Faculty of Sports of the University of Porto

Effectiveness of a Remotely Monitored Therapeutic Exercise Program on the Torque of Shoulder Rotator Muscles in Elite Swimmers

The present thesis was written to achieve the PhD degree included in the doctoral course in Physiotherapy by the Faculty of Sport of the University of Porto under Decree-Law nº65/2018 from August 16th.

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Para ser grande, sê inteiro: nada
Teu exagera ou exclui.
Sê todo em cada coisa. Põe quanto és
No mínimo que fazes.
Assim em cada lago a lua toda
Brilha, porque alta vive.

Ricardo Reis, 14-2-1933

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF PUBLICATIONS

This Doctoral Thesis is based on the following original studies, which are referred to in the text by their Roman numerals, respectively:

I. Tavares, N., Dias, G., Carvalho, P., Vilas-Boas, J. P., & Castro, M. A. (2022). Effectiveness of therapeutic exercise in musculoskeletal risk factors related to swimmer's shoulder. *Eur J Investing Health Psychol Educ*, *12*(6), 601-615. https://doi.org/10.3390/ejihpe12060044

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The following oral presentations and posters were presented at national and international scientific events.

Oral presentations

1) Tavares, N., Vilas-Boas, J.P., & Castro, M.A. (2023). Difference in the electromyographic activity of serratus anterior between two preventive exercise programs for swimmer's shoulder: elastic band versus weight. Presented at the X Congresso da Sociedade Portuguesa de Biomecânica, Figueira da Foz, Portugal.
2) Tavares, N., Castro, M.A., & Vilas-Boas, J.P. (2023). An electromyographic analysis of shoulder muscles in scapular punches exercise in swimmers. Presented at the X Congresso da Sociedade Portuguesa de Biomecânica, Figueira da Foz, Portugal.
3) Tavares, N., Vilas-Boas, J.P., & Castro, M.A. (2025). Effectiveness of a 12-week elastic band exercise program for swimmer's shoulder on rotator cuff strength and balance in competitive swimmers. Presented at the XI Congresso da Sociedade Portuguesa de Biomecânica, Sesimbra, Portugal.

Posters

1) Tavares, N., Vilas-Boas, J. P., & Castro, M. A. (2024). Effect of two 12-week prevention exercise programs on swimmer's shoulder epidemiology in competitive swimmers. Presented at the 7th International Olympic Committee World Conference on Prevention of Injury and Illness in Sport, Monaco.
2) Tavares, N., Vilas-Boas, J. P., & Castro, M. A. (2025). Effectiveness of exercise programs for swimmer's shoulder prevention in competitive swimmers: a randomized controlled trial. Presented at the World Physiotherapy Congress 2025, Tokyo, Japan.
3) Tavares, N., Vilas-Boas, J. P., & Castro, M. A. (2025). Impact of two dry-land exercise programs on the symmetry of shoulder rotator cuff strength and rotational muscle balance between dominant and non-dominant shoulders in swimmers. Presented at the Biomechanics – Sport and Clinics 2025, Porto, Portugal.

RESUMO

O ombro do nadador, lesão desportiva mais comum em nadadores, é definido por uma dor na região anterior do ombro resultante da aplicação desadequada ao longo do tempo de energia cinética proveniente do gesto desportivo, sobre os tecidos moles da região subacromial. De forma a prevenir esta lesão, o exercício terapêutico tem surgido como uma intervenção com bons resultados. No entanto, ainda existem bastantes dúvidas sobre a caracterização desta intervenção ou a dimensão do efeito provocado. O principal objetivo desta tese foi avaliar a efetividade de programas de exercício específicos em fatores de risco músculo-esqueléticos e na prevalência do ombro do nadador. Com esse intuito, recrutaram-se 30 nadadores de competição, posteriormente divididos através de randomização estratificada em dois grupos de intervenção e num grupo de controlo. Tendo por base uma revisão sistemática da literatura científica existente e uma posterior análise eletromiográfica, selecionaram-se e implementaram-se 2 programas de 5 exercícios durante 12 semanas. Um dos grupos experimentais efetuou um programa com halteres, e o outro um programa com banda elástica. Ambos foram supervisionados individualmente por um fisioterapeuta. Adicionalmente, existiu um grupo de controlo que efetuou uma intervenção placebo. No início e no final destas 12 semanas, recorrendo ao dinamómetro isocinético *Biodex System 3*, avaliou-se o torque máximo dos rotadores internos e externos de ambos os ombros, nas suas ações concêntrica e excêntrica, a 60º/s, 120º/s e 180º/s. Posteriormente, foram calculados os rácios convencionais e funcionais do ombro. Para além da avaliação deste fator de risco, durante 6 meses fez-se um registo dos episódios de lesão desportiva e respetiva caracterização nos participantes. No que diz respeito aos resultados, no geral verificou-se uma diminuição do torque máximo dos rotadores do ombro, mais pronunciada no grupo de controlo. Os grupos experimentais apresentaram um maior equilíbrio dos rácios avaliados no final das 12 semanas. Não foram observadas diferenças significativas entre os 2 programas preventivos. Por último, registaram-se menos episódios desta lesão desportiva nos grupos experimentais. Em conclusão, a inclusão de um programa criterioso nas rotinas semanais dos nadadores de competição parece ser uma excelente estratégia preventiva desta lesão desportiva.

ABSTRACT

Swimmer's shoulder is the most common injury among swimmers. It is a painful condition located in the anterior region of the shoulder, caused by the inappropriate application of kinetic energy from swimming techniques over time. This repetitive motion affects the soft tissues in the subacromial region of the shoulder. Therapeutic exercise has been identified as an effective intervention to prevent this injury. However, many questions remain regarding the characterization of this intervention and the magnitude of its effects. The main objective of this thesis was to evaluate the effectiveness of targeted exercise programs on musculoskeletal risk factors and on the prevalence of swimmer's shoulder. To achieve this aim, 30 competitive swimmers were recruited and randomly assigned to two intervention groups and a control group using stratified randomization. After reviewing the current scientific literature and conducting an electromyographic analysis, 2 programs consisting of 5 exercises each were chosen and implemented over 12 weeks. One experimental group performed a weights exercise program, while the other participated in an elastic band program. Both groups received individual supervision from a physiotherapist. Additionally, there was a control group that engaged in a placebo intervention. Before and after 12 weeks, the peak torque of the internal and external rotators of both shoulders was assessed using the isokinetic dynamometer Biodex System 3. This assessment was performed during both concentric and eccentric actions at angular velocities of 60º/s, 120º/s, and 180º/s. Following these evaluations, the conventional and functional ratios of the shoulders were calculated. Additionally, over 6 months, swimmer's shoulder episodes and respective characterization were registered among the participants. In general, the results indicated a decrease in the peak torque of the shoulder rotators, with a more pronounced decline observed in the control group. The experimental groups demonstrated improved rotator cuff balance at the end of the 12 weeks. There were no significant differences between the effects of the two preventive programs. Additionally, the experimental groups reported fewer episodes of swimmer's shoulder. In conclusion, integrating a specific program into the weekly routines of competitive swimmers appears to be an effective strategy for preventing swimmer's shoulder injury.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

A

ABD – Abduction

AD – Anterior deltoid

ADD – Adduction

AgCl – Silver chloride

Al – Aluminum

ASCM - American College of Sports Medicine

C

CDRSP – Centre for Rapid and Sustainable Product Development

CEIPC – Comissão de Ética do Instituto Politécnico de Coimbra

CEMMPRE – Centre for Mechanical Engineering, Materials and Processes

CG – Control group

CIAFEL – Centro de Investigação em Atividade Física, Saúde e Lazer

CIFI2D – Centre for Research, Training, Innovation and Intervention in Sport

CKC – Closed kinetic chain

con – concentric

conER:conIR – Concentric external rotation divided by concentric internal rotation

CR – Conventional ratio

D

Dwg – Downgraded

E

EBP – Elastic band program

ecc – eccentric

eccER:conIR – Eccentric external rotation divided by concentric internal rotation

eccER:eccIR – Eccentric external rotation divided by eccentric internal rotation

eccIR:conER – Eccentric internal rotation divided by concentric external rotation

e.g. – For example

EG – Experimental group

EMG – Electromyography

ER – External rotation

EXT – Extension

F

FCT – Fundação para a Ciência e Tecnologia

FLX – Flexion

FR – Functional ratio

G

G1 – Group 1

G2 – Group 2

GIRD – Glenohumeral internal rotation deficit

GRADE – Grading of Recommendations, Assessment, Development, and Evaluations

H

h – Hours

HABD – Horizontal abduction

HADD – Horizontal adduction

HT – Humeral torsion

I

I2A – Instituto de Investigação Aplicada

IBM – International Business Machines Corporation

IR – Internal rotation

IS – Infraspinatus

J

JPS – Joint position sense

L

LABIOMEP-UP – Porto Biomechanics Laboratory-University of Porto

LT – Lower trapezius

M

MATLAB – Matrix Laboratory

MD – Middle deltoid

MeSH – Medical Subject Headings

MT – Middle trapezius

MVIC – Maximum voluntary isometric contraction

N

NA – Not applicable

NR – Not reported

O

OKC – Open kinetic chain

P

p – p-value

PEDro – Physiotherapy Evidence Database

PF – Peak force

PM – Pectoralis major

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PST – Posterior shoulder tightness

PT – Peak torque

Q

QREN – Quadro de Referência Estratégico Nacional

R

RCT – Randomized controlled trial

Rep – Repetition

RM – Repetition maximum

RoB2 – Risk of Bias 2

ROM – Range of motion

RPE – Rate of perceived exertion

S

SA – Serratus anterior

SD – Standard deviation

SENIAM – Surface Electromyography for the Non-Invasive Assessment of Muscles

SP – Standing position

SPSS – Statistical Package for the Social Sciences

SSI – Swimmer's shoulder injury

T

TRROM – Total rotational range of motion

U

USA – United States of America

UT – Upper trapezius

V

VAS – Visual Analogue Scale

W

wk – Week

WP – Weight program

CHAPTER I

- General introduction

The conceptual model of van Mechelen et al. (1992) is the rationale behind this doctoral thesis, and it justifies the execution order of the different studies that compose it. According to this conceptual model, four steps constitute the sports injury prevention cycle (Figure 1.1).

- The first step is to elaborate a functional profile of “normal” athletes for each sport and identify the most prevalent injuries in each context (Cools et al., 2021; van Mechelen et al., 1992).
- In the second step, the etiology and the mechanisms of sports injuries are collected (van Mechelen et al., 1992). At this stage, it is necessary to survey the various risk factors that characterize each sport’s injury. Sports injury risk factors may be modifiable (e.g., strength and proprioception) or non-modifiable (e.g., age and sex) (Asker et al., 2018; Cools et al., 2021; Tavares et al., 2022). The possibility of modification and the high impact on sports injury prevention mean that it is given greater emphasis on modifiable factors, especially in a clinical context (Feijen et al., 2021; Schlueter et al., 2021).
- In the third step of the model, a preventive measure is introduced, such as an exercise program, changing the rules of the sport, introducing protective equipment, or adapting the quality of sports equipment (Bahr & Krosshaug, 2005; Cools et al., 2021; van Mechelen et al., 1992).
- Finally, the fourth step evaluates the effectiveness of the preventive intervention. It's fundamental to investigate the modification of risk factors and the impact of the implemented intervention on injury epidemiology, previously assessed in the first step (Cools et al., 2021; van Mechelen et al., 1992).

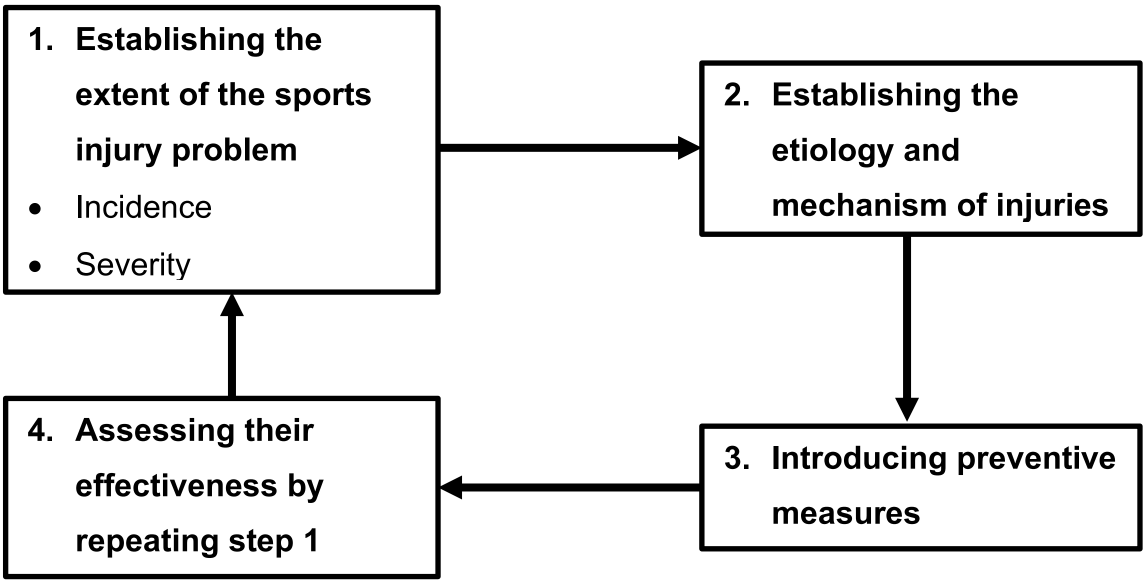

Figure 1.1. The "sequence of prevention" of sports injuries (adapted from van Mechelen et al., 1992).

Elite swimmers swim approximately 14,000 meters daily, which results in about 2,500 shoulder revolutions per workout and 16,000 per training week (Struyf et al., 2017). Many of these revolutions are performed in sequence, without any rest for the muscles to recover (Cools et al., 2021; Struyf et al., 2017). This large number of shoulder revolutions can easily overload the soft tissue structures around the shoulder and lead to an overuse injury (Struyf et al., 2017).

Regarding all possible injuries in swimmers, 2.6–3.0 injuries are reported for every 1000 hours of training, with about half of these injuries occurring in the shoulder, the most affected anatomical region (McKenzie et al., 2023; Trinidad et al., 2021).

Swimmer's shoulder is the most prevalent injury in swimmers (Feijen et al., 2020; Schlueter et al., 2021; Struyf et al., 2017; Walker et al., 2012), and results from the excessive impingement of the rotator cuff under the coracoacromial arch during the technical gesture of swimming (Hill et al., 2015; Struyf et al., 2017; Tavares et al., 2022). It's estimated that around 40–91% of swimmers have this clinical problem at least once throughout their career (Drigny et al., 2020; Matzkin et al., 2016), and 20–35% of competitive swimmers experience a training or competition time loss due to this injury each year (Drigny et al., 2020; Gaunt & Maffulli, 2012).

Several types of risk factors related to a swimmer´s shoulder are described in the literature, such as musculoskeletal, training, epidemiological, physiological, and lifestyle factors (Feijen et al., 2021; Feijen et al., 2020; Gaunt & Maffulli, 2012; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017; Tavares et al., 2022; Wanivenhaus et al., 2012). Specifically, the risk factors with the highest injury predictive value in this context are the shoulder rotator strength and endurance, the swimmer's competitive level, the training load, the incorrect hand entry during the technical swimming gesture (Feijen et al., 2021; McKenzie et al., 2023), and a previous history of shoulder injury (McKenzie et al., 2023).

Of these risk factors, shoulder rotator strength and endurance should be subject to constant assessment by the physiotherapist throughout the swimming season, because they are modifiable factors with a lot of influence on the onset of this injury (Feijen et al., 2021; McKenzie et al., 2023; Tavares et al., 2022). Due to many training and competition events, there is a normal tendency during the season for a progressive imbalance of shoulder rotator ratios in elite swimmers (So et al., 2022).

Usually, in overhead sports athletes, the external rotation (ER) and the internal rotation (IR) peak torques (PT) in a concentric or eccentric action, measured through the isokinetic dynamometer (Batalha & Silva, 2013; Collado-Mateo et al., 2018; Drigny et al., 2020; Olivier & Daussin, 2018), are the main outcomes collected to evaluate these risk factors (Batalha & Silva, 2013; Drigny et al., 2020; So et al., 2022). With these outcomes, unilateral conventional or functional ER/IR ratios are commonly calculated to assess rotator cuff muscle balance (Batalha & Silva, 2013; Feijen et al., 2020; Wanivenhaus et al., 2012).

Strength prevention programs with a few exercises performed out of the water and in an open kinetic chain appear to have good results in minimization of rotator cuff imbalance and consequently preventing the swimmer's shoulder injury (Tavares et al., 2022; Yoma et al., 2022), However, some authors report no effect of these preventive programs on strength and endurance variables in swimmers (Hibberd et al., 2012; Swanik et al., 2002) and other overhead sports athletes (Fredriksen et al., 2021). Furthermore, it is necessary to check how long the preventive program should be to produce an effect on these risk factors, verify what exercises have more potential to prevent this injury, and clarify the impact of individual monitoring on the program execution (Wright et al., 2021).

Therefore, the primary objective of this thesis was to investigate the effect of preventive exercise programs on variables related to shoulder rotator strength and endurance, and to assess their impact on the incidence of swimmer's shoulder injury in competitive swimmers. For that, it was necessary to characterize the swimmer's shoulder, evaluate all risk factors inherent to this injury, identify and test which exercises should be included in preventive programs, implement the intervention, and assess the variables related to the relevant risk factors as well as their impact on the epidemiology of the injury.

This thesis is divided into six chapters.

