the prone and supine positions. Measurements were made with a Myrin goniometer/clinometer (item no. 711432, Bålsta, Sweden). The purpose of the goniometry measurements was to record the range of motion of both shoulders.

Isokinetic dynamometry: the purpose of the isokinetic assessment was to measure the strength of the shoulder muscles during the concentric phase of muscle activation. Three angular velocities were selected: low (60°/s), intermediate (180°/s) and high (300°/s). Measurements were made using a HumacNorm 770 CSMi isokinetic dynamometer (Stoughton, MA, USA). flexion abduction/extension adduction or PNF D2 of the shoulder joint was performed for both shoulders. Differences in force level in n/m, deficit, between flexor and extensor muscles, and the flexor and extensor muscle ratio for both shoulders in were recorded and evaluated.

Procedure

During the preparation period of the teams, a questionnaire was administered to the teams of the first division of the A1 Men's and A1 Women's League. The purpose was to collect data for the selection of athletes who would meet the inclusion criteria for the study. A total of 198 male and female athletes responded to the questionnaire. A random selection of 20 individuals who met the inclusion criteria was then made. All of them showed evidence of scapular dyskinesia, they were divided into two groups of 10 subjects. In group A, the control group, each athlete followed the usual team training program. In group B, the study group, each athlete followed an inter-

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ventional training program (exercise program 3 times a week for 3 months) in addition to the usual team training program. The same measurements were made for all subjects. For the Goniometry measurements it was taken abduction, adduction in the standing position and extension, flexion of the scapula in the prone and supine positions. The purpose of the goniometry measurements was to record the range of motion of both shoulders. The purpose of the isokinetic assessment was to measure the strength of the shoulder muscles during the concentric phase of muscle activation. Differences in force level in n/m, deficit, between flexor and extensor muscles, and the flexor and extensor muscle ratio for both shoulders in %, expressed as Mean (M) and Standard Deviation (SD) were recorded and evaluated.

Intervention program of the study team

The investigation of the evaluation and impact of the program involved muscle activation of both shoulders. The study group had to perform the exercise program 3 times a week for 3 months. Each workout started with a range of motion warm-up followed by a strengthening workout. The exercises involving one arm were performed on the affected side only. If both shoulder blades were affected, then the entire exercise program was applied to both sides. Strengthening exercises focused on the general area of the scapula, specifically the transverse and lower trapezius and the anterior serratus, while stretching exercises focused on the upper trapezius, the pectoral muscles and the posterior glenohumeral joint capsule. The program included the following exercises:1) Cobra Stretch, with the palms next to the chest and the legs extended, lifting the torso with full extension at the elbows in forward flexion, and 2) Cross Body Stretch, cross extension with arm adduction in lateral flexion. Strengthening exercises: 3) Push-up plus external rotation, with shoulder abduction; 4) Supine punch, 5) Side Lying with Forward Flexion up to 135°, arm flexion ≥ 135° in lateral flexion, 6) Arm Extension in Prone Position, lateral forward flexion to 135°; 7) Prone horizontal abduction with external rotation. The exercise program was designed to improve muscle activation for muscular endurance and strength. In each exercise, each participant performed one training set using 50% resistance of perceived 1-RM. The strength training included 3 sets / 15 repetitions of each exercise. Figures 1- 7 shows the exercises included in the intervention program.