- **Chapter I** provides a general introduction and explains in detail the conceptual injury prevention model that supports the organization of the thesis. After that, the main objectives of the thesis are described, and each chapter is briefly presented.
- **Chapters II to V** were dedicated to the presentation of each study performed during the doctoral process in a journal article format, including an introduction, methodology, results, discussion, conclusion, and references.
- **Chapter II** consists of a systematic review that supports the other studies. It started with an analysis of a swimmer's shoulder risk factors. After that, a detailed review of the impact of different exercise programs on the musculoskeletal risk factors for the most prevalent injury in swimming is performed. This first step tries to find exercises with previous good results to test in the next steps of the thesis.
- **Chapter III** contains two exploratory studies followed by a clinical trial based on the established methodology. This chapter presents an electromyographic (EMG) analysis of two shoulder strength programs, each comprised of five exercises. This analysis aims to provide greater reliability and justification for the exercises, materials, and loads evaluated in the subsequent phase.
- **Chapter IV** includes three randomized controlled trials that applied and evaluated the effects of two preventive exercise programs previously analyzed in Chapter II. A sample of competitive swimmers performed the

respective intervention for 12 weeks. Before and after the application, the swimmers underwent an assessment using an isokinetic dynamometer. The three randomized controlled trials reported an intra-group and an inter-group analysis of the effect of each preventive exercise program on rotator cuff strength and balance variables.

- **Chapter V** analyzes the epidemiology of swimmer's shoulder in competitive swimmers who have previously participated in the anterior step. This chapter investigated the impact of the prevention exercise programs on injury epidemiology indicators over 6 months of the swimming season.
- **Chapter VI** presents the final considerations of this thesis, summarizing the main conclusions drawn from all studies. Additionally, it discusses the limitations, practical implications, and suggestions for future research in this field.

Finally, the appendices presented documents supporting this thesis's realization and participation in scientific events.

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CHAPTER II

- **Study I –** Effectiveness of Therapeutic Exercise in Musculoskeletal Risk Factors Related to Swimmer's Shoulder

STUDY I

Systematic Review

Effectiveness of Therapeutic Exercise in Musculoskeletal Risk Factors Related to Swimmer's Shoulder

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ABSTRACT

Background: Therapeutic exercise seems to minimize musculoskeletal risk factors related to swimmer's shoulder. However, there is an absence of a qualitative evaluation of these programs and great variability regarding the characteristics of exercises. The objective of this review was to identify, evaluate, and compare exercise programs used to minimize musculoskeletal risk factors related to swimmer's shoulder. Methods: PubMed, Cochrane Library, ScienceDirect, and Medscape were searched during January 2022. The research was limited to meta-analyses, systematic reviews, and randomized controlled trials written in English, Spanish, and Portuguese without publication time. The research papers had swimmers as the population, compared an exercise program with another program or without intervention, and had as outcomes musculoskeletal risk factor variables. Results: Eleven articles were considered for analysis. There were three positive effects of strength programs on shoulder rotators' strength and endurance, two positive effects of strength and stretching programs on shoulder posture, and one positive effect of a stretching program on shoulder range of motion and a plyometric program on proprioception. Conclusions: There is high heterogeneity and little methodological quality evidence about the theme. However, strength programs with five or fewer open kinetic chain exercises performed out of the water seems to lead to better results in the swimmer's shoulder prevention.

Keywords: Swimming, Therapeutic exercise, Shoulder, Swimmer's shoulder, Injury prevention.

INTRODUCTION

Elite swimmers swim around 14,000 meters daily, which results in about 2,500 shoulder revolutions each workout and 16,000 each training week. This large amount of shoulder revolutions can easily overload soft tissue structures around the shoulder and create an overuse injury (Struyf et al., 2017). Swimmer's shoulder is the most common injury in swimmers and is defined as a painful syndrome that occurs mostly in the anterior region of the shoulder and results from repetitive impingement of the rotator cuff under the coracoacromial arch during the technical gesture of swimming (Hill et al., 2015; Struyf et al., 2017). It is estimated that 91% of competitive swimmers experience this injury during their sports career (Feijen et al., 2020; Struyf et al., 2017), leading to the major cause of missed practice (Feijen et al., 2020; Hill et al., 2015; Schlueter et al., 2021; Walker et al., 2012). Described in the literature are several types of risk factors related to swimmer's shoulder, such as musculoskeletal, training, epidemiological, physiological, and lifestyle factors (Feijen et al., 2021; Feijen et al., 2020; Gaunt & Maffulli, 2012; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017; Wanivenhaus et al., 2012) (Table 2.1). Musculoskeletal risk factors have great importance in the clinical context because they are modifiable factors and some of them have good power to predict this injury (Feijen et al., 2021).

Table 2.1. Summary table of main risk factors related to swimmer's shoulder.

Type	Risk Factors
Musculoskeletal	Strength and endurance (Feijen et al., 2021; Hill et al., 2015; Schlueter et al., 2021; Wanivenhaus et al., 2012), shoulder posture (Feijen et al., 2021; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017), proprioception (Hill et al., 2015; Struyf et al., 2017), glenohumeral instability (Hill et al., 2015; Struyf et al., 2017; Wanivenhaus et al., 2012), shoulder range of motion (Feijen et al., 2021; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017), and scapular dyskinesia (Feijen et al., 2021; Hill et al., 2015; Struyf et al., 2017).
Training	Competitive level (Feijen et al., 2021; Hill et al., 2015), style (Hill et al., 2015; Schlueter et al., 2021), technique (Feijen et al., 2021; Wanivenhaus et al., 2012), distance (Gaunt & Maffulli, 2012; Hill et al., 2015), volume (Feijen et al., 2021; Feijen et al., 2020; Hill et al., 2015), load, intensity, years of experience, breathing side, training equipment, cross training, and stretching (Hill et al., 2015).
Epidemiological	Sex (Hill et al., 2015), age, and previous injuries (Feijen et al., 2020; Hill et al., 2015).
Psychological	Subjective pain perception and beliefs (Feijen et al., 2021; Feijen et al., 2020).
Lifestyle	Social status (Hill et al., 2015).

In the last two decades, several studies have been carried out to test some prevention exercise programs to minimize swimmer’s shoulder musculoskeletal risk factors (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Van de Velde et al., 2011). Most of them have had a positive effect, favorable to therapeutic exercise when compared to no intervention, leading to the assertion that therapeutic exercise seems to be one of the principal tools available to prevent this injury (Batalha et al., 2015; Chepeha et al., 2018; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002). Mostly, the impact of these therapeutic exercise programs has been studied on variables that characterize the strength and endurance of the shoulder musculature (Batalha et al., 2018; Batalha et al., 2015; Hibberd et al., 2012; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Van de Velde et al., 2011), which seems to be the musculoskeletal risk factor with the highest rate of injury prediction (Feijen et al., 2021). However, although in a minority, some studies have investigated the impact of therapeutic exercise on other important swimmer’s shoulder risk factors such as posture (Kluemper et al., 2006; Lynch et al., 2010), proprioception (Swanik, Lephart, et al., 2002), shoulder range of motion (ROM) (Chepeha et al., 2018), and scapular dyskinesia (Hibberd et al., 2012). The great variability regarding the characteristics of the prevention exercise programs tested, as well as the lack of a detailed qualitative evaluation of each study, makes it impossible to extract strong conclusions that guide and support clinical practice. Currently, although therapeutic exercises are used in the swimming context, there are no criteria about the best type of exercise, what characteristics it should have, or what its purpose is in the context of prevention. This adds interest to the present study that attempted to fulfill the lack of information about the real effectiveness of therapeutic exercises for swimmers’ shoulder musculoskeletal risk factors.

The main objective of this systematic review was to identify, evaluate, and compare the effectiveness of different therapeutic exercise programs reported in the scientific literature in changing musculoskeletal risk factors related to swimmer’s shoulder: strength and endurance, shoulder posture, proprioception, glenohumeral instability, shoulder range of motion, and scapular dyskinesia.

METHODOLOGY

The protocol followed in this review began with the search and selection of individual studies, quality assessment of the studies, data collection, analysis and interpretation of results, and extraction of conclusions. To structure the systematic review, the PRISMA recommendations were used (Page et al., 2021) (Table 2.6). This systematic review was carried out with the participation of 5 researchers. Two researchers conducted the entire process of creating the systematic review and made the final decision on the selection of studies, while the others were responsible for supervising the process and the final evaluation of the review.

Eligibility Criteria

The research was limited to meta-analyses, systematic reviews, and randomized controlled trials (RCTs) written in English, Spanish, or Portuguese and published in scientific journals. There were no restrictions on the year of publication of the articles sought. The population considered for the searched articles included competitive swimmers of any age without shoulder pain. All articles with athletes from other water sports, such as water polo, synchronized swimming, surf, or sports that combined swimming with other sports activities, such as aquathlon or triathlon, were excluded. Studies that performed a comparison between a therapeutic exercise program with another program or with no intervention were sought. The outcomes were variables that characterize musculoskeletal risk factors described in Table 2.1. All articles that did not meet the criteria presented above related to study design, language, population, intervention, comparison, and outcomes were excluded from this systematic review. All studies that investigated the acute effects of therapeutic exercise were excluded, and only articles that studied the effect of intervention applied for a minimum of 2 weeks were accepted.

Information Sources

To conduct bibliographic research, the PubMed, Cochrane Library, ScienceDirect, and Medscape databases were consulted from January 1st to 31st, 2022.

Search Strategy

The criteria applied to each database, as well as the descriptors used in the research, are listed in Table 2.2.

Table 2.2. Databases, criteria applied, and descriptors used in bibliographic research.

Database	Applied Criteria	Descriptors
PubMed	#1 and #2 without MeSH terms and #3 with MeSH terms.	#1: (“swimming” OR “swimmer”) AND (“shoulder” OR “shoulder injury” OR “swimmer’s shoulder”) #2: (“swimming” OR “swimmer”) AND (“shoulder” OR “shoulder injury” OR “swimmer’s shoulder”) AND (“prevention” OR “injury prevention” OR “injury risk factors” OR “risk factor”) #3: (“swimming”) AND (“shoulder pain” OR “shoulder injuries”) AND (“exercise” OR “exercise therapy” OR “exercise movement techniques”) AND (“muscle strength” OR “range of motion, articular” OR “joint instability” OR “proprioception” OR “posture”)
Cochrane Library	Limited to study design: Cochrane reviews and trials.	#4: “swimming” AND “shoulder” #5: “swimming” AND “shoulder pain”
Science Direct	Limited to study design: review and research articles, and in the research area: medicine and dentistry and nurse, and health professions.	#6: (“swimming”) AND (“shoulder pain”) AND (“exercise” OR “exercise therapy”) AND (“risk factor OR prevention”)
Medscape	Research carried out in the Medline section	#7: (“swimming” OR “swimmer”) AND (“shoulder” OR “shoulder pain” OR “swimmer’s shoulder”) AND (“exercise” OR “exercise therapy”)

Selection Process

After performing the bibliographic search, repeated articles were verified and excluded. Then, all titles were read and studies whose population were not swimmers or whose anatomical region under study was not the shoulder were removed. Subsequently, the abstracts were read, and all articles that did not have the qualifying study design for this systematic review were excluded. Furthermore, all articles whose intervention was not a therapeutic exercise program and whose results were not variables that characterize musculoskeletal risk factors related to swimmer's shoulder were also excluded. Finally, the articles were read in full, and the studies that only investigated the acute effect of the therapeutic exercise were removed.

Data Collection Process

The present data in this systematic review were collected by reading the selected articles, and it was used the information expressed in the published full text. Article identification, eligibility criteria, number of participants, sample characteristics, study design, type of intervention, the outcome of interest, number of dropouts, statistical significance, and, if available, study limitations were collected.

Data Items

The independent variables of this review were swimmers and therapeutic exercise programs. All variables characterizing musculoskeletal risk factors for swimmer's shoulder were dependent variables:

- Strength and endurance: PT or peak force (PF), time to PT or PF, PT or PF to body weight ratio, torque decrement, amortization time, conventional and functional agonist–antagonist PT or PF ratios, and fatigue index.
- Shoulder posture: acromial distance, forward head angle, total scapular distance, and pectoralis minor length.
- Proprioception: joint position sense (JPS), kinesthesia, and force sense.
- Glenohumeral instability: inferior, anterior, and posterior displacement of the humeral head.
- Shoulder ROM: physiological shoulder ROM of IR, ER, flexion (FLX), extension (EXT), adduction (ADD), abduction (ABD), horizontal adduction (HADD), and horizontal abduction (HABD); glenohumeral internal rotation deficit (GIRD), total rotational range of motion (TRROM), posterior shoulder tightness (PST), and humeral torsion (HT).

- Scapular dyskinesia: mean difference in the position of the scapula evaluated in IR and ER, elevation and depression, protraction and retraction, anterior and posterior tipping, and upward and downward rotation.

Study Risk of Bias Assessment

The assessment of the risk of bias in the studies included in this review was performed by applying the PEDro scale criteria (de Morton, 2009). Whenever the article was already classified in the Physiotherapy Evidence Database (https://pedro.org.au accessed on 13 February 2022), this score was accepted. When this did not happen, the article was read in its entirety and subsequently evaluated by two authors (N.T. and M.A.C.), using the available criteria. The final score higher than 7 was attributed to a study with "high quality", between 5 and 6 for "moderate quality" was considered, and scores lower than 4 were of "low quality" (Pereira et al., 2022).
Additionally, the RoB2 tool (https://riskofbias.info/welcome/rob-2-0-tool accessed on 20 February 2022) from Cochrane was used. The "robvis (visualization tool)" (https://mcguinlu.shinyapps.io/robvis accessed on 20 February 2022) was used to access the risk of bias characterization charts of the individual studies. A generic evaluation grid was chosen, and two types of charts: a summary plot, where an assessment of certain biases was carried out in each study, and a traffic light plot, which revealed the global percentage of studies that contained the different biases.

Effect Measures

If possible, the measures collected from the individual studies were the effect size, the mean difference between sample groups, the respective confidence interval, and its statistical significance (*p*-value).

Certainty Assessment

Certainty assessment of the positive effects was performed by two authors (N.T. and M.A.C.) based on four domains of GRADE assessment: risk of bias, inconsistency, indirectness, and imprecision (Higgins et al., 2023).

RESULTS

Study Selection

After consulting PubMed, Cochrane Library, ScienceDirect, and Medscape databases, a total of 918 articles were found, of which 157 were excluded because they were repeated in more than one database. Then, the title was read, and all articles that did not have swimmers as a population and that did not investigate the shoulder were excluded, leaving 225 articles. Of these publications, the abstract was read, and all study designs that were not meta-analyses, systematic reviews, or RCTs were excluded. In the same way, articles that did not compare an exercise program with another program or with no intervention and that did not investigate the impact of exercise on the variables that characterize the musculoskeletal risk factors in swimmer's shoulder were also excluded. Finally, the 13 remaining articles were fully read, and 2 studies were excluded from this systematic review as they investigated the immediate effects of a therapeutic exercise intervention (Figure 2.1).

Study Characteristics

The characteristics of the individual studies are described in Table 2.3.

Risk of Bias in Studies

The assessment of the risk of bias in the individual studies is described in Table 2.4 and Figure 2.2.

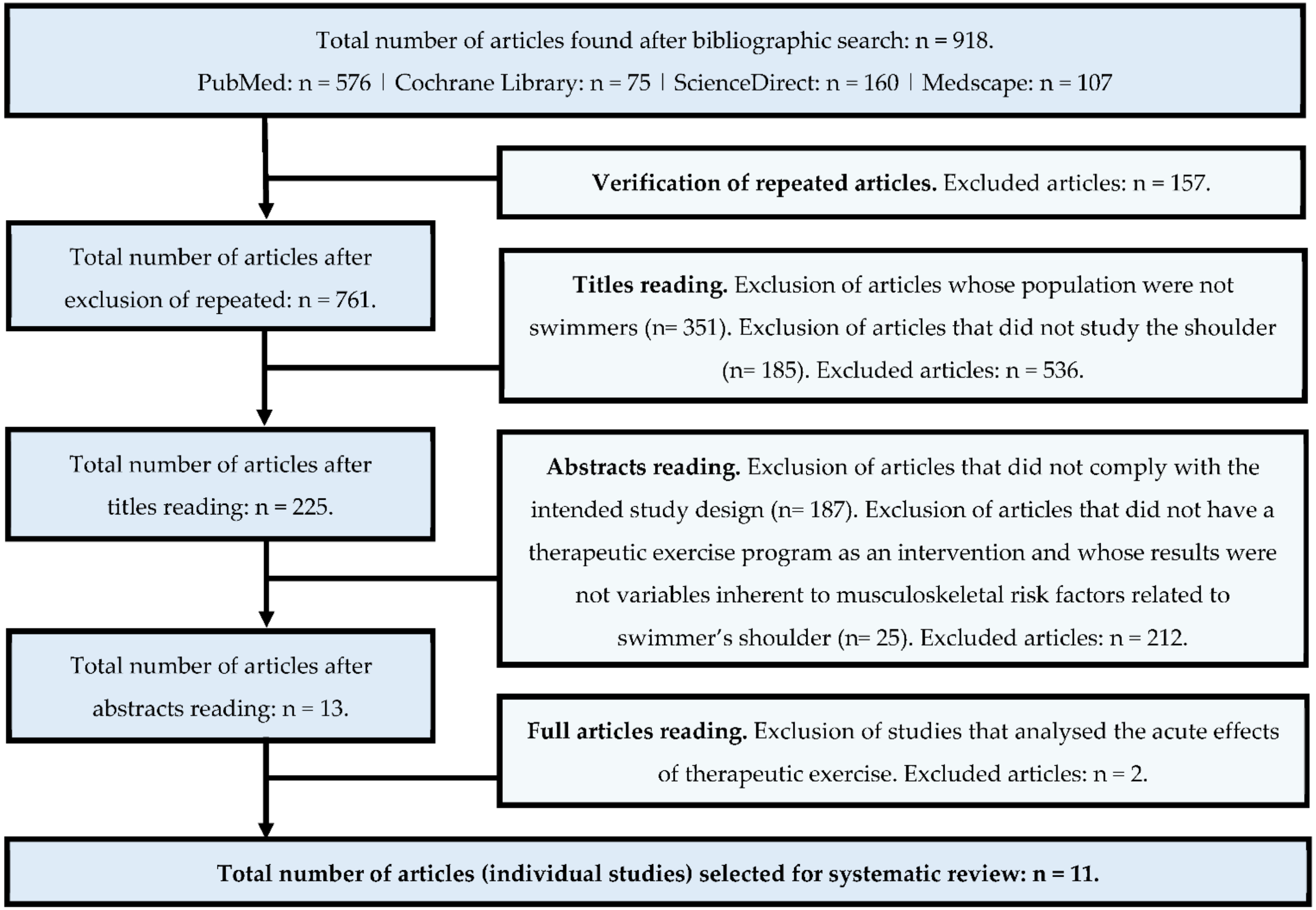

Figure 2.1. The study selection process for the systematic review.