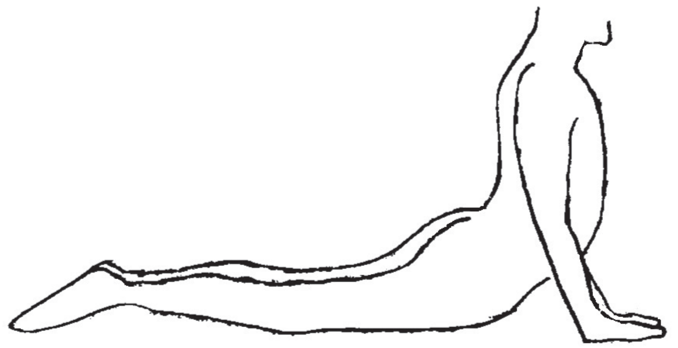

Figure 1. Cobra Stretch

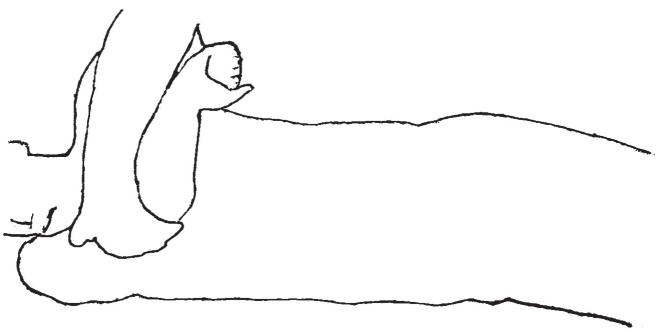

Figure 2. Cross Body Stretch

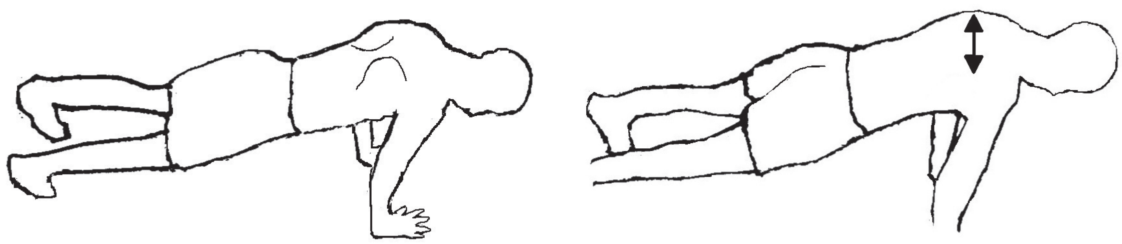

Figure 3. Push up Plus External Rotation

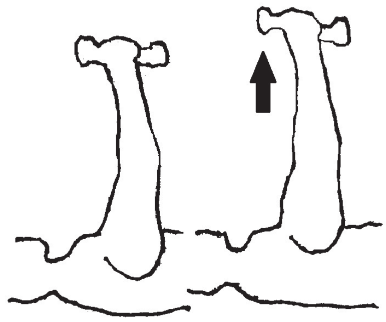

Figure 4. Supine Punch

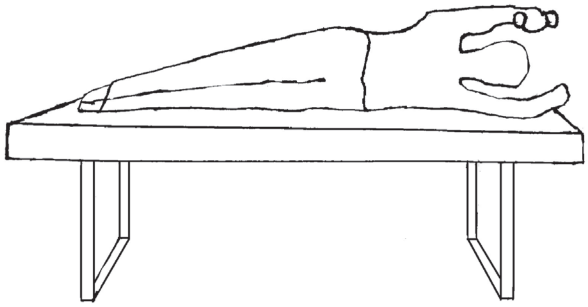

Figure 5. Side Lying with Forward Flexion up to 135°

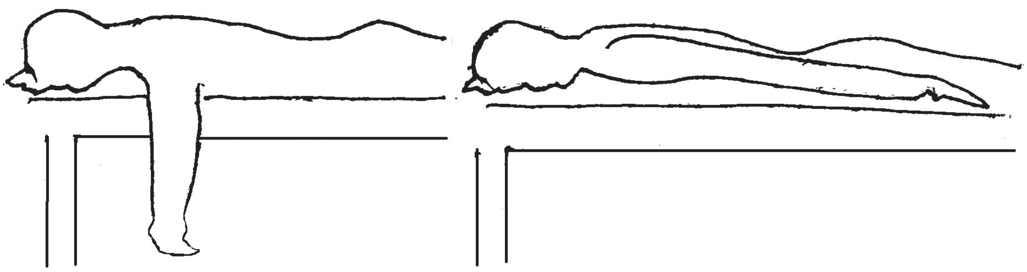

Figure 6. Arm Extension in Prone Position

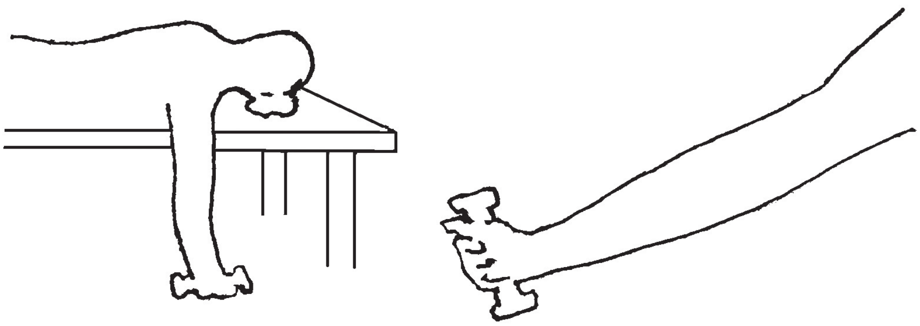

Figure 7. Prone horizontal abduction with external rotation

Statistical analysis

The results were analyzed both descriptively and inferentially. Descriptively, the mean (M) and standard deviation (SD) were used, as well as the frequency of values and their corresponding percentage. Inferentially, two way ANOVAs was used with repeated measures with group factors and measurement for main effects and with group factors and measurement for interaction. IBM SPSS 22.0 was used to statistically process the above and the significance level was set at 0.05.

This study was approved in advance by the Research Ethics Committee of the Department of Physical Education and Sports Science of Thessaloniki. Each participant voluntarily provided written informed consent prior to participation.

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Results

Shoulder goniometry

Table 1 shows the differences between the study group and the control group at the first and second goniometry, i.e. before and after the administration of the intervention program to the study group, expressed in sig and Partial Eta Square (PES). PES is a statistical indicator that shows the magnitude of the effect expressed by a value that shows sometimes small, sometimes medium and sometimes high. In this table we can see that in many cases we have a result that according to the value of PES, the load shows sometimes small, sometimes medium and sometimes high effect.

Isokinetic evaluation of the shoulders

Table 2 shows the results of the isokinetic assessment for the measurements taken before and after the intervention program was given to the study group expressed in sig and Partial Eta Square (PES). The same table presents the isokinetic assessment data in the study group and the control group. These were examined in terms of the deficit between flexor and extensor muscles, and the ratio between flexor and extensor muscles of both shoulders.

Table 1 First and second goniometry before and after the intervention programe (F-test - F, Partial Eta Square – PES) before intervention (1), and after intervention (2)

	Experimental Group	Control Group	Experimental Group	Control Group	Main effect			Interaction		
	1	1	2	2						
	Mean SD	Mean SD	Mean SD	Mean SD	F	p-value	PES	F	p-value	PES
Abduction right	135.5 ±14.17	125.5 ±12.69	134.8 ±17.08	138.8 ±13.76	2.238	0.152	0.111	2.796	0.112	0.134
Abduction left	135.2 ±12.68	122.8 ±13.14	132.2 ±17.81	138.5 ±15.28	1.903	0.185	0.960	4.018	0.096	0.182
Adduction right	23.30 ±7.76	24.7 ±7.07	23.20 ±7.24	22.10 ±5.70	0.817	0.378	0.043	0.700	0.414	0.037
Adduction left	22.07 ±7.15	21.8 ±6.32	17.00 ±4.52	16.9 ±4.12	16.026*	0.001	0.471	0.091	0.766	0.005
Extension right	32.4 ±13.86	31.5 ±8.22	30.1 ±11.66	41.1 ±13.91	1.972	0.177	0.099	5.239**	0.034	0.225*
Extension left	33.5 ±10.7	32.0 ±8.58	30.40 ±13.39	38.10 ±15.27	0.251	0.622	0.014	2.361	0.142	0.116
Flexion right	159.9 ±9.15	157.7 ±24.54	152.9 ±9.46	146.4 ±19.14	8.959*	0.008	0.332	0.495	0.491	0.027
Flexion left	156.2 ±18.93	163.7 ±18.47	145.7 ±19.62	151.10 ±12.83	14.105*	0.001	0.439	0.117	0.737	0.006

Note: Significance level *<0.01, **<0.05.