Table 2.3. Individual study characteristics: population, intervention, and conclusion.

Study	Sample	Interventions	Name of Exercises	Exercise Program Characteristics	Conclusion
Swanik, Lephart, et al. (2002)	24 competitive female swimmers with an average of 20.0 ± 1.1 years.	EG: Plyometric exercises. CG: No intervention.	Concentric IR using an elastic tube. Pitchback system: throw and catch a weighted ball.	Duration: 6 wks. Frequency: 2× wk. Sets: 3. Reps: 15. Progressions: 1st 2 wks – elastic band; after – pitchback system (ball weight 2–8 Kg), cycles – 1 throwing every 2 s. Moment of realization: No reference. Monitoring: Investigator.	Significant improvement after the plyometric program in kinesthesia and some muscle performance characteristics.
Swanik, Swanik, et al. (2002)	26 swimmers	EG: Functional training. CG: No intervention.	Elastic-tubing exercises: IR at 90°, ER at 90°, HABD and FLX, HADD and EXT. Prone exercises: ER with 120° ABD, ER with 90° ABD. Push-up plus.	Duration: 6 wks. Frequency: 3× wk. Sets: 3. Reps: 15. Progressions: started – 2nd resistance level elastic band and 2 Kg prone exercises; progresses when performing all sets without difficulty. Moment of realization: Preseason. Monitoring: Swimming coach.	No differences were found between groups in muscle performance parameters. There was a significant decrease in the incidence of shoulder pain.
Kluemper et al. (2006)	39 competitive swimmers with a mean age of 16 ± 2 years.	EG: Strength and stretching exercises. CG: No intervention	Strength exercises: Scapular retraction, ER at 90°, Y's. Stretching exercises: Pectoral minor stretching, pectoralis major stretching.	Duration: 6 wks. Frequency: 3× wk. Strength – Sets: 3. Reps: 15. Stretching – Sets: 2. Duration: 30 s. Progressions: Initial resistance – 5 reps of each strength exercise; wk1 – 3 × 10; wk2 – 3 × 15; wk3 – 3 × 20; wk4 – 3 × 10 + difficult elastic band; wk5 – 3 × 15; wk6 – 3 × 20. Moment of realization: After warm-up. Monitoring: Investigators.	The EG significantly reduced the distance from the acromion to the wall in the relaxed standing position compared to the CG.

Lynch et al. (2010)	28 competitive swimmers between 17 and 23 years.	EG: Strength and stretching exercises. CG: No intervention.	Strength exercises: Y to W, L to Y, elbow push-up. Stretching exercises: Pectoralis flexibility, chin tucks.	Duration: 8 wks. Frequency: 3× wk. Strength – Sets: 3. Reps: 10. Stretching – Sets: 10. Duration: 5 s. Progressions: No progressions. Moment of realization: During regular dry-land training. Monitoring: Investigator.	The intervention carried out led to a decrease in head and shoulder forward posture in young competitive swimmers.
Van de Velde et al. (2011)	18 swimmers with an average of 14.7 ± 1.3 years.	G1: Strength exercises. G2: Endurance exercises.	Serratus anterior: Dynamic hug movement, elbow push-up. Lower trapezius: ER with a dumbbell, bilateral HABD + scapular retraction with 2 dumbbells.	Duration: 12 wks. Frequency: 3× wk. Strength – Sets: 3. Reps: 10. Endurance – Sets: 3. Reps: 20. Progressions: Loads assessment after 6 wks. Moment of realization: Before water training. Monitoring: Physiotherapist.	Both exercise programs increased absolute strength, but neither had a positive effect on scapular muscle endurance parameters.
Hibberd et al. (2012)	37 young competitive swimmers.	EG: Strength and stretching exercises. CG: No intervention	Strength: Shoulder FLX, Shoulder EXT, IR at 90°, ER at 90°, throwing acceleration, throwing deceleration, low scapular rows, scapular punches, Y's, T's, W's. Stretching: Sleeper stretch, corner stretch.	Duration: 6 wks. Frequency: 3× wk. Strength – Sets: 2. Reps: 15. Stretching – Sets: 2. Duration: 30 s. Progressions: No progressions. Moment of realization: After swimming training. Monitoring: Swimming coach.	There were no significant changes in the strength of the glenohumeral and scapular musculature and scapular kinematics between the groups.
Batalha et al. (2015)	40 competitive male swimmers aged between 14 and 15 years.	G1: Strength exercises. G2: No exercise. GC: Sedentary youth.	Exercises with TheraBand: W's, Y's, shoulder press.	Duration: 16 wks. Frequency: 3× wk. Sets: 3, 30 s rest. Reps: 20 – 1st 2 sets, maximum possible – 3rd set. Progressions: TheraBand resistance was increased after 30 reps in the 3rd set. Moment of realization: During training. Monitoring: No reference.	Significant improvement in shoulder IR strength and rotator cuff balance, especially at 60°/s.

Manske et al. (2015)	43 young swimmers under 18 years.	EG: Strength exercises. CG: No intervention	Exercises with TheraBand: Shoulder ABD, shoulder EXT, shoulder IR, shoulder ER.	Duration: 12 wks. Frequency: 2/3× wk. Sets: 2. Reps: 15. Progressions: Initial TheraBand resistance assessment – progressively test all resistances, athletes referring 0–10 difficulty of execution, ideal resistance when felt > 6; next progression when the athlete felt < 6 after exercises. Moment of realization: Before water training. Monitoring: Investigators.	Swimmers belonging to the EG had a significantly increased strength of shoulder ER compared to the CG.
Batalha et al. (2018)	25 young swimmers aged between 12 and 15 years.	G1: Dry-land strength exercises. G2: In-water strength exercises.	Dry-land exercises: W's, Y's, ER at 90°. In-water exercises: ER with TheraBand, ER with hand paddles, sculling.	Duration: 10 wks. Frequency: 3× wk. Dry-land – Sets: 3, 30 s rest. Reps: 20 – 1st 2 sets, maximum possible – 3rd set. Progressions: TheraBand resistance was increased after 30 reps in the 3rd set. In-water – Sets: 3–5, 10 s rest. Progressions: Every 2 wks – wk1–3 × 30 s; wk3 – 4 × 30 s; wk5 – 3 × 45 s; wk7 – 4 × 45 s; wk9 – 5 × 30 s. Moment of realization: No reference. Monitoring: Swimming coach.	A dry-land strength program was found to be more effective in improving shoulder rotator balance and ER endurance compared to an in-water program.
Chepeha et al. (2018)	8 swimmers aged between 18 and 35 years.	EG: Stretching exercise. CG: No intervention	Sleeper stretch.	Duration: 8 wks. Frequency: 7× wk. Sets: 5, 1–2 min rest. Duration: 2 min. Progressions: No progressions. Moment of realization: No reference. Monitoring: Swimming coach – swimmer's performance, physiotherapist – assessment.	There was an increase in dominant shoulder IR and HADD ROM.

Shahpar et al. (2019)	45 competitive male swimmers aged between 18 and 25 years.	G1: Stretching and strength exercises in OKC. G2: Stretching and strength exercises in CKC. CG: No intervention.	Warm-up: Run or cycle. Pendular arm movements, posterior deltoid stretching, passive IR, passive ER, sleeper stretch, and corner stretch. Strength in OKC: ER, IR, dumbbell fly, reverse dumbbell fly. Strength in CKC: Push-up, scapular push-up, scapular dip, crab walk.	Duration: 8 wks. Frequency: 3× wk. Stretching – Sets: 1–3. Reps: 4–10, 30 s rest. Strength in OKC – Sets: 3. Reps: 8–15, 3 min rest. Strength in CKC – Sets: 3. Reps: 6–8, 1–3 min rest. Progressions: Performed regularly over time, strength training load 80–90% of 1RM. Moment of realization: No reference. Monitoring: No reference.	Both exercise programs increased the strength of the shoulder ER and IR in swimmers. The authors also suggested that OKC exercises are more effective compared to CKC exercises.

EG – Experimental group; CG – Control group; G1 – Group 1; G2 – Group 2; wk – week; wks – weeks; Reps – Repetitions; s – seconds; IR – Internal rotation; ER – External rotation; FLX – Flexion; EXT – Extension; ABD – Abduction; HABD – Horizontal abduction; HADD – Horizontal adduction; ROM – Range of motion; OKC – Open kinetic chain; CKC – Closed kinetic chain; 1RM – One repetition maximum.

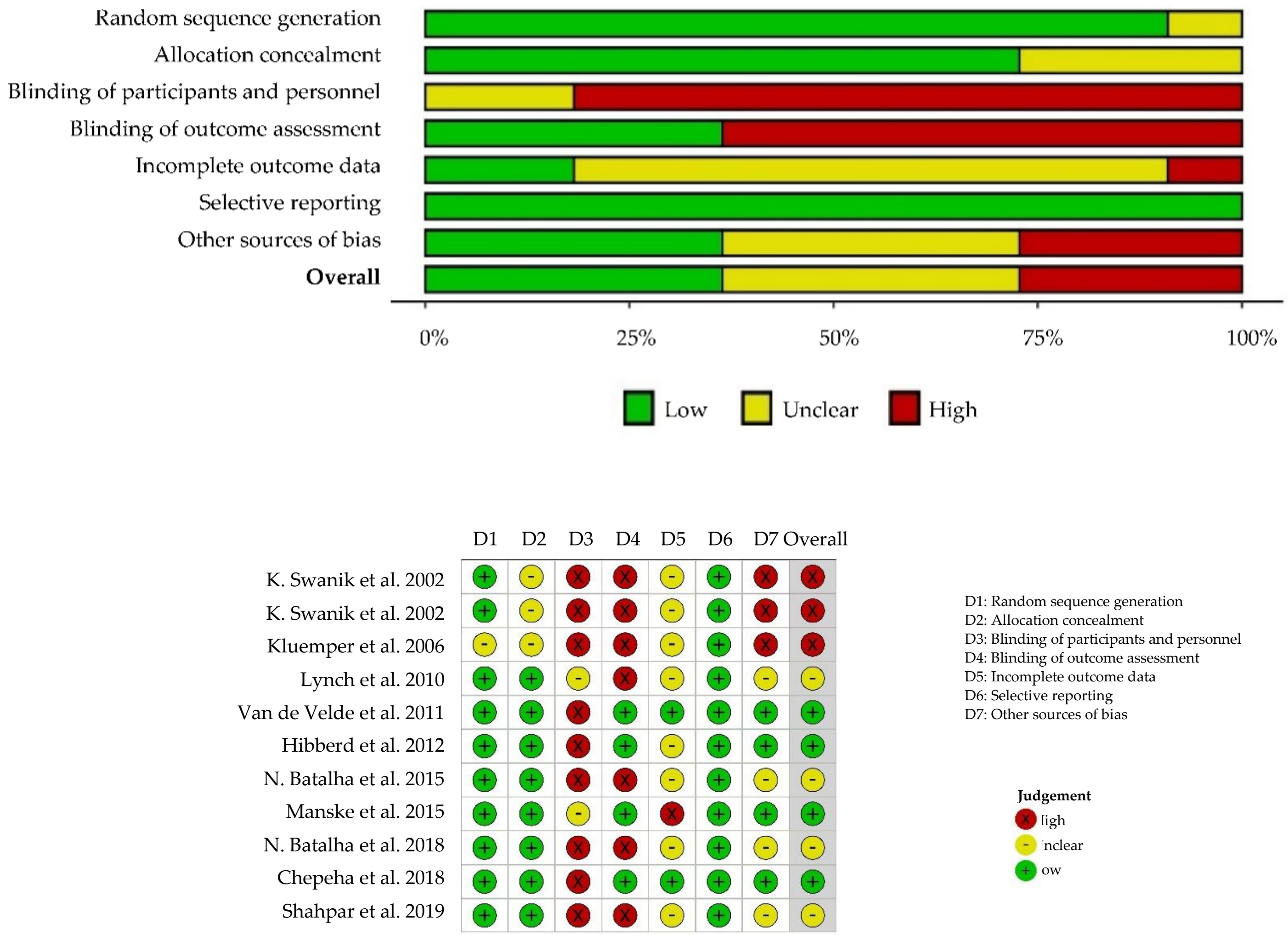

Figure 2.2. Risk of bias assessment using RoB2: generic – summary plot and traffic light plot.

Table 2.4. Risk of bias assessment of individual studies using the PEDro scale.

	Risk of Bias Assessment Criteria – PEDro Scale Item											
	1*	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Final Score**	**Quality**
Swanik, Lephart, et al. (2002)	•	•								•	•	3/10	Low
Swanik, Swanik, et al. (2002)	•	•								•	•	3/10	Low
Kluemper et al. (2006)	•									•	•	2/10	Low
** Lynch et al. (2010)	•	•								•	•	4/10	Low
Van de Velde et al. (2011)	•	•		•				•		•	•	5/10	Moderate
** Hibberd et al. (2012)	•	•		•			•			•	•	5/10	Moderate
Batalha et al. (2015)	•	•		•						•	•	4/10	Low
** Manske et al. (2015)	•	•		•			•			•	•	5/10	Moderate
Batalha et al. (2018)	•	•		•						•	•	4/10	Low
** Chepeha et al. (2018)	•	•		•			•	•		•	•	6/10	Moderate
Shahpar et al. (2019)	•	•		•						•	•	4/10	Low

PEDro Scale Item

1 – Eligibility criteria specified; 2 – Random allocation; 3 – Concealed allocation; 4 – Group similar at baseline; 5 – Subject blinding; 6 – Therapist blinding; 7 – Assessor blinding; 8 – Less than 15% dropouts; 9 – Intention-to-treat analysis; 10 – Between-group statistical comparisons; 11 – Point measures and variability data.

* PEDro scale criteria n°1 does not contribute to the final score.

** The final score was obtained through the Physiotherapy Evidence Database (PEDro).

Results of Individual Studies

- Strength Program vs. No Intervention

After performing a 6-week program of plyometric exercises, significant differences were visible in the experimental group in the time to PT of the shoulder IR evaluated at 60°/s ($p = 0.020$) and 240°/s ($p = 0.001$), in the time of amortization evaluated at 450°/s ($p = 0.008$), and in torque decrement rated at 240°/s ($p = 0.002$). There were no differences between groups in the PT to body weight ratio of IR and ER/IR ratio (Swanik, Lephart, et al., 2002). In turn, the application of a strength program over 16 weeks led to significant mean differences verified in the experimental group in the PT of the ER: 2.93 ± 2.83 Nm, $p = 0.008$ (dominant side at 60°/s); 3.23 ± 1.68 Nm, $p = 0.015$ (non-dominant side at 60°/s); and 2.81 ± 2.66 Nm, $p = 0.015$ (dominant side at 180°/s), and in the ER/IR ratio: 10.31 ± 9.98 Nm, $p = 0.001$ (dominant side at 60°/s); 10.31 ± 9.98 Nm, $p = 0.036$ (non-dominant side at 60°/s); and 12.18 ± 8.66 Nm, $p = 0.020$ (dominant side at 180°/s). No significant differences were visible between groups in the PT of IR (Batalha et al., 2015). Similarly, the realization of a strength program for 12 weeks also showed a significant difference ($p \leq 0.05$) found in the experimental group in the isometric maximum strength of the ER. After the intervention, the experimental group increased 1.19 ± 0.55 kg, which is equivalent to a 23% difference compared to the initial evaluation, and the control group increased 0.46 ± 0.63 kg; that is, an 11% difference compared to the initial evaluation (Manske et al., 2015). In the opposite direction, the performance of a 6-week program of functional training did not lead to any significant difference between the experimental and control groups regarding the PT to body weight ratio, tested at 180°/s and 300°/s in IR, ER, HADD, HABD, and Serratus punch (Swanik, Swanik, et al., 2002).

- Strength and Stretching Program vs. No Intervention

Although the application of the combined strength and stretching program over 6 weeks resulted in differences in maximal strength of the shoulder flexors ($p = 0.020$) and abductors ($p = 0.014$) in the intervention group, this was not considered statistically significant using the Bonferroni test. There were also significant gains in maximal strength in the shoulder extensors ($p = 0.005$) and muscles responsible for scapular retraction ($p < 0.005$), but this occurred similarly in both groups (Hibberd et al., 2012). Similarly, another combined strength and stretching program did not cause significant differences between the control and experimental group in maximal strength of the middle trapezius, lower trapezius, and serratus anterior. When performing an analysis between the initial and final evaluation, there were visible improvements in the maximum strength of these muscles ($p < 0.05$); however, this increase occurred identically in both groups and may be related to the intensity of swimming training (Lynch et al., 2010).

- Strength Program vs. Strength Program

The 12-week strength program compared with a 12-week endurance program caused significant improvements in maximal strength and scapular protraction–retraction ratio in both sample groups. However, these programs also led to a significant increase in the fatigue index for protraction on both sides ($p = 0.05$) and retraction on the non-dominant side ($p = 0.009$). Therefore, there seems to be a tendency for both programs to have positive effects on strength outcomes, but not on endurance outcomes (Swanik, Swanik, et al., 2002). In another study, the effectiveness of a dry-land strength program was compared with another strength program performed in water for 10 weeks. The final evaluation showed significant differences ($p < 0.05$) in the group that performed aquatic exercises in the PT of the IR in both shoulders tested at 60°/s and in the non-dominant shoulder tested at 180°/s. However, this intervention induced a significant decrease in the ER/IR ratios in this experimental group, leading to an imbalance in the shoulder stabilizing muscles of the swimmers. Additionally, the authors described a significant decrease in the ER fatigue ratio of both shoulders ($p < 0.05$) in the group that performed a dry-land exercise program (Batalha et al., 2018). Another research compared the effectiveness of an 8-week combined stretching and strength program in an open kinetic chain with another stretching and strength program in a closed kinetic chain and with a control group. The study concluded that open and closed kinetic chain exercises improved ($p < 0.05$) the PT of ER and IR significantly at all speeds tested – 60°/s, 120°/s, and 180°/s. The improvement in strength was more pronounced in the group that performed the open kinematic chain (OKC) exercise program (Shahpar et al., 2019).

- Shoulder Posture

After performing a 6-week strength and stretching program, a significant decrease of 9.6 ± 7.3 mm ($p < 0.05$) in the acromial distance measured in the standing relaxed position was observed in the experimental group (Kluemper et al., 2006). Likewise, after applying an 8-week strength and stretching program, a significant reduction was observed in the anterior angle of the head ($p = 0.005$) and in the anterior translation of the shoulder ($p = 0.001$) in the experimental group. No differences were found between groups regarding scapular distance (Lynch et al., 2010).

- Proprioception

The application of a plyometric program for 6 weeks led to significant improvements in the experimental group in the two components of proprioception evaluated. Regarding JPS, there was a significant improvement in the 0° ER during the ER movement ($p = 0.015$); 75° ER during the ER ($p = 0.013$) and IR ($p = 0.007$) movements; and 90% of the maximum ER position during the ER ($p = 0.032$) and IR ($p = 0.003$) movements. In the kinesthesia, significant differences were visible in all measurements evaluated: 0° ER to IR ($p = 0.016$) and ER ($p = 0.003$), 75° ER to IR ($p = 0.028$) and ER ($p = 0.001$), and 90% of the maximum ER to IR ($p = 0.001$) and ER ($p = 0.003$) (Swanik, Lephart, et al., 2002).

- Shoulder ROM

Before and after 4 and 8 weeks of sleeper stretch, IR and HADD ROM were evaluated in the shoulders. The results indicated a significant gain in the experimental group in dominant shoulder IR ROM ($p < 0.001$) and in GIRD ($p < 0.001$) after 4 and 8 weeks; and in non-dominant shoulder IR ROM ($p = 0.03$), dominant shoulder HADD ROM ($p = 0.003$), and non-dominant shoulder HADD ROM ($p = 0.05$) after 8 weeks (Chepeha et al., 2018).

- Shoulder Dyskinesia

After execution of the combined strength and stretching program for 6 weeks, it was observed that the differences between the scapular kinematics variables were insignificant. Although there seems to be a tendency for the experimental group to achieve a greater scapular IR at 0° and 30° of flexion and some differences in scapular elevation and depression, this was not considered a significant interaction (Hibberd et al., 2012).

Certainty of Evidence

The effectiveness of a strength program on shoulder rotators' strength and endurance (Batalha et al., 2015; Manske et al., 2015; Swanik, Lephart, et al., 2002) and a strength and stretching program on shoulder posture (Kluemper et al., 2006; Lynch et al., 2010) were classified as moderate evidence because they present a high risk of bias, an average of 4/10 and 3/10 on the PEDro scale. The other two positive effects were classified as low evidence. The first problem is related to the fact that it is impossible to classify the consistency in both cases because there was only one study that reported a positive effect. Additionally, both samples have limitations in their constitution. The effect of a plyometric program (Swanik, Lephart, et al., 2002) was observed only in female swimmers, and the effect of a stretching program (Chepeha et al., 2018) was studied in a small and poorly characterized sample. Finally, in the first case, there was also a high risk of bias – 3/10 on the PEDro scale (Table 2.5).

Table 2.5. Certainty of evidence assessment.

Positive Effects	Risk of Bias	Inconsistency	Indirectness	Imprecision	Certainty of Evidence
Strength program on shoulder rotators' strength/endurance	Dwg	Not dwg	Not Dwg	Not Dwg	Moderate
Strength and stretching programs on shoulder posture	Dwg	Not dwg	Not Dwg	Not Dwg	Moderate
Plyometric program on proprioception	Dwg	–	Dwg	Not Dwg	Low
Stretching program on shoulder ROM	Not dwg	–	Dwg	Not Dwg	Low

Dwg – downgraded

DISCUSSION

The main objective of this review was to identify, evaluate, and compare the different therapeutic exercise programs used to minimize musculoskeletal risk factors related to swimmer's shoulder.

Eleven articles were considered for analysis. There were three positive effects of strength programs on shoulder rotators' strength and endurance (Batalha et al., 2015; Manske et al., 2015; Swanik, Lephart, et al., 2002), two positive effects of strength and stretching programs on shoulder posture (Kluemper et al., 2006; Lynch et al., 2010), and one positive effect of a stretching program on shoulder ROM (Chepeha et al., 2018) and a plyometric program on proprioception (Swanik, Lephart, et al., 2002). In general, it was observed that there is high heterogeneity in the genesis of these investigations. This fact led to the creation of a systematic review without meta-analyses. One of the examples of this huge variability is in maximal strength. This variable appeared in six different studies (Batalha et al., 2018; Batalha et al., 2015; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Van de Velde et al., 2011), and the authors used two different outcomes for their characterization (PT and PF), two different assessment instruments (isokinetic dynamometer and manual dynamometer), and three different units (Nm, N, and kg). Additionally, when evaluating the sample groups of these six studies, it was observed that some have compared a therapeutic exercise program with a control group (Batalha et al., 2015; Lynch et al., 2010; Manske et al., 2015), and others with another therapeutic exercise program under different conditions (Batalha et al., 2018; Shahpar et al., 2019; Van de Velde et al., 2011).

Regarding the qualitative evaluation of the articles, 7 of the 11 studies (Batalha et al., 2018; Batalha et al., 2015; Kluemper et al., 2006; Lynch et al., 2010; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002) had low quality, which necessarily leads to the conclusions of this systematic review having to be viewed with some caution (Table 2.4). The blinding of the participants and the blinding of the evaluators were the main biases found in the individual studies, with a prevalence of high risk of bias above 75% and 50%, respectively (Figure 2.2).

Strength and endurance were the most analyzed risk factors in individual studies (Batalha et al., 2018; Batalha et al., 2015; Hibberd et al., 2012; Lynch et al., 2010;

Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Van de Velde et al., 2011). All strength programs that caused significant differences in favor of the experimental group had five or fewer exercises (Batalha et al., 2015; Manske et al., 2015; Swanik, Lephart, et al., 2002), and the only study where this was not observed had seven exercises (Swanik, Swanik, et al., 2002). When strength programs were tested alone compared to a control group, there seemed to be a positive effect in favor of the experimental group, especially in maximal ER strength (Batalha et al., 2015; Manske et al., 2015). In contrast, some studies have applied a combined strength and stretching program that did not show significant changes in strength and endurance variables (Hibberd et al., 2012; Lynch et al., 2010). Lastly, strength programs performed out of the water (Batalha et al., 2018) with open kinematic chain exercises (Shahpar et al., 2019) seems to lead to more significant improvements in strength and endurance outcomes.

In contrast, there were a small number of studies investigating the influence of therapeutic exercise on other musculoskeletal risk factors (Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Swanik, Lephart, et al., 2002). In two of these studies, the effect of a combined strength and stretching program on shoulder posture was observed, with significant differences favorable to the experimental group in the acromial distance (Kluemper et al., 2006), anterior shoulder translation, and in the head forward angle (Lynch et al., 2010). Although it lacks more robustness, there seems to be a tendency for a strength program to improve some of the components of proprioception (Swanik, Lephart, et al., 2002) and a stretching program to contribute to a better balance in rotation ROM between the dominant and non-dominant shoulder (Chepeha et al., 2018). The analysis of the influence of exercise on the improvement of scapular dyskinesia in swimmers did not show a significant difference; however, this risk factor was only evaluated after a very extensive intervention that combined strength and stretching exercises (Hibberd et al., 2012). No studies were found that explore the impact of therapeutic exercise on glenohumeral instability in swimmers.

About the characteristics of exercise programs, due to their enormous variability, it is difficult to draw strong conclusions. Strength exercises were usually performed with elastic bands (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Manske et al., 2015; Swanik, Lephart, et al., 2002), focusing mostly on the ER, IR, middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA). All therapeutic exercise programs found had a minimum duration of 6 weeks (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Van de Velde et al., 2011), and normally were carried out 2–3 times a week (Batalha et al., 2018; Batalha et al., 2015; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Van de Velde et al., 2011). The most frequently reported volume for strength exercises was three sets of 10 or 15 repetitions (Kluemper et al., 2006; Lynch et al., 2010; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Van de Velde et al., 2011). In turn, muscle stretching exercises tended to be static, with the pectoralis minor being the most targeted muscle (Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Shahpar et al., 2019) (Table 2.3). Five of seven positive effects considered in this review had progressions over time (Batalha et al., 2015; Kluemper et al., 2006; Manske et al., 2015; Swanik, Lephart, et al., 2002).

The main limitation of this systematic review is the high heterogeneity of the analyzed evidence, making it impossible to carry out a meta-analysis of the results, combined with the low methodological quality of the individual studies, which decreases the reliability of the conclusions obtained.

CONCLUSIONS

Therapeutic exercise is a strong and safe tool that can be used in the clinical practice of swimming to reduce the risk of injury associated with some musculoskeletal factors. Strength programs, with five or fewer exercises, performed out of the water and with OKC exercises, seem to lead to more improvements in the strength and endurance of the shoulder rotators, and possibly reduce the impact of this musculoskeletal risk factor on swimmer's shoulder. This program should last for 6 weeks, be carried out 2–3 times a week, and have progressions over time. Programs that combine strength and stretching

exercises seem to improve some variables that characterize shoulder posture, but not strength and endurance.
However, there is evidence with high heterogeneity and low methodological quality regarding the effectiveness of therapeutic exercise programs on musculoskeletal risk factors related to swimmer's shoulder. In the future, more studies are needed to give better consistency and robustness to the conclusions obtained in this review regarding shoulder strength, endurance, and posture. Further investigations are essential to verify the impact of therapeutic exercise on other musculoskeletal risk factors related to swimmer's shoulder, such as proprioception, shoulder ROM, scapular dyskinesia, and glenohumeral instability.

Supplementary Materials

The following supporting information is at the end of Study I (Table 2.6) or by downloading at: https://www.mdpi.com/article/10.3390/ejihpe12060044/s1.

Author Contributions

Conception and study design N.T. and M.A.C.; search and selection of studies, N.T. and M.A.C.; writing, N.T.; visualization, N.T., G.D., P.C., J.P.V.-B., and M.A.C.; manuscript revision, J.P.V.-B. and M.A.C. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

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Informed Consent Statement

Not applicable.

Data Availability Statement

Data sharing not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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Table 2.6. PRISMA 2020 checklist.

Section/Topic	Item #	Checklist item	Reported on page
TITLE			
Title	1	Identify the report as a systematic review.	45
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	46
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	46-48
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	48-49
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	49
Information sources	6	Specify all databases, registers, websites, organizations, reference lists, and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	50
Search strategy	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	50, Table 2.2
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	51
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and, if applicable, details of automation tools used in the process.	51
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g., for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	51-52
	10b	List and define all other variables for which data were sought (e.g., participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	NR
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study, and whether they worked independently, and if applicable, details of automation tools used in the process.	52
Effect measures	12	Specify for each outcome the effect measure(s) (e.g., risk ratio, mean difference) used in the synthesis or presentation of results.	52
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g., tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	NA
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics or data conversions.	NA
	13c	Describe any methods used to tabulate or visually display the results of individual studies and syntheses.	NA
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NA
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g., subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess the risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	53

Section/Topic	Item #	Checklist item	Reported on page
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	53
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	53
Study characteristics	17	Cite each included study and present its characteristics.	53, Table 2.3
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	53, Table 2.4, Figure 2.2
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g., confidence/credible interval), ideally using structured tables or plots.	61-64
Results of syntheses	20a	For each synthesis, briefly summarize the characteristics and risk of bias among contributing studies.	NA
	20b	Present the results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g., confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present the results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present the results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	64, Table 2.5
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	65-67
	23b	Discuss any limitations of the evidence included in the review.	66-67
	23c	Discuss any limitations of the review processes used.	67
	23d	Discuss implications of the results for practice, policy, and future research.	67-68
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including the register name and registration number, or state that the review was not registered.	NA
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NA
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	68
Competing interests	26	Declare any competing interests of review authors.	69
Availability of data, code, and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	NA

NR – Not reported | NA – Not applicable

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. DOI: 10.1136/bmj.n71
For more information, visit: http://www.prisma-statement.org/

CHAPTER III

- **Study II –** Difference in the Electromyographic Activity of Serratus Anterior Between Two Preventive Exercise Programs for Swimmer’s Shoulder: Elastic Band Versus Weight

- **Study III –** An Electromyographic Analysis of Shoulder Muscles in Scapular Punches Exercise in Swimmers

- **Study IV –** Electromyographic Activity of Shoulder Muscles on Two Preventive Exercise Programs for Swimmer’s Shoulder: Elastic Band versus Weight

STUDY II

Exploratory Study

Difference in the Electromyographic Activity of Serratus Anterior Between Two Preventive Exercise Programs for Swimmer's Shoulder: Elastic Band Versus Weight

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ABSTRACT

Strength programs, with few exercises, performed out of the water and in an open kinetic chain, seem to have better results in the swimmer's shoulder prevention. On the other hand, the less activity of the serratus anterior during swimming is an important musculoskeletal risk factor for swimmer's shoulder. This study aimed to analyze the difference between an elastic band and a weight prevention exercise program in the surface electromyographic activity of the serratus anterior in swimmers. Eight competitive swimmers performed two strength programs consisting of five exercises each, while the analysis of electromyography activity in the serratus anterior for each exercise was performed. The superficial electromyography BioSignalsPlux equipment was used to collect data at a sampling frequency of 1000 Hz. Electromyography data analysis was made with MATLAB 2020 software, and statistical analysis was performed using IBM SPSS Statistics 27. The differences in electromyographic activity of the serratus anterior between the elastic band and the weight were positive for the weight in four of the five exercises. The preventive exercise program with weights seems to be more effective in the electromyographic activity of the serratus anterior. This program produces better strength improvement in the serratus anterior, which may be important to reduce the impact of this risk factor on the performance of swimmers with shoulder pain.

Keywords: Swimming, Swimmer's shoulder, Serratus anterior, Elastic band, Weight.

INTRODUCTION

Swimmer's shoulder is the most common injury in swimmers and is defined as a painful syndrome that occurs mostly in the anterior region of the shoulder and results from repetitive impingement of the rotator cuff under the coracoacromial arch during the technical gesture of swimming (Hill et al., 2015; Struyf et al., 2017). It is estimated that 91% of competitive swimmers experience this injury during their sports career (Feijen et al., 2020; Hill et al., 2015), leading to the major cause of missed practice (Feijen et al., 2020; Schlueter et al., 2021; Struyf et al., 2017; Walker et al., 2012).

The SA plays an important role in moving and stabilizing the scapula during upper extremity motion (Kang et al., 2019). Less activity of SA is very common in swimmer's shoulder and impairs the swimmer's performance, especially during freestyle swimming (Struyf et al., 2017).

There is a tendency for strength programs, with few exercises, performed out of the water and in an OKC to have better results in the prevention of the swimmer's shoulder injury (Tavares et al., 2022; Yoma et al., 2022). Elastic bands and weights are described as the most used instruments in these preventive exercise programs (Tavares et al., 2022).

This study aimed to analyze the difference between the use of an elastic band and weight to perform an identical exercise program in the surface EMG activity of the SA in swimmers.

METHODS

Participants

This exploratory study was carried out at the RoboCorp Laboratory at the Polytechnic Institute of Coimbra after approval from the Ethics Committee of Polytechnic Institute of Coimbra (CEIPC 6/2022), based on the revised version of the 2013 Declaration of Helsinki (Holt, 2014). Eight competitive swimmers, with a mean age of 19.63 ± 3.34 years, who practiced 13.38 ± 5.88 hours of weekly swimming and with 8.13 ± 3.00 federated years were included in this study (Table 3.1). To be included in the sample, participants must be federated swimmers aged between 16 and 35 years old and belong to a club affiliated with the Portuguese Swimming Federation during season 22/23; have a minimum of 5 years of experience in national competitions; perform a minimum of 6 hours of weekly swim training and accept to participate in the study by filling out a Free and Informed Consent. All individuals who have a clinical history of significant shoulder pain in the last 6 months, a clinical history of traumatic shoulder injuries such as fractures, subluxations, previous shoulder surgeries, a shoulder range of motion deficit, or neurological injuries, were excluded.

Table 3.1. Sample characterization variables.

Variables	Mean ± SD
Age (years)	19.63 ± 3.34
Mass (kg)	65.90 ± 10.17
Height (m)	1.70 ± 0.10
BMI (kg/m^2)	22.73 ± 2.05
Fat mass (%)	16.44 ± 7.76
Lean mass (kg)	53.52 ± 9.73
Bone mass (kg)	2.94 ± 0.47
Swimming practice (hours)	13.38 ± 5.88
Competitive swimming (years)	8.13 ± 3.00

SD – Standard deviation.

Exercise programs protocol

Each participant performed two strength programs consisting of five exercises: IR at 90°, ER at 90°, scapular punches, T's, and Y's (Table 3.2). One program was performed with an elastic band Bodytone Power Band with 15, 20, or 25 kg (Figure 3.1), and the other with two weights Domyos with 2, 3, or 4 kg (Figure 3.2). These exercises were the most described in the literature to prevent the swimmer's shoulder injury (Tavares et al., 2022; Yoma et al., 2022). The load used to perform the programs with elastic bands and weights was previously assessed and adjusted for each swimmer, corresponding to 80 % of one repetition maximum (1RM) (Liguori, 2017).