Table 2. Isokinetic assessment before and after the intervention program (F-test - F, Partial Eta Square – PES) before intervention (1), and after intervention (2)

	Experimental Group	Control Group	Experimental Group	Control Group	Main effect			Interaction		
	1	1	2	2						
	Mean SD	Mean SD	Mean SD	Mean SD	F	p-value	PES	F	p-value	PES
60°/sec right extension	63.20 ±17.59	62.10 ±20.28	67.20 ±23.74	64.20 ±11.19	0.756	0.396	0.040	0.073	0.790	0.004
60°/secleft extension	67.10 ±21.68	62.00 ±16.84	70.40 ±29.98	66.60 ±14.82	1.817	0.194	0.092	0.049	0.827	0.003
60°/sec Extensional deficit	8.9 ±4.68	15.3 ±15.24	9.50 ±5.02	5.90 ±4.98	2.715	0.117	0.131	3.506	0.077	0.163
60°/sec right flexion	90.50 ±37.28	84.40 ±29.91	87.20 ±33.56	91.50 ±27.50	0.157	0.697	0.009	1.176	0.292	0.061
60°/sec left flexion	84.60 ±37.85	76.50 ±16.95	87.50 ±35.00	83.30 ±22.05	1.955	0.179	0.098	0.316	0.581	0.017
60°/sec flexural deficit	11.50 ±6.54	21.20 ±20.19	7.20 ±5.00	13.10 ±7.46	2.163	0.159	0.107	.203	0.658	0.011
60°/sec Ratio right	140.5 ±24.63	133.6 ±22.57	128.6 ±18.90	140.6 ±23.67	0.191	0.667	0.011	2.849	0.109	0.137
60°/sec Ratio left	124.2 ±19.49	125.9 ±17.37	125.1 ±15.10	126.6 ±14.10	0.029	0.866	0.002	0.000	0.983	0.000
180°/sec right extension	45.40 ±21.30	50.50 ±12.10	55.20 ±20.12	54.70 ±10.90	11.213**	0.004	0.384	1.794	0.197	0.091
180°/sec left extension	51.00 ±19.84	53.60 ±12.43	57.30 ±25.71	56.70 ±11.64	4.998*	0.038	0.217	0.579	0.456	0.031

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Table 2. Isokinetic assessment before and after the intervention program (F-test - F, Partial Eta Square – PES) before intervention (1), and after intervention (2)