The order of programs and exercises was random, and 2 minutes of rest were preserved between exercises. Each participant performed 1 set of 8 valid repetitions (Liguori, 2017). The repetitions were considered valid when the athlete reached the target ROM previously described for each exercise (Table 3.2). The swimmer performed the concentric and eccentric phases of the exercise for 5 s each (Ekstrom et al., 2003). This time was controlled by a Tabata Timer mobile application. A physiotherapist was responsible for positioning the material, demonstrating, and correcting each athlete's technique during the execution of the programs.

Data Acquisition

Before the EMG procedure, the skin surface was cleaned, shaved, and scrubbed with alcohol (Park et al., 2013; Patselas et al., 2021; Tsuruike et al., 2020; Werin et al., 2020). For data acquisition, superficial EMG BioSignalPlux (Plux, Lisbon, Portugal) equipment was used. The EMG collection was performed at a sampling frequency of 1000 Hz (Park et al., 2013; Patselas et al., 2021). Electrodes were always placed by one of the researchers (N.T.), in parallel to the SA fibers of the dominant shoulder of each participant, with a 20 mm center-to-center distance. The intersection of the axillary midline and the lower angle of the scapula line was used as a reference for placing the electrodes on the SA (Ekstrom et al., 2005; Park et al., 2013; Patselas et al., 2021; Tsuruike et al., 2020; Werin et al., 2020) and muscle contraction to visualize muscle bellies. For the evaluation of maximum voluntary isometric contraction (MVIC) of SA, 3 maximum contractions of 5 s with 30 s of rest were made (Werin et al., 2020). A ground electrode was placed on the ipsilateral clavicle (Park et al., 2013).

Table 3.2. Exercise description of the elastic band and weight programs.

Exercise	Elastic band program	Weight program
IR at 90°	The elastic band should be fixed at shoulder height. Movement: 90° of shoulders IR (5 s) and return to the start position (5 s).	Started in a supine position, 90° of shoulders ABD, 90° of ER, and 90° of elbows FLX. Movement: 90° of shoulders IR and return to the start position (5 s).
ER at 90°	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: 90° of shoulders ER (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. Movement: 90° of shoulders ER (5 s) and return to the start position (5 s).
Scapular punches	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: Elbow EXT (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. Movement: Elbows EXT (5 s) and return to the start position (5 s).

T's	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. The elastic band should be fixed at shoulder height. Movement: 90° of shoulders HABD (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. Movement: 90° of shoulders HABD (5 s) and return to the start position (5 s).
Y's	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. The elastic band should be fixed at shoulder height. Movement: 90° of shoulders HABD and maximum shoulders FLX (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. Movement: 90° of shoulders HABD and maximum shoulders FLX (5 s) and return to the start position (5 s).

IR – Internal rotation; ER – External rotation; FLX – Flexion; EXT – Extension; ABD – Abduction; HABD – Horizontal abduction; s – Seconds.

Figure 3.1. Illustration of the elastic band program: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

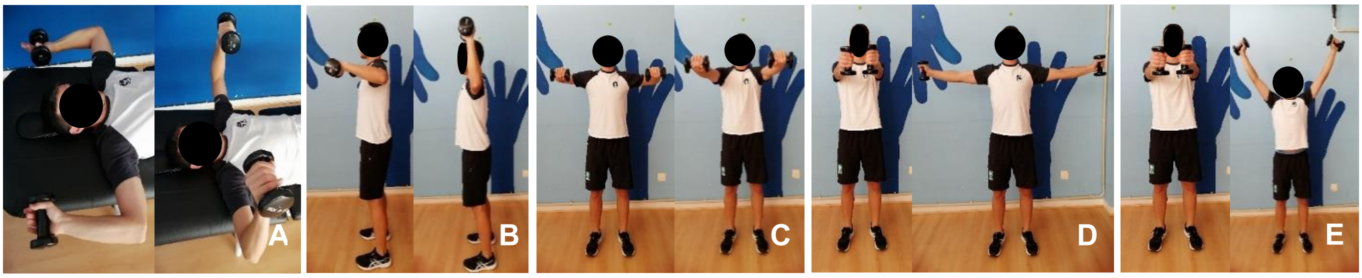

Figure 3.2. Illustration of the weight program: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

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Data Analysis

EMG data were digitally filtered (10–490 Hz), full-wave rectified, and smoothed with a low-pass filter 12 Hz, Butterworth 4th order digital filter using MATLAB 2020 software (MathWorks Inc., Natick, Massachusetts, USA). The main outcome sought was the muscle activity normalized to the %MVIC of SA for each exercise. All statistical analysis was carried out using IBM SPSS Statistics 27 software. The Shapiro–Wilk test was used to verify the normality of the sample distribution, and the Independent Sample T-test to compare SA EMG activity between the two programs.

RESULTS

The differences in SA activity between the elastic band and weight were positive for the weights in ER at 90°, scapular punches, T's, and Y's. Only in IR at 90°, the elastic band produces a greater SA EMG activity (Table 3.3). All differences between programs were statistically significant ($p \leq 0.05$). The greatest difference in SA EMG activity was 38.29 % ($p < 0.001$) in favor of weight and occurred in the T's exercise.

Table 3.3. Difference in SA EMG activity between the program with elastic band and weights.

Exercise	Elastic band (%)	Weight (%)	Difference (%)	*p*-value
IR at 90º	14.67 ± 7.07	6.77 ± 3.06	7.90	0.012*
ER at 90º	20.00 ± 11.92	34.95 ± 14.97	-14.95	0.044*
Scapular punches	14.34 ± 5.70	39.54 ± 14.02	-25.20	0.001*
T's	7.25 ± 2.13	45.54 ± 19.48	-38.29	<0.001*
Y's	24.75 ± 10.65	52.28 ± 31.46	-27.53	0.045*

* Statistically significant difference

IR – Internal rotation; ER – External rotation.

DISCUSSION

The purpose of this study is to analyze the difference between the use of an elastic band and weight to perform an identical exercise program in the EMG activity of the SA in swimmers.

In 4 of the 5 exercises, the difference in EMG activity was statistically significant and favorable for the weight ($p < 0.05$). This did not happen only in the IR at 90°, where the elastic band produced 7.90 % more EMG activation than the weight. The T's was the exercise that showed the greatest difference between the two objects (38.29 %), and the Y's performed with weight was the one that had the highest EMG activation value of the SA (52.28 ± 31.46 %).

The SA is a muscle that has its origin in the upper 8th ribs and its insertion on the medial margin of the scapula, thus assuming a very important role in the stability of the scapula (Ekstrom et al., 2005; Moore & Dalley, 2003). The fact that it promotes coaptation of the scapula against the costal grid allows other muscles to use it as a fixed point for humerus movement (Moore & Dalley, 2003). Although the two programs have the same intensity, the fact that the weight has a different resistance vector compared to the elastic band means that while performing the exercises, there is a greater demand on the anterior shoulder muscles, such as the anterior deltoid, which also has one of the parts of its muscular origin in the scapula (scapular spine, acromion). One of the possible explanations for an overall result favorable to the weights could be the fact that this greater demand on the anterior deltoid leads to a greater force of coaptation of the scapula against the costal grid and a greater need for the SA action. This possibility would also explain why this did not happen in IR at 90º. The fact that IR at 90º with weights was performed in the supine position reduced the need to use the anterior deltoid, and the exercise position itself promoted greater stability and coaptation of the scapula.

Ekstrom et al. evaluated the SA EMG activity in several exercises performed with weights at an intensity of 85–90 % of 1RM. Among these exercises were the ER at 90º, T's and Y's in the supine position, and scapular punches in the prone position. The SA EMG activity of these exercises was relatively low compared to other exercises tested in the standing position (Ekstrom et al., 2003). Similarly, the relatively lower SA EMG activity was also verified in 6 exercises in the prone position performed with body weight, which were the T's. Y's and ER at 90º were included (Oyama et al., 2010). On the other hand, an evaluation of exercises performed in a standing position with a fixed-intensity elastic resistance showed slightly higher SA EMG activity values. IR at 90º had 53.5 ± 32.2 %, ER at 90º had 66.2 ± 39.4 % and scapular punches had 66.7 ± 45.4 % (Myers et al., 2005). It should be noted that the populations studied in these three studies were not athletes (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010).

CONCLUSION

The preventive program with weights seems to be more effective, considering the EMG activation of SA, especially when the exercises were performed in a standing position.

The use of this program could represent a better strength improvement in SA, which may be important to reduce the impact of this musculoskeletal risk factor on the performance of swimmers with shoulder pain. However, these results should be interpreted considering several risk factors that influence the performance of swimmers with shoulder pain. More studies are needed to explore in detail the true impact of exercise interventions in sport injury prevention in athletes.

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STUDY III

Exploratory Study

An Electromyographic Analysis of Shoulder Muscles in Scapular Punches Exercise in Swimmers

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ABSTRACT

Scapular punches are one of the most common exercises included in swimmer's shoulder preventive programs. In previous electromyography analyses carried out in non-swimmers, it was verified that in this exercise, there is a higher mean electromyographic activity in the serratus anterior compared to the remaining shoulder muscles. This study intends to carry out an electromyography analysis of shoulder muscles in scapular punches exercise in swimmers and compare the results with previous studies. Eight swimmers performed scapular punches with elastic bands and weights in a random order, while the analysis of the mean electromyographic activity of middle trapezius, lower trapezius, infraspinatus, serratus anterior, and pectoralis major were performed. The superficial EMG BioSignalsPlux equipment was used and collecting data at a sampling frequency of 1000 Hz. EMG data analysis was made using MATLAB 2020 software, and statistical analysis was performed using IBM SPSS Statistics 27. The scapular punches with weights produced higher electromyographic activity in the five muscles tested compared to the elastic bands. The exercise performed with an elastic band produced a higher electromyographic activity in the middle trapezius and serratus anterior, and when performed with weights, produced a higher electromyographic activity in the infraspinatus and serratus anterior. Similar to previous studies, scapular punches seem to produce an important electromyographic activation of the serratus anterior. However, in swimmers, this activation is not as high and differentiated compared to other shoulder muscles.

Keywords: Swimming, Scapular punches, Swimmer's shoulder, Elastic band, Weight.

INTRODUCTION

Swimmer's shoulder is a term that has generally been used to describe a syndrome with anterior shoulder pain elicited by repetitive impingement of the rotator cuff under the coracoacromial arch (Struyf et al., 2017). It is the most common injury in swimmers (Hill et al., 2015; Struyf et al., 2017), and the major cause of missed practice (Feijen et al., 2020; Schlueter et al., 2021; Struyf et al., 2017; Walker et al., 2012). There are described in literature several types of risk factors related to a swimmer's shoulder such as musculoskeletal, training, epidemiological, physiological, and lifestyle factors (Feijen et al., 2021; Feijen et al., 2020; Gaunt & Maffulli, 2012; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017; Wanivenhaus et al., 2012). Musculoskeletal risk factors have great importance in the clinical context because they are modifiable factors and some of them have a good power to predict this injury (Feijen et al., 2021).

The less activity of the SA during swimming is an important musculoskeletal risk factor for the swimmer's shoulder (Struyf et al., 2017) because this muscle plays an important role in moving and stabilizing the scapula during upper extremity motion (Kang et al., 2019). To minimize the impact of this risk factor, some exercises to strengthen the SA have been included in swimmers' shoulder preventive programs, such as the scapular punches (Hibberd et al., 2012; Tavares et al., 2022). This exercise is usually performed with elastic band and weights (Ekstrom et al., 2003; Myers et al., 2005; Tavares et al., 2022). In previous EMG analyses carried out in non-swimmers, it was verified that in this exercise, there is a higher EMG activity in the SA compared to the remaining shoulder muscles (Ekstrom et al., 2003; Myers et al., 2005). There is no EMG analysis carried out on these exercises in swimmers. In this way, this study intends to perform an EMG analysis of shoulder muscles in scapular punches in swimmers and compare the results with the previous studies that analyzed this exercise in non-swimmers.

METHODS

Participants

This exploratory study was carried out at the RoboCorp Laboratory at the Polytechnic Institute of Coimbra after approval from the Ethics Committee of Polytechnic Institute of Coimbra (CEIPC 6/2022), based on the revised version of the 2013 Declaration of Helsinki (Holt, 2014). Eight competitive swimmers, with a mean age of 19.63 ± 3.34 years, who practiced 13.38 ± 5.88 hours of weekly swimming and with 8.13 ± 3.00 federated years were included in this study (Table 4.1). To be included in the sample, participants must be federated swimmers aged between 16–35 years old and belong to a club affiliated with the Portuguese Swimming Federation during season 22/23; have a minimum of 5 years of experience in national competitions; perform a minimum of 6 hours of weekly swim training and accept to participate in the study by filling out a Free and Informed Consent. All individuals who have a clinical history of significant shoulder pain in the last 6 months, a clinical history of traumatic shoulder injuries such as fractures, subluxations, previous shoulder surgeries, a shoulder range of motion deficit, and neurological injuries, were excluded.

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Swimming practice (hours)	13.38 ± 5.88
Competitive swimming (years)	8.13 ± 3.00

SD – Standard deviation.

Exercise programs protocol

Each participant performed the scapular punches with an elastic band Bodytone Power Band with 15, 20, or 25 kg and two weights Domyos with 2, 3, or 4 kg in random order (Figure 3.1). In both situations, the swimmer started in a standing position, with 90º of shoulder abduction, 90º of elbow flexion, and hands at the same height as the shoulders. The movement of scapular punches consists of performing a maximum extension of the elbows and returning to the initial position. For each instrument, 1 set of 8 valid repetitions was carried out, followed by a 2-minute rest period (Liguori, 2017). The repetitions were considered valid when the athlete reached the target ROM previously described. The swimmer performed the concentric and eccentric phases of the exercise for 5 s each (Ekstrom et al., 2003). This time was controlled by a Tabata Timer mobile application. A physiotherapist was responsible for positioning the material, demonstrating, and correcting each athlete’s technique during the execution of the programs. The load used to perform the exercise with elastic band and weights was previously assessed and adjusted for each swimmer, corresponding to 80 % of 1RM (Liguori, 2017).

Figure 4.1. Illustration of the scapular punches exercise with an elastic band and weights.

Data acquisition

The skin was previously prepared for the EMG procedure through cleaning, shaving, and scrubbing with alcohol (Ekstrom et al., 2005; Park et al., 2013; Patselas et al., 2021; Tsuruike et al., 2020; Werin et al., 2020). EMG data were collected with active surface electrodes (Al/AgCl, disk shape, 10 mm of diameter) and superficial EMG BioSignalPlux telemetric equipment (Plux, Lisbon, Portugal). EMG data were collected with a 1000 Hz sampling frequency (Park et al., 2013; Patselas et al., 2021). Electrodes were always placed by one of the researchers (N.T.) in parallel to the MT, LT, infraspinatus (IS), SA, and pectoralis major (PM) fibers of the dominant shoulder of each participant, with a 20 mm center-to-center distance (Figure 4.2). For the placement of the electrodes on the MT and LT, the European recommendations of Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) were used (Hermens, 2024). The reference used for the IS was the mid-distance between the scapula spine and the inferior angle of the scapula, 20 mm lateral from the scapula medial border (Herrington et al., 2015; Pontillo et al., 2007; Tsuruike et al., 2020). The intersection of the axillary midline and the lower angle of the scapula line was used as a reference for placing the electrodes on the SA (Ekstrom et al., 2005; Herrington et al., 2015; Park et al., 2013; Patselas et al., 2021; Pontillo et al., 2007; Tsuruike et al., 2020; Werin et al., 2020). The location used for PM was 40–50 mm below the clavicle, 20 mm medial to the anterior axillary border, one-third of the distance from the great tuberosity to the xiphoid process, in a horizontal line in alignment with the muscle fibers (Herrington et al., 2015; Park et al., 2013; Pontillo et al., 2007; Werin et al., 2020). A ground electrode was placed on the ipsilateral clavicle (Park et al., 2013). For the evaluation of maximum voluntary isometric contraction (MVIC) of MT, LT, IS, SA, and PM, 3 maximum contractions of 5 s with 30 s of rest were made (Werin et al., 2020).

Figure 4.2. Placement of EMG electrodes in MT, LT, IS, SA, and PM.

Data analysis

EMG data were digitally filtered (10–490 Hz), full-wave rectified, and smoothed with a low-pass filter 12 Hz, Butterworth 4th order digital filter using MATLAB 2020 software (MathWorks Inc., Natick, Massachusetts, USA). The main outcome sought was the muscle activity normalized to the % of MVIC of the five muscles in each of the exercises. All statistical analysis was carried out using IBM SPSS Statistics 27 software. The Shapiro–Wilk test was used to verify the normality of the sample distribution, and the Independent Sample T-test to verify the significance of inter-muscular differences.

RESULTS

The scapular punches performed with weights produced a higher EMG activity in the five muscles tested – MT, LT, IS, SA, and PM – when compared to the same exercise carried out with elastic bands in swimmers (Figures 4.3 and 4.4). The MT and SA (Figure 4.3) produced a higher EMG activity when the exercise was executed with an elastic band. The inter-muscular EMG activity difference was statistically significant between MT and IS ($p < 0.001$), MT and PM ($p = 0.023$), and SA and IS ($p = 0.037$). On the other hand, the exercise performed with weights produced a higher EMG activity in the IS and SA (Figure 4.4). The inter-muscular EMG activity difference was statistically significant between IS – PM (p = 0.008), SA – PM ($p < 0.001$), and SA – LT (p = 0.021).

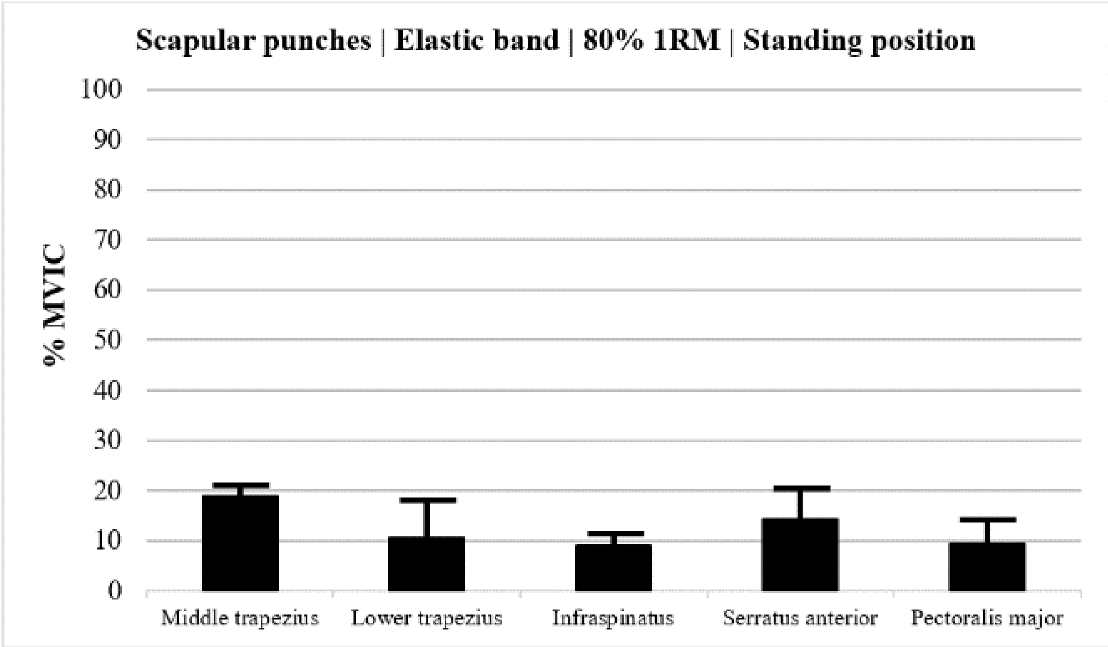

Figure 4.3. EMG activity in % of MVIC and standard deviation in scapular punches with elastic band at 80 % of 1RM in the standing position.

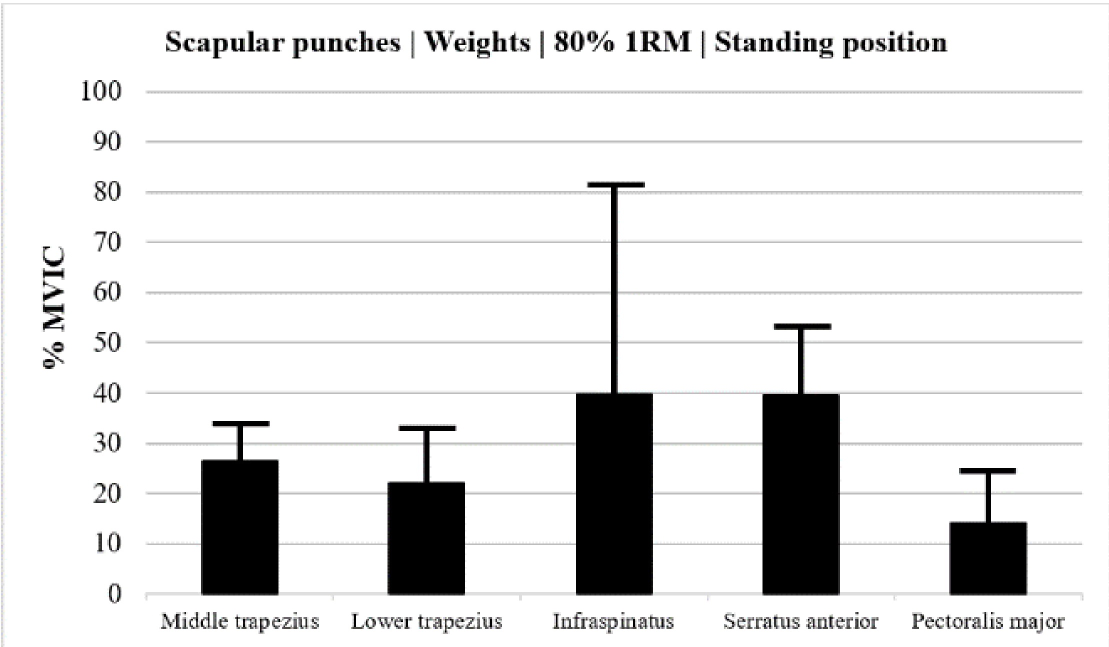

Figure 4.4. EMG activity in % of MVIC and standard deviation in scapular punches with weights at 80 % of 1RM in the standing position.

Table 4.2. Comparison with other studies of the EMG analysis of shoulder muscles in scapular punches exercise.

Muscle	**In this study** Elastic band (%)	**In this study** Weight (%)	**Myers et al. (2005)** Elastic tube (%)	**Ekstrom et al. (2003)** Weight (%)
MT	18.76 ± 1.81	26.35 ± 7.65	–	12.00 ± 10.00
LT	10.51 ± 7.17	22.19 ± 11.13	39.20 ± 31.70	11.00 ± 5.00
IS	9.08 ± 2.03	39.67 ± 42.23	35.00 ± 16.50	–
SA	14.34 ± 5.70	39.54 ± 14.02	66.70 ± 45.40	62.00 ± 19.00
PM	9.46 ± 4.46	14.06 ± 10.19	19.40 ± 33.20	–

MT – Middle trapezius, LT – Lower trapezius, IS – Infraspinatus, SA – Serratus anterior, PM – Pectoralis major.

DISCUSSION

The purpose of this study is to perform an EMG analysis of shoulder muscles in scapular punches in swimmers and compare the results with the previous studies that analyzed this exercise in non-swimmers.

When the scapular punches were carried out with weight, a greater EMG activation was verified in all muscles (Table 4.2). The IS was the muscle that presented the biggest difference (30.59 %), and the PM was the one that showed the smallest difference (4.6 %) in EMG activation between the elastic band and weights.

In the exercise performed with an elastic band, the MT and SA were the most active muscles and the only ones that presented statistically significant differences ($p < 0.05$) compared to the other evaluated muscles. Myers et al. (2005) evaluated 15 physically active subjects and non-swimmers in 10 repetitions of the same exercise performed with a 9.1 kg elastic resistance tube. Similarly, there was greater EMG activation of the SA (66.70 ± 45.40 %), compared to the other muscles. The MT was not evaluated in this study.

When the exercise was performed with weights, the IS and SA were the muscles with the highest EMG activation and the only ones that obtained statistically significant differences ($p < 0.05$) compared to the remaining muscles evaluated. Ekstrom et al. (2003) evaluated in 30 non-swimmers the EMG activation of the upper trapezius (UT), MT, LT, and SA in 3 repetitions of scapular punches with weights in a supine position, with a load of 85–80 % of 1RM. Of the 4 evaluated muscles, the SA was the one that presented the highest EMG activity (62.00 ± 19.00 %). The IS was not evaluated in this study.

In an identical way to our study, in the previous studies, the scapular punches seem to be a good exercise to train the SA. However, the EMG value of our study is lower compared with that verified by other authors. This aspect may be due to the different population used. Probably, competitive swimmers need more load/intensity in the exercise to produce the same EMG activity as a non-swimmer (Ekstrom et al., 2003; Myers et al., 2005). Another reason that may explain this difference is the fact that in at least one previous study, the load used is superior to 80 % of 1RM (Ekstrom et al., 2003).

In our study, the scapular punches also seemed to be a good exercise to train other muscles, like the MT with elastic band and the IS with weights. This fact needs to be further investigated, as none of the previous studies have assessed these two muscles under the same conditions as ours (Ekstrom et al., 2003; Myers et al., 2005).

CONCLUSION

The scapular punches performed with weights seem to be more effective in shoulder muscle EMG activation compared to the exercise executed with elastic bands. Similarly, to what occurs in previous studies, this exercise seems to produce an important EMG activation of SA. However, it seems that in swimmers this activation is not as high and differentiated compared to other shoulder muscles, such as the MT (elastic bands) and IS (weights). New studies are needed to analyze in detail exercises included in injury preventive programs in swimmers and the athletic population in general.

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STUDY IV

Clinical Trial

Electromyographic Activity of Shoulder Muscles on Two Preventive Exercise Programs for Swimmer's Shoulder: Elastic Band versus Weight

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ABSTRACT

Strength programs have shown good results in preventing swimmer's shoulder. However, there aren't studies based on electromyographic analysis in these programs. This study aims to compare the electromyographic activity of the middle trapezius, lower trapezius, infraspinatus, serratus anterior, and pectoralis major in two swimmer's shoulder preventive programs – one performed with elastic band and the other with weights. Twenty competitive swimmers performed two strength programs consisting of five exercises each, while the analysis of electromyographic activity in middle trapezius, lower trapezius, infraspinatus, serratus anterior, and pectoralis major for each exercise was recorded. The superficial electromyography was used to collect data at a sampling frequency of 1000 Hz. The Paired Sample T-test or the Wilcoxon test was applied to compare electromyographic activity between programs. The internal rotation at 90º ($p < 0.001$) and external rotation at 90º ($p \leq 0.01$) exercises produced high myoelectric shoulder muscles activity with an elastic band. Conversely, scapular punches ($p < 0.001$) exercise has high shoulder electromyographic activity when performed with weights. Performing the same preventive exercise program with two different instruments produces great variability in the myoelectric activity of the shoulder muscles.

Keywords: Strength exercises, Injury prevention, Swimming, Electromyography, Shoulder.

INTRODUCTION

Swimmer's shoulder is a term that has generally been used to describe a syndrome with anterior shoulder pain elicited by repetitive impingement of the rotator cuff under the coracoacromial arch during the technical gesture of swimming (Hill et al., 2015; Struyf et al., 2017). It is the most common injury in swimmers, and the major cause of missed practice and competition (Feijen et al., 2020; Schlueter et al., 2021; Struyf et al., 2017; Walker et al., 2012).

Several types of risk factors related to a swimmer´s shoulder are described in the literature, such as musculoskeletal, training, epidemiological, physiological, and lifestyle factors (Feijen et al., 2021; Feijen et al., 2020; Gaunt & Maffulli, 2012; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017; Tavares et al., 2022;

Wanivenhaus et al., 2012). These factors can be classified as modifiable or non-modifiable. The management of modifiable factors, like musculoskeletal, could significantly reduce the prevalence of this injury in swimmers and its impact on their athletic performance and career (Feijen et al., 2021; Schlueter et al., 2021). Exercise seems to be one of the principal tools available to minimize musculoskeletal risk factors for a swimmer’s shoulder (Batalha et al., 2015; Chepeha et al., 2018; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002; Tavares et al., 2022; Yoma et al., 2022). Strength programs, with few exercises, performed out of the water and in an open kinetic chain seem to have better results in preventing this injury (Tavares et al., 2022; Yoma et al., 2022). Normally, this type of program is performed with elastic bands or weights and focuses on muscular activation of shoulder external and internal rotators, MT, LT, and SA (Tavares et al., 2022).

The elastic band provides linear variable resistance throughout the range of motion (ROM), not only in the vertical plane but also in the horizontal plane. Elastic resistance does not depend on gravity but on the elongation of each polymeric elastic material (Folkins et al., 2021; Hughes & McBride, 2005; Melchiorri & Rainoldi, 2011). In contrast, weight provides a constant external load only in the vertical plane (Folkins et al., 2021). Elastic bands have the advantage of being relatively inexpensive, easy to use, portable, and a safe instrument. In turn, weight is an instrument that allows better control and load adjustment in each exercise (Folkins et al., 2021; Melchiorri & Rainoldi, 2011).

Traditionally, elastic bands and weights are used in clinical practice during strength exercises with swimmers. However, the fact that the external load of the two instruments is applied with different resistance vectors in distinct planes raises doubts as to whether they both produce the same muscle activation when used with the same intensity. In a systematic review carried out in 2019, it was concluded that training with elastic band promotes similar strength gains to weight resistance training in different populations and using diverse protocols (Lopes et al., 2019). On the other hand, considering differences in resistive torque along the ROM and symmetrical concentric-eccentric curve torque, it was speculated that a greater motor unit recruitment can be demanded by elastic resistance (Page & Ellenbeker, 2003).

To our knowledge, there is only one article that analyzed and compared the myoelectric activity of shoulder muscles between exercises performed with elastic band and weights. The authors conclude that no instrument is better than the other, and a combination of exercises with elastic band and weights seems to be the better choice to increase the training response. They report that tubing exercises are better for diagonal or standing movements, while weights are more indicated for exercises in a prone position (Hughes & McBride, 2005). However, this study has some limitations: loads of the elastic band and weights were not normalized, the electrodes were placed with no care in avoiding innervation zones, poor exercise description, and some limitations in the analysis of the EMG signal (Melchiorri & Rainoldi, 2011). Some problems present in the Hughes and McBride (2005) study take away some strength of the conclusions reached and lead to the need for improving the study design to try to give more robust answers to the questions raised. Although some studies carried out an EMG analysis in isolated programs with elastic bands or weights used to prevent a swimmer's shoulder, none of them were conducted in a swimmer population (Cools et al., 2007; Ekstrom et al., 2003; Hibberd et al., 2012; Moseley et al., 1992; Myers et al., 2005; Oyama et al., 2010)

The purpose of this study was to compare the EMG activity of MT, LT, IS, SA, and PM in two swimmer's shoulder prevention programs consisting of five exercises in competitive swimmers. One of these programs was performed with an elastic band, and the other with weights. This study hypothesized that the five exercises performed with an elastic band and weight produce different myoelectric muscle activity of MT, LT, IS, SA, and PM in competitive swimmers.

METHODOLOGY

Participants

This study included 20 competitive swimmers, 10 men and 10 women, with a mean age of 22.70 ± 3.83 years, who practiced 11.00 ± 5.11 hours of weekly swimming training and with 7.70 ± 2.87 years of competition in the national swimming federation (Table 5.1). To be included in the sample, participants should be aged between 16 and 35 years old, belong to a club affiliated with the Portuguese Swimming Federation during the 2022/2023 season, have a minimum of five years of experience in national competitions, and perform a minimum of six hours of weekly swim training. Clinical situations such as a history of significant shoulder pain in the last six months (Oyama et al., 2010), a history of traumatic shoulder injuries such as fractures, subluxations, previous shoulder surgeries, shoulder range of motion deficits, or neurological injuries, were considered as exclusion criteria (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010). Each participant read and signed a written informed consent form based on the revised version of the 2013 Declaration of Helsinki (Holt, 2014; Vandenbroucke et al., 2014). The sample identity protection was preserved following the European Union General Data Protection Regulation – Regulation (EU) – 2016/679. All procedures were approved by the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022). This clinical trial was carried out at the RoboCorp Laboratory at the Polytechnic Institute of Coimbra.

Table 5.1. Sample characterization variables.

Variables	Mean ± SD
Age (years)	22.70 ± 3.83
Body Mass (kg)	62.98 ± 10.28
Height (m)	1.69 ± 0.11
Body Mass Index (kg/m^2)	22.01 ± 1.82
Fat mass (%)	13.98 ± 7.27
Lean mass (kg)	51.84 ± 10.48
Bone mass (kg)	2.78 ± 0.52
Swimming practice (hours)	11.00 ± 5.11
Competitive swimming (years)	7.70 ± 2.87

SD – Standard deviation

Exercise programs protocol

To evaluate the two preventive exercise programs, a randomized crossover design was applied. Each swimmer performed in a same day, two strength programs consisting of the five exercises most often reported in the literature to prevent swimmer shoulder injury (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Tavares et al., 2022; Van de Velde et al., 2011): IR at 90°, ER at 90°, scapular punches, T's, and Y's (Table 5.2). One program was carried out with an elastic band Bodytone Power Band with 10, 15, 20, 25, or 30 kg (Figure 5.1), and the other with two weights Domyos with 1, 2, 3, 4, or 5 kg (Figure 5.2). The load used to perform the programs with elastic band and weights was previously assessed and adjusted for each swimmer, corresponding to 80 % of 1RM (Baechle & Earle, 2008).

Some criteria were preserved to minimize the impact of fatigue on results. The order of the 10 exercises was randomized from athlete to athlete. Half of the swimmers started the collection with an elastic band exercise, and the other half with a weight exercise. During the protocol, the participants always alternate an exercise with an elastic band with an exercise with a weight. Two minutes of rest were provided between different exercises (Baechle & Earle, 2008).

Each participant performed one set of eight valid repetitions in each exercise (Baechle & Earle, 2008). The repetitions were considered valid when the athlete reached the target ROM previously described for each exercise (Table 5.2). The concentric and eccentric phases of each exercise were performed for five seconds (Ekstrom et al., 2003). A Tabata Timer mobile application controlled this time. A physiotherapist was responsible for positioning the material, demonstrating, and correcting each athlete's technique during the execution of the programs. The athletes started the programs in standing, 90° of shoulders abduction, 90° of elbows flexion, and overhead hands.

Table 5.2. Description of five exercises that constitute the elastic band and weight-based programs.

Exercise	Elastic band program	Weight program
IR at 90°	The elastic band should be fixed at shoulder height. Movement: 90° of shoulders IR (5 s) and return to the start position (5 s).	Started in a supine position, 90° of shoulders ABD, 90° of ER, and 90° of elbows FLX. Movement: 90° of shoulders IR and return to the start position (5 s).
ER at 90°	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. Theraband should be fixed at shoulder height. Movement: 90° of shoulders ER (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. Movement: 90° of shoulders ER (5 s) and return to the start position (5 s).