	Experimental Group	Control Group	Experimental Group	Control Group	Main effect			Interaction		
	1	1	2	2						
	Mean SD	Mean SD	Mean SD	Mean SD	F	p-value	PES	F	p-value	PES
180°/sec Extensional deficit	15.70 ±16.52	10.20 ±10.24	9.70 ±7.66	6.10 ±6.35	1.999	0.174	0.100	0.071	0.793	0.004
180°/sec right flexion	71.8 ±43.05	73.9 ±22.87	78.9 ±33.81	81.00 ±22.47	4.597*	0.046	0.203	0.000	1.00	0.00
180°/sec left flexion	73.20 ±35.95	70.30 ±15.87	80.00 ±30.95	71.40 ±19.43	1.326	0.265	0.069	0.690	0.417	0.037
180°/sec flexural deficit	24.80 ±20.76	25.20 ±17.33	11.20 ±5.14	12.8 ±8.42	7.718*	0.012	0.300	0.016	0.899	0.001
180°/sec Ratio right	146.4 ±37.11	133.1 ±53.40	140.5 ±27.11	150.5 ±30.41	0.330	0.573	0.018	1.356	0.259	0.070
180°/sec Ratio left	141.2 ±24.74	132.0 ±17.33	140.0 ±23.43	128.5 ±21.7	0.129	0.724	0.007	0.031	0.863	0.002
300°/sec right extension	46.5 ±19.93	40.5 ±15.87	41.20 ±17.91	40.9 ±8.34	0.324	0.576	0.018	0.439	0.516	0.024
300°/sec left extension	37.9 ±12.33	55.4 ±12.29	47.9 ±20.68	58.3 ±19.42	2.301	0.147	0.113	0.697	0.415	0.037
300°/sec Extensional deficit	27.20 ±18.91	22.30 ±27.13	17.5 ±8.70	26.5 ±20.47	0.258	0.618	0.014	1.648	0.215	0.084
300°/secright flexion	54.8 ±32.06	64.10 ±21.23	63.0 ±30.31	68.10 ±20.67	1.663	0.213	0.085	0.197	0.662	0.011
300°/secleft flexion	56.50 ±32.46	62.5 ±15.49	60.5 ±25.23	64.60 ±19.64	0.518	0.481	0.028	0.050	0.825	0.003
300°/sec flexural deficit	14.10 ±16.94	11.7 ±10.03	13.4 ±6.43	14.8 ±9.25	0.093	0.764	0.005	0.233	0.635	0.013
300°/sec Ratio right	125.7 ±75.82	163.5 ±46.51	154.3 ±33.63	157.4 ±68.08	0.410	0.530	0.022	0.974	0.337	0.051
300°/sec Ratio left	142.30 ±44.11	121.5 ±39.22	130.2 ±23.93	122.1 ±25.65	0.338	0.568	0.018	0.412	0.529	0.022

Note: Significance level *<0.01, **<0.05.

Discussion

Goniometry

The main findings of our study on goniometry are as follows. In the left adduction: Main effect with sig: 0.001.and PES: 0.471, with no present interaction. In the extension right: Lack of main effect, present interaction with sig: 0.034 and PES: 0.225. In flexion right: Main effect with sig: 0.008 and PES: 0.332, no interaction present. And in the left flexion: main effect with sig: 0.001 and PES: 0.439. The main findings at isokinetic dynamometry of our study are as follows. In the torque of 180°/s of extension right: Main effect with sig: 0.004 and PES: 0.384, no interaction present. On the torque of 180°/s of extension left: Main effect with sig: 0.038 and PES: 0.217, with no interaction present. On the torque of 180°/s of right flexion: Main effect with sig: 0.046 and PES: 0.203, with no present interaction. And on the 180°/s flexion deficit with sig: 0.012 and PES: 0.300, with no interaction present. More specifically at goniometry performed in this study, it is noted that in the measurement before the intervention program, statistically significant difference in both study and control groups was observed only in the left shoulder adduction test, with main effect shown. No interaction appeared to be present in this series. This appears to be in agreement with Dashottar et al. (2014), who made similar comparisons of angle measurements in the general population. There was a direct reduction in range of motion in all measurements except for adduction. In the present study, it appeared that there were better results on the first measurement than the second. In other words, there was a reduction in range of motion in both groups in the second measurement. Also, in the right extension with no main effect on any measurement, there was an interaction between the first and second measurement in the control group. From the results, it appeared that the control group had better adjustments in the second measurement. In flexion on both sides (left and right) had main effect with statistically significant difference in both groups (experimental and control). In right shoulder flexion, there was a main effect; this result is also strengthened by the strong load on the PES value. In left shoulder flexion, we also had a main effect and strong load on PES. It seems that from before both groups had better results compared to the second measurement, with no interaction. More specifically, there was a decrease in the range of motion of flexion of both shoulders in the initial measurement compared to the final measurement. In all other cases of the angle