Scapular punches	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: Elbow EXT (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders ABD, 90° of elbows FLX, and hands at the same height as the shoulders. Movement: Elbow EXT (5 s) and return to the start position (5 s).
T's	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. The elastic band should be fixed at shoulder height. Movement: 90° of shoulders HABD (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. Movement: 90° of shoulders HABD (5 s) and return to the start position (5 s).
Y's	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. The elastic band should be fixed at shoulder height. Movement: 90° of shoulders HABD and maximum shoulders FLX (5 s) and return to the start position (5 s).	Started in a standing position, 90° of shoulders FLX, and maximum elbows EXT. Movement: 90° of shoulders HABD and maximum shoulders FLX (5 s) and return to the start position (5 s).

IR – Internal rotation; ER – External rotation; FLX – Flexion; EXT – Extension; ABD – Abduction; HABD – Horizontal abduction; s – Seconds.

Figure 5.1. Illustration of the strength exercise program with an elastic band: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

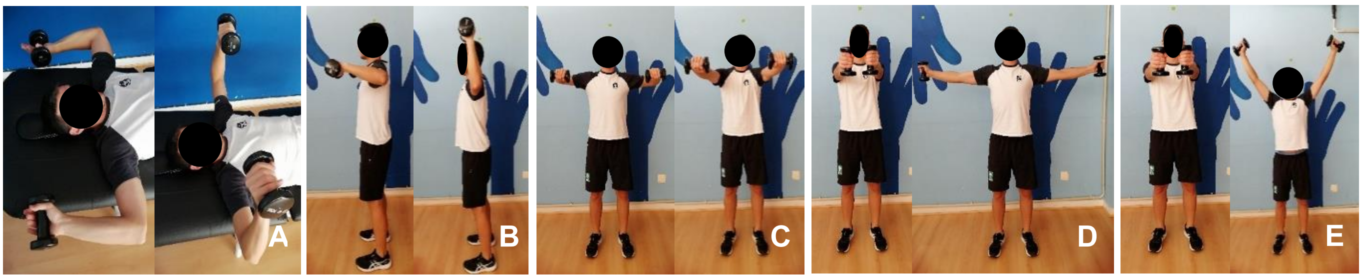

Figure 5.2. Illustration of the strength exercise program with weights: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

EMG data collection protocol

The skin was previously prepared for the EMG procedure through cleaning, shaving, and scrubbing with alcohol (Hermens et al., 2000; Park et al., 2013; Patselas et al., 2021; Tsuruike et al., 2020; Werin et al., 2020). EMG data were collected with active surface electrodes (Al/AgCl, disk shape, 10 mm of diameter) and superficial EMG BioSignalPlux telemetric equipment (Plux, Lisbon, Portugal). EMG data were collected with a 1000 Hz sampling frequency (Park et al., 2013; Patselas et al., 2021). Electrodes were always placed by one of the researchers in parallel to the MT, LT, IS, SA, and PM fibers of the dominant shoulder of each participant, with a 20 mm center-to-center distance (Hermens et al., 2000). For the placement of the electrodes on the MT and LT, the European recommendations of SENIAM were used (Hermens, 2024). The reference used for the IS was the mid-distance between the scapula spine and the inferior angle of the scapula, 20 mm lateral from the scapula medial border (Herrington et al., 2015; Pontillo et al., 2007; Tsuruike et al., 2020). The intersection of the axillary midline and the lower angle of the scapula line was used as a reference for placing the electrodes on the SA (Ekstrom et al., 2003; Herrington et al., 2015; Park et al., 2013; Patselas et al., 2021; Pontillo et al., 2007; Tsuruike et al., 2020; Werin et al., 2020). The location used for PM was 40–50 mm below the clavicle, 20 mm medial to the anterior axillary border, one-third of the distance from the great tuberosity to the xiphoid process, in a horizontal line in alignment with the muscle fibers (Herrington et al., 2015; Park et al., 2013; Pontillo et al., 2007; Werin et al., 2020). A ground electrode was placed on the ipsilateral clavicle (Hermens et al., 2000; Park et al., 2013). For the evaluation of voluntary MVIC of MT, LT, IS, SA, and PM, three maximum contractions of five seconds with thirty seconds of rest were conducted (Hermens et al., 2000; Werin et al., 2020), fifteen minutes before performing the exercise program protocols. Manual muscle testing procedures for each muscle were used according to SENIAM recommendations (Hermens, 2024; Tsuruike et al., 2020).

Data analysis

EMG data were digitally filtered (10–490 Hz), full-wave rectified, and smoothed with a low-pass filter 12 Hz, Butterworth 4th order digital filter using MATLAB 2020 software (MathWorks Inc., Natick, Massachusetts, USA). The main outcome sought was the muscle activity normalized to the % of MVIC of the five muscles in each exercise. The mean and standard deviation of the EMG activity of 160 repetitions were calculated – 8 repetitions for each exercise x 20 swimmers. All statistical analysis was carried out using IBM SPSS Statistics 27 software. The Shapiro-Wilk test was used to verify the normality of the sample distribution. The Paired Sample T-test or the Wilcoxon test was applied to compare EMG activity between the two programs. A *p*-value ≤ 0.05 was considered the level of significance for each difference in EMG activity between exercises performed with elastic bands and weights.

RESULTS

In scapular punches, it was observed that all differences ($p < 0.001$) happened when the exercise was performed with weight. These differences occurred in MT (10.65 % of MVIC), LT (13.63 % of MVIC), IS (30.00 % of MVIC), and SA (20.45 % of MVIC). In IR at 90º and ER at 90º, there were significantly higher ($p \leq 0.01$) EMG values when the exercises were performed with an elastic band. In the first exercise, these differences were greater for the elastic band in MT (17.32 % MVIC), LT (6.34 % of MVIC), IS (5.12 % of MVIC), and SA (5.92 % of MVIC), and only in PM evaluation did the opposite occur (8.20 % of MVIC). Performing the ER at 90º with an elastic band produced greater EMG activity values in: MT (11.35 % of MVIC), LT (8.47 % of MVIC), and IS (5.00 % of MVIC), and when carried out with weight, it activated the SA more (12.10 % of MVIC). The other two exercises were more balanced in terms of differences observed. The T's produced greater differences ($p < 0.001$) in MT (14.65 % of MVIC) when done with an elastic band, and higher differences ($p < 0.001$) in SA (32.38 % of MVIC) and PM (15.39 % of MVIC) when carried out with weight. In turn, the Y's with an elastic band led to greater EMG activity values in the MT (14.83 % of MVIC), and LT (12.62 % of MVIC), and when performed with weight, this was verified in the SA (26.46 % of MVIC) and PM (13.30 % of MVIC) (Table 5.3).

Considering only the highest mean, the exercises that produced the greatest EMG activity of the five evaluated muscles in swimmers were as follows: ER at 90º with an elastic band for the MT (42.63 % of MVIC), Y's with an elastic band for the LT (39.21 % of MVIC) and for the IS (42.50 % of MVIC), Y's with weights for the SA (50.95 % of MVIC), and T's with weights for the PM (21.91 % of MVIC) (Table 5.3).

Table 5.3. Differences in EMG activity of MT, LT, IS, SA, and PM between the five exercises performed with elastic bands and weights.

Exercise	Muscle	Elastic band (% of MVIC)	Weight (% of MVIC)	Difference (% of MVIC)	*p*-value
IR at 90º	MT	19.64 ± 9.75	2.32 ± 2.69	17.32	<0.001*
	LT	7.80 ± 6.17	1.46 ± 0.70	6.34	<0.001*
	IS	9.46 ± 5.64	4.34 ± 3.67	5.12	<0.001*
	SA	12.63 ± 5.34	6.71 ± 2.92	5.92	<0.001*
	PM	8.75 ± 6.96	16.95 ± 11.69	-8.20	<0.001*
ER at 90°	MT	42.63 ± 13.99	31.28 ± 10.63	11.35	<0.001*
	LT	33.01 ± 14.10	24.54 ± 11.20	8.47	0.001*
	IS	35.73 ± 11.11	30.73 ± 7.76	5.00	0.010*
	SA	19.51 ± 13.18	31.61 ± 13.94	-12.10	<0.001*
	PM	3.33 ± 2.24	4.64 ± 4.73	-1.31	0.227
Scapular punches	MT	14.31 ± 5.70	24.96 ± 7.28	-10.65	<0.001*
	LT	10.11 ± 6.46	23.74 ± 10.47	-13.63	<0.001*
	IS	11.10 ± 4.00	41.10 ± 25.35	-30.00	<0.001*
	SA	14.36 ± 6.00	34.81 ± 14.18	-20.45	<0.001*
	PM	13.41 ± 7.65	17.13 ± 11.75	-3.72	0.120
T's	MT	41.86 ± 9.59	27.21 ± 9.60	14.65	<0.001*
	LT	30.63 ± 10.10	28.25 ± 12.94	2.38	0.377
	IS	41.04 ± 28.38	37.40 ± 12.69	3.64	0.823
	SA	6.21 ± 3.01	38.59 ± 18.17	-32.38	<0.001*
	PM	6.52 ± 3.70	21.91 ± 14.71	-15.39	<0.001*
Y's	MT	36.63 ± 11.38	21.80 ± 6.83	14.83	<0.001*
	LT	39.21 ± 12.07	26.59 ± 14.19	12.62	<0.001*
	IS	42.50 ± 20.13	37.83 ± 12.18	4.67	0.681
	SA	24.49 ± 15.40	50.95 ± 22.86	-26.46	<0.001*
	PM	7.54 ± 6.98	20.84 ± 15.24	-13.30	<0.001*

* Statistically significant difference

MVIC – Maximum voluntary isometric contraction; IR – Internal rotation; ER – External rotation; SP – Scapular punches.

DISCUSSION

This study intends to compare the EMG activity of five shoulder muscles in two programs consisting of the most described exercises in the literature for swimmer's shoulder prevention: one performed with an elastic band and the other with weights. Regarding the results of this study, it is possible to verify that performing the same preventive exercise program with two different instruments produces great variability in the myoelectric activity of the shoulder muscles.

The only study (Hughes & McBride, 2005) that compares the EMG activity of shoulder muscles between elastic bands and weights in shoulder exercises presents some limitations in its methodology, including the poor description of the performed exercises. After an analysis of this study, there appear to be two exercises: "ER exercise" and "Full Can Exercise", like the ER at 90° and Y's assessed in our study. However, the results found are different. The EMG activity values were overall higher than ours, probably because the sample used were not swimmers. In the "ER exercise", the IS had the highest EMG activity when performed with weights (65–87 % of MVIC), and there were three differences for the elastic band in the MT, IS, and PM. In our study, the ER at 90º produced the highest EMG activity in the MT (42.63 % of MVIC) and had differences in MT, LT, and IS when executed with an elastic band. Regarding the comparison of "Full Can Exercise" with Y's, they found a difference for the elastic band in IS, and in our study, it was not significant (Table 5.3).

Another four studies (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010; Tsuruike et al., 2020) were found that carried out an EMG analysis of some exercises included in swimmer's shoulder prevention programs, but none of them compared their execution with different instruments. Only one of them analyses a sporting population. Tsuruike et al. (2020) evaluated the EMG activity of the UT, middle deltoid (MD), SA, LT, and IS in three exercises with elastic bands with different resistances (0 %, 20 %, and 40 %), performed isometrically or with oscillation in baseball athletes. Two of these exercises are identical to the Y's and ER at 90º. The other three studies (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010) evaluate some shoulder exercises in a sample of non-athletes. This is a possible reason that explains why, in general, the results found in these three studies are slightly higher than those observed in Tsuruike et al. (2020) and our study. Conversely, there is a lot of variability between these four studies (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010) regarding the description of the exercise programs evaluated. Ekstrom et al. (2003) evaluated the EMG activity of the UT, MT, LT, and SA in 10 exercises performed 3 times each by 30 non-swimmers, where the scapular punches in a supine position, the T's and Y's in a prone position, and the T's and Y's in a standing position were present. Myers et al. (2005) evaluated the EMG activity of the PM, anterior deltoid (AD), MD, latissimus dorsi, SA, biceps brachii, triceps brachii, LT, and IS in twelve rubber-tubing resistance exercises performed ten times each by 15 physical active subjects. These exercises included the IR at 90°, ER at 90°, and scapular punches, carried out in a standing position with a fixed resistance of 9.1 kg. Lastly, Oyama et al. (2010) made an EMG evaluation in 25 non-swimmers of the UT, MT, LT, and SA, in six exercises performed only with body weight in a prone position. Part of these six exercises are the T's and the Y's performed in two different modes: with the palm facing the ground and the thumb pointing to the ceiling.

In our analysis, the standing IR at 90º with an elastic band proved to be a better exercise for activating the MT, LT, IS, and SA, compared to the same exercise with weights. In a similar direction, Myers et al. (2005) observed that the standing IR at 90º with an elastic band promoted high EMG activity values of the LT (53.70 % of MVIC), IS (23.70 % of MVIC), and SA (53.50 % of MVIC). In both cases, this exercise performed with an elastic band does not seem to be the most suitable if it is intended to promote the activation of the PM.

The ER at 90º and Y's with elastic band seem to be good exercises for activating the LT. In both cases, when the exercise was performed with an elastic band, there were differences ($p < 0.001$) in the EMG activity values of the LT compared to weights. Similarly, in Tsuruike et al. (2020), ER at 90º and Y's were the exercises that produced the highest activation of LT. The ER at 90º with 0 %, 20 %, and 40 % of elastic band resistance produced 32.30 % of MVIC, 43.00 % of MVIC, and 48.10 % of MVIC, and the Y's obtained 31.10 % of MVIC, 43.80 % of MVIC, and 48.80 % of MVIC, respectively. In Oyama et al. (2010), the Y's in a lying position and without load show a high % of MVIC value in the LT when participants performed the exercise with the palm facing the ground (67.80 % of MVIC) and when carried out the movement with the thumb pointing to the ceiling (71.90 % of MVIC).

The standing scapular punches with weights was the only exercise that produced greater EMG activity values in all shoulder muscles evaluated, particularly in SA and IS, leading to the conclusion that it will be more advantageous to perform it with weights compared to the elastic band. It should be noted that it is common that the SA always emerged as one of the greatest activation muscles in this exercise. Tsuruike and Ellenbecker (2019) showed that SA can be highly activated with a dumbbell against gravity in a standing position compared with a quadruped and prone positions. In Ekstrom et al. (2003), scapular punches with weights in a lying position also produced a good value of % MVIC in the SA (62.00 % of MVIC), however, in this study, there is no comparison with a standing position. On the other hand, in Myers et al. (2005), standing scapular punches with an elastic band produced higher % MVIC values in the LT (39.20 % of MVIC), IS (35.00 % of MVIC), and SA (66.70 % of MVIC). It would be interesting in this study to have a comparison with the same exercise with weights. The SA is a muscle that has its origin in the upper eight ribs and its insertion on the medial margin of the scapula, thus assuming a very important role in the stability of the scapula (Ekstrom et al., 2005; Moore & Dalley, 2003). The fact that it promotes coaptation of the scapula against the coastal grid allows other muscles to use it as a fixed point for humerus movement (Moore & Dalley, 2003). The fact that the weight has a different resistance vector compared to the elastic band means that while performing the exercises, there is a greater demand on the anterior shoulder muscles, such as the AD, which also has one of the parts of its muscular origin in the scapula (scapular spine, acromion). One of the possible explanations why standing exercises with weight promote a good activation of the SA could be the fact that this greater demand on the AD leads to a greater force of coaptation of the scapula against the coastal grid and a greater need for the SA action.

The standing T's (38.59 % of MVIC) and Y's (50.95 % of MVIC) with weights produced a high EMG activity of the SA, identically what happens in standing T's (62.00 % of MVIC) and Y's (96.00 % of MVIC) in the study of Ekstrom et al. (2003). However, when these two exercises are performed with an elastic band or in other positions, they produce a greater EMG activity of the MT, LT, and IS (Cools et al., 2007; Ekstrom et al., 2005; Myers et al., 2005; Oyama et al., 2010). If we focus specifically on what happens with different shoulder muscles, it is possible to observe that the most posterior muscles evaluated, such as MT, LT, and IS, presented a higher % of MVIC in four exercises when performed with an elastic band. On the contrary, higher EMG activity values were observed in four exercises with weights in SA, and in five exercises with weights in PM, the most lateral and anterior muscles evaluated (Table 5.3). The different planes of force application characteristic of the two instruments during the execution of the exercises could be one of the possible explanations for this inter-muscular difference.

Contrary to what often happens in clinical practice, it does not seem correct to state that there is a better exercise for a particular muscle. There were cases in which the theoretical target muscle of certain exercise did not correspond to the one that obtained the highest EMG activity average, such as the IS in the ER at 90°: 2nd highest mean value verified with elastic band and 3rd with weights, or the LT in the Y's: 3rd highest mean value verified with elastic band and weights. On the other hand, it was found that the muscle with the highest mean EMG activity in the five exercises varied from swimmer to swimmer. This great intra-subject variability can be visible in the high standard deviations of some of the observed mean results (Table 5.3).

One of this study's limitations is that only the mean and the standard deviation of the EMG activity are evaluated. An analysis of the temporal variability of the EMG curves obtained for each subject could add important information. On the other hand, as most of the evaluated exercises were performed in a standing position, it limits comparison with previous studies (Cools et al., 2007; Ekstrom et al., 2005; Myers et al., 2005; Oyama et al., 2010) that often carry out this EMG evaluation in a lying position.

CONCLUSION

There is a great variability in the EMG activity values of the shoulder muscles from exercise to exercise when executed with different instruments. The standing IR at 90º with an elastic band seems to be a greater exercise for LT, IS, and SA, but not for PM. The standing ER at 90º and Y's with the elastic band was an interesting exercise for activating the LT. The standing scapular punches were a good exercise for SA and produced a better activation of the stabilizing shoulder muscles when performed with weights. The standing T's and Y's with weights produced a high EMG activity of the SA, but not when executed in other positions.