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measurement, although in some there was strengthening and low, medium and high load was recorded in the PES value, no statistically significant difference was found. These results are in contrast to a study by Jurgel et al. (2005) conducted in patients with frozen shoulder. There it was shown that there were significant changes in shoulder range of motion after a 4-week rehabilitation program that improved range of motion in shoulder flexion, extension, abduction and adduction. However, these data should be interpreted with caution because it is difficult to compare the findings of this study with those of previous studies. This is due to differences in design, measurement methods and sample selection. The specific adaptations of our study are probably due to the fact that the intervention program given to the study group had only two stretching exercises, while it relied more on strengthening, which included five exercises. A second possible explanation is that the study group only applied the intervention program, possibly neglecting the range-of-motion exercises in the group training.

Isokinetic evaluation

Regarding the results of the isokinetic evaluation of the analysis of variance with Two Way ANOVAs with Repeated Measures, in the 180°/sec torque in extension on both sides (left and right), there was a main effect in the experimental group, having better results in the second measurement. This result is strengthened by the large load shown by the value of PES, revealing a large effect on both shoulders. However, there was no interaction reported at the series also.

In the present study it appeared that the experimental group had better results than the control group on the second measurement after the intervention program. Moreover, in the torque of 180°/sec in the right shoulder flexion there was a main effect in the experimental group, having better results in the second measurement. This result is strengthened by the large load shown by the value of PES, revealing a large effect. However, no interaction appeared to be present in this case either. In the 180°/sec deficit, there was also an effect in the experimental group, with the deficit decreasing more in the experimental group in the second measurement. This result is strengthened by the large load shown by the value of PES, revealing a large effect. However, there was no interaction appeared at this series, also. The better adaptation that the experimental group seemed to have to the above angular velocity suggests that the intervention program had, to some extent, a positive effect, increasing strength levels and reducing muscle deficits between the two shoulders. However, at the faster angular velocities, those of 300°/sec, no statistically significant difference in main effect was seen. The same seems to be the case in the interactions, where we also had no statistically significant difference. The only observation that could be mentioned is in the PES values, which at the 300°/sec speeds, had from low to moderate loading, revealing some kind of effect. In other words, we expected better adaptations at the faster angular velocities, i.e. those that more closely resemble the shoulder movement during the shoot. The most likely reason for this result is that, the smaller than expected adaptations were due to the small loading load demanded by the intervention program on the experimental group. In the literature, most studies report isometric measurements based on portable dynamometers and focus on internal and external rotation. The findings of the present study appear to be consistent with a previous, similar study by Cook et al. (1987), but that study involved baseball athletes. There it was reported that extensors produced greater movements than flexors at 180°/sec and 300°/sec. Although some useful conclusions can be drawn from the results of this study, the research was conducted with some limitations. More specifically, only handball players in the top leagues participated. Also, due to COVID-19, the study included mainly male and female athletes from Northern Greece and the study lasted more than one season.

Conclusions

Evaluating the sample of the present study, the intervention program was found to have a partially beneficial effect in some areas and to varying degrees. More specifically, in the goniometry of the experimental group we had a reduction in range of motion in both shoulder flexion, left shoulder adduction, and right shoulder extension. Therefore, the benefit of the intervention program on range of motion was not demonstrated. However, in isokinetic dynamometry we had positive adaptations in extension and flexion at some angular velocities. These are not the requested angular velocities, similar to shooting in handball, where most injuries occur. Perhaps in future similar studies, incorporate more stretching and more powerful strengthening exercises. Further analysis is needed to explore this issue with additional data, for example, a larger sample and research in wider geographical areas. In addition, the research should be conducted over a longer period of time with a greater number of functional exercises. Also, a specific outcome indicator should be defined for the whole process for the shoulders and the upper limbs in general, as is the case for the lower limbs, knee, and ankle. The observed adaptations of such interventional programs in handball athletes are useful and provide important information for the athletes (coaches, medical team, administrators), while providing feedback to the athletes.

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