When the exercises were performed with an elastic band, they produced greater EMG activity of the MT, LT, and IS – the most posterior muscles evaluated. When they were carried out with weights, they led to the highest EMG activity of the SA and PM – the most lateral and anterior muscles evaluated.
There is very little information about EMG analysis performed in swimmer's shoulder preventive exercises, often leading to these being anecdotally applied in practice. More EMG studies are needed to clarify the potential of each dry-land exercise included in preventive programs for overhead athletes.

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Conceptualization, N.T. and M.A.C.; methodology, N.T. and M.A.C.; software, N.T. and M.A.C.; validation, N.T. and M.A.C.; formal analysis, J.P.V-B. and M.A.C.; investigation, N.T.; resources, N.T. and M.A.C.; data curation, N.T. and M.A.C.; writing – original draft preparation, N.T.; writing – review and editing, N.T.; J.P.V-B. and M.A.C.; visualization, N.T.; J.P.V-B. and M.A.C.; supervision, J.P.V-B. and M.A.C. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement
The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Polytechnic Institute of Coimbra (CEPC 6/2022).

Data Availability Statement
The data that support the findings of this study are available from the corresponding author (N.T.) upon reasonable request.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Disclosure statement

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CHAPTER IV

- Brief introduction to Chapter IV

- **Study V –** Effect of Preventive Exercise Programs for Swimmer's Shoulder Injury on Rotator Cuff Torque and Balance in Competitive Swimmers: A Randomized Controlled Trial

- **Study VI –** An Inter-Group Analysis of the Rotator Cuff Strength and Balance After Implementing Two 12-Week Preventive Exercise Programs for Swimmer's Shoulder: A Randomized Controlled Trial

- **Study VII –** Influence of Dry-Land Exercise Programs on Symmetry of Shoulder Rotator Cuff Strength and Balance in Competitive Swimmers – A Randomized Controlled Trial

Chapter IV focuses on the main studies group of this thesis, which is reflected in its title. After a thorough review and analysis of various exercise programs conducted in previous chapters, this chapter presents the testing of two preventive interventions specifically designed for competitive swimmers. This study group aimed to evaluate the effects of these exercise interventions on rotator cuff torque, balance, and symmetry, which are key musculoskeletal risk factors for swimmers' shoulder injuries.

A sample of competitive swimmers was divided into three groups: two groups participated in a targeted swimmer's shoulder prevention program, while a third group received a sham intervention. All interventions were conducted twice a week over 12 weeks. Before and after each intervention, all athletes were assessed using an isokinetic dynamometer. The complete methodological protocol for the studies presented in this chapter has been registered on https://clinicaltrials.gov under the clinical trial registration number NCT06552585. Based on extensive data collected, three major analyses were conducted, resulting in three randomized controlled studies with distinct objectives aimed at answering different questions:

- **Are there any observed effects on rotator cuff torque and balance among the competitive swimmers due to the interventions?** The first study aimed to determine the differences in rotator cuff torque and balance indicators before and after interventions within each sample group. In other words, an intra-group analysis was conducted to verify the changes brought about by the intervention in each group. To complement this study, the rotator cuff balance values were compared to reference values recommended for preventing shoulder injuries in swimmers, both before and after each intervention.
- **Are there more effective interventions for improving rotator cuff torque and balance in competitive swimmers?** The second study aimed to compare the differences in rotator cuff torque and balance variables between the three sample groups. This inter-group analysis focuses on determining whether the intervention produced more beneficial results compared to another.
- **Do targeted interventions significantly impact the strength symmetry between the right and left shoulders of competitive swimmers?** The third

study examined another musculoskeletal risk factor for swimmer's shoulder injury: the symmetry of rotator cuff strength between the right and left shoulders. This analysis aimed to assess differences in this variable before and after interventions in each group separately.

All randomized controlled trials followed the CONSORT 2010 checklist to ensure optimal methodological organization. Adhering to the specific criteria of this checklist required the repetition of some topics, tables, and figures in the methodology section of each study, as the same protocol was applied throughout. All other sections, including the introduction, results, discussion, and conclusions, are distinct and address different information for a more robust and complete analysis in this chapter.

The details of the three randomized controlled trials will be presented below.

STUDY V

Randomized Controlled Trial

Effect of Preventive Exercise Programs for Swimmer's Shoulder Injury on Rotator Cuff Torque and Balance in Competitive Swimmers: A Randomized Controlled Trial

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ABSTRACT

Background: Over the season, competitive swimmers experience a progressive imbalance in rotator cuff strength, predisposing them to a significant risk factor for a swimmer's shoulder injury. Objectives: Verify the effectiveness of two 12-week preventive programs on the shoulder rotators' peak torque and conventional/functional ratios. Design: A care provider and participant-blinded, parallel, randomized controlled trial with three groups. Participants: Competitive swimmers aged 16 to 35 years with no prior clinical issues related to their shoulders. Interventions: Twice a week, over 12 weeks, the two experimental groups performed five exercises where the only difference was executing the program with weights or elastic bands, and the control group performed a sham intervention. Main outcome measures: The concentric and eccentric peak torque of the internal and external rotators of the dominant shoulder were assessed before and after the intervention using an isokinetic dynamometer Biodex System 3, at 60°/s, 120°/s, and 180°/s. Results: Among the experimental groups, only one test indicated a reduction ($p \leq 0.05$) in rotator peak torque, while the control group showed a decrease ($p \leq 0.05$) in five tests. Swimmers who completed the prevention programs demonstrated less imbalance in conventional/functional ratios than controls. Conclusions: Implementing a 12-week preventive program minimizes the progressive shoulder rotational imbalance over the season in competitive swimmers. Clinical Trial Registration number: NCT06552585.

Keywords

Swimmer's shoulder injury; Elastic band program; Weight program; Rotator cuff; Injury prevention; Preventive medicine.

INTRODUCTION

Swimmer's shoulder is the most common injury among swimmers (Feijen et al., 2020; Hill et al., 2022; Schlueter et al., 2021; Struyf et al., 2017; Walker et al., 2012; Yoma et al., 2022). It is characterized by non-specific anterior shoulder pain resulting from the repetitive impingement of the rotator cuff under the coracoacromial arch (Hill et al., 2022; Struyf et al., 2017; Tavares et al., 2022; Walker et al., 2012; Yoma et al., 2022). This impingement can result in functional impairments and decreased athletic performance (Hill et al., 2015). It is estimated that around 40–91 % of swimmers will experience this issue at least once during their careers (Drigny et al., 2020; Hill et al., 2022; Matzkin et al., 2016; Schlueter et al., 2021). Furthermore, 20–35 % of competitive swimmers experience a loss of training or competition time each year due to this injury (Drigny et al., 2020; Gaunt et al., 2012; Matzkin et al., 2016). The causes of swimmer's shoulder are dynamic and multifactorial (Tavares et al., 2022; Yoma et al., 2022; Yoma et al., 2021). Several risk factors contribute to this painful syndrome, including muscle strength imbalances (Feijen et al., 2021; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017), swimming volume (Feijen et al., 2021; Feijen et al., 2020; Hill et al., 2015; Yoma et al. 2021), fatigue (Buoite et al., 2024; Feijen et al., 2021; Yoma et al., 2021), competitive level (Feijen et al., 2021; Hill et al., 2015), poor stroke mechanics (Feijen et al., 2021; Wanivenhaus et al., 2012), lack of scapular stability (Hill et al., 2015; Feijen et al., 2021; McKenzie et al., 2023; Struyf et al., 2017), changes in mobility (Feijen et al., 2021; Hill et al., 2015; McKenzie et al., 2023; Schlueter et al., 2021; Struyf et al., 2017), and a previous history of injury (Feijen et al., 2021; Feijen et al., 2020; Hill et al., 2015).

Modifiable risk factors are crucial for identifying athletes at increased injury risk. Many of these factors can be altered through therapeutic interventions (Yoma et al., 2022). Rotator cuff imbalances are a modifiable musculoskeletal risk factor and one of the strongest predictors of swimmer's shoulder (Tavares et al., 2022; Yoma et al., 2021). These muscle imbalances can lead to abnormal movements of the glenohumeral and scapulothoracic joints, which may continuously aggravate susceptible tissues (Buoite et al., 2024). Usually, in overhead sports athletes, the ER and the IR PTs in concentric or eccentric action, measured through the isokinetic dynamometer (Batalha et al., 2013; Collado-Mateo et al., 2018; Drigny et al., 2020; Olivier et al., 2018), are the main outcomes collected to evaluate this risk factor (Batalha et al., 2013; Collado-Mateo et al., 2018; Drigny et al., 2020; Olivier et al., 2018; So et al., 2023). Through these values, it is possible to calculate the strength balance of shoulder rotators using different ratios (Drigny et al., 2020; Olivier et al., 2018; So et al., 2023). The conventional ratios are the division between ER and IR PTs in a concentric (conER:conIR) or eccentric (eccER:eccIR) contraction mode. The functional ratios are calculated by dividing the ER PT during an eccentric action by the IR PT during a concentric action (eccER:conIR), or the reverse (eccIR:conER). The eccER:conIR ratio is generally deemed more suitable for evaluating the eccentric action of the antagonist muscles, which contributes to the dynamic stability of the glenohumeral joint. Conversely, the eccIR:conER ratio reflects the arm cocking action during overhead throwing (Drigny et al., 2020).

Several studies have verified reference ratio values to predict or not predict shoulder pain associated with sports (Andrade et al., 2013; Bak & Magnusson, 1997; Edouard et al., 2013; Ellenbecker & Davies, 2000; Olivier et al., 2008). However, some controversy remains regarding the appropriate ratio intervals for competitive overhead athletes (Batalha et al., 2013). Ellenbecker and Davies (2000) concluded that to prevent shoulder injuries in overhead sports, the conER:conIR ratio should be between 0.66 and 0.75. Consequently, the strength of the ER should be 2/3 compared to the IR of the shoulder. Regarding functional ratio, Bak and Magnusson (1997) reported an eccER:conIR ratio = 0.86 % in asymptomatic swimmers. Drigny et al. (2020) considered that swimmers have a 4.5-fold increased risk of in-season shoulder injury with an eccER:conIR ratio < 0.68.

Due to many training and competition events, there is a normal tendency during the season for a progressive imbalance of shoulder rotator ratios in competitive swimmers (So et al., 2023). Batalha et al. (2013) found a decrease from 0.79 to 0.71 in the conER:conIR ratio in swimmers after 8 months of a competitive season. Strength prevention programs have been tested to minimize this predisposition for imbalance during a swimmer's season and normally show good results (Batalha et al., 2015; Chepeha et al., 2018; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002; Tavares et al., 2022; Yoma et al., 2022). However, some authors report no effect of these preventive programs on strength and endurance variables in swimmers (Hibberd et al., 2012; Swanik, Swanik, et al., 2002) and other overhead sports athletes (Fredriksen et al., 2021). In general, these studies are characterized by a high heterogeneity: in the quantity and type of exercises performed during the program, in the kind of instrument used in the exercises, and in the monitoring, duration, and progression of the program over time. Therefore, it does not allow us to draw strong conclusions regarding the real effect of each preventive program on this musculoskeletal risk factor for the swimmer's shoulder injury.

Recent reviews indicate that strength programs with a few exercises performed out of the water and in an open kinetic chain appear to have better results in preventing this sports injury (Tavares et al., 2022; Yoma et al., 2022), pointing to the need to clarify precisely the dimension of this effect.

Verifying the difference between performing open kinetic chain exercises with weights or elastic bands is important. In shoulder exercises, the elastic band typically produces more electromyographic activity in the posterior muscles, while weights engage the lateral and anterior muscles (Tavares et al., 2024). This significant distinction may lead to different potential effects from each exercise program.

Furthermore, it is necessary to check how long the preventive program should be to produce an effect on the strength balance of the rotator cuff. Some studies indicated no effects of the 8-week (Fredriksen et al., 2021) or 6-week preventive programs used (Hibberd et al., 2012; Swanik, Swanik, et al., 2002). According to the American College of Sports Medicine (ACSM) guidelines, strength or endurance exercise programs demonstrated significant improvements only after 10 weeks of training (ACSM, 2009).

Additionally, there is a need to clarify the impact of individual monitoring of the program execution. Some tested programs do not indicate monitoring (Batalha et al., 2015; Shahpar et al., 2019) or seem to do group monitoring (Hibberd et al., 2012).

The primary aim is to verify the effectiveness of two 12-week preventive programs for swimmers' shoulder injuries on the IR and ER PTs and the respective conventional and functional ratios. These programs include regular monitoring and progression over time. One program utilizes weights while the other employs elastic bands. This objective seeks to clarify the lack of consensus on the most effective preventive programs. The secondary aims include examining the differences between the weight and elastic band programs, evaluating whether a 12-week program duration leads to significant results, and analyzing the impact of individualized monitoring on reducing dropout rates during the follow-up period.

The study hypothesizes that the two tested preventive programs reduce rotator cuff imbalances in competitive swimmers. Conversely, the absence of a preventive program does not affect rotator cuff strength and balance.

METHODS

Trial design

A care provider and participant-blind, parallel, randomized controlled trial with three groups was completed from September 2022 to April 2023. This trial follows the CONSORT 2010 checklist for reporting randomized controlled trials (Table 6.5). All procedures received approval from the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022). The protocol for the randomized controlled trial has been registered on https://clinicaltrials.gov with the registration number NCT06552585.

Participants

Swimmers were recruited from two national competitive teams in Portugal, affiliated with the Portuguese Swimming Federation, during the 2022/2023 season. To be included in the study, participants had to be aged between 16 and 35 years, have at least five years of experience in national competitions (Batalha et al., 2015), and engage in a minimum of eight hours of swimming training per week (Batalha et al., 2018; Batalha et al., 2015; Hibberd et al., 2012). Exclusion criteria included a history of shoulder pain within the past six months (Hibberd et al., 2012; Kluemper et al., 2006; Van de Velde et al., 2011), prior shoulder surgeries (Chepeha et al., 2018; Lynch et al., 2010; Manske et al., 2015; Van de Velde et al., 2011), traumatic shoulder injuries, cervical or thoracic conditions (Van de Velde et al., 2011), ROM deficits, or neurological injuries (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010). Exclusion also applied to swimmers undergoing recent treatment, such as physical therapy, injections, or medications, for at least six weeks (Chepeha et al., 2018; Lynch et al., 2010). All eligibility criteria were verified through an individual questionnaire before sample selection. Each participant read and signed a written informed consent form based on the revised version of the Declaration of Helsinki from 2013 (Holt, 2014). After selection, all swimmers were weighed using a Tanita RD-953 body composition scale, and their height was measured with a stadiometer. The assessment of female athletes was conducted outside of their menstrual period. The confidentiality of participants' identities was maintained following the European Union General Data Protection Regulation (Regulation (EU)

2016/679). This randomized controlled trial was conducted at the RoboCorp Laboratory at the Polytechnic Institute of Coimbra.

Intervention programs

Twice a week for 12 weeks (Baechle & Earle, 2008; Manske et al., 2015), two intervention groups participated in a preventive program consisting of five open kinetic chain exercises commonly recommended in the literature for preventing swimmer's shoulder injury (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Tavares et al., 2022; Van de Velde et al., 2011): IR at 90°, ER at 90°, scapular punches, T's, and Y's (Table 6.1). The weight program group performed these exercises using Domyos weights of 1, 2, 3, 4, or 5 kg (Figure 6.1), while the elastic band program group used Bodytone Power elastic bands with resistance levels of 10, 15, 20, 25, or 30 kg (Figure 6.2). The load for each participant was assessed and adjusted to 75 % of their 1RM (Baechle & Earle, 2008). After six weeks of training, each swimmer underwent another 1RM test to evaluate their ability to progress the load (Shahpar et al., 2019; Van de Velde et al., 2011). The protocol for the 1RM test followed the guidelines outlined in Baechle and Early (2008). The T's exercise was selected for this assessment. Before the 1RM test, a warm-up consisting of ten repetitions of the T's exercise was performed using a very light load, either with weights or an elastic band. For each preventive exercise, participants completed two sets of ten valid repetitions (Baechle & Earle, 2008). Repetitions were considered valid when the swimmer achieved each exercise's target ROM, as detailed in Table 6.1. Each repetition consisted of five-second concentric and eccentric phases (Ekstrom et al., 2003). A Tabata Timer mobile application was used to monitor this timing. Additionally, one minute of rest was allowed between different exercises and sets (Baechle & Earle, 2008). The programs were supervised by a sports physiotherapist who was independent of the study. Each athlete received personalized monitoring, which included regular corrections to their exercise technique during all sessions. The first session was conducted in person, while the remaining sessions were monitored online via WhatsApp Messenger or Zoom Video Communications, Inc. Each session was individualized and lasted about 30 minutes.

Table 6.1. Description of five exercises that constitute the elastic band and weight-based programs.

Exercise	Weight program	Elastic band program
IR at 90°	Started in a supine position, 90° shoulder ABD, 90° ER, and 90° elbow FLX. Movement: 90° shoulder IR and return to the starting position (5 s).	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: 90° shoulder IR (5 s) and return to the starting position (5 s).
ER at 90°	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. Movement: 90° shoulder ER (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder ABD, 90 elbow FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: 90° shoulder ER (5 s) and return to the starting position (5 s).
Scapular punches	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. Movement: Elbow EXT (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: Elbow EXT (5 s) and return to the starting position (5 s).
T's	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. Movement: 90° shoulder HABD (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. The elastic band should be fixed at shoulder height. Movement: 90° shoulder HABD (5 s) and return to the starting position (5 s).
Y's	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. Movement: 90° shoulder HABD and maximum shoulder FLX (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. The elastic band should be fixed at shoulder height. Movement: 90° shoulder HABD and maximum shoulder FLX (5 s) and return to the starting position (5 s).

SP – standing position; s – seconds; ABD – Abduction; ER – External rotation; IR – Internal rotation; FLX – Flexion; EXT – Extension; HABD – Horizontal abduction.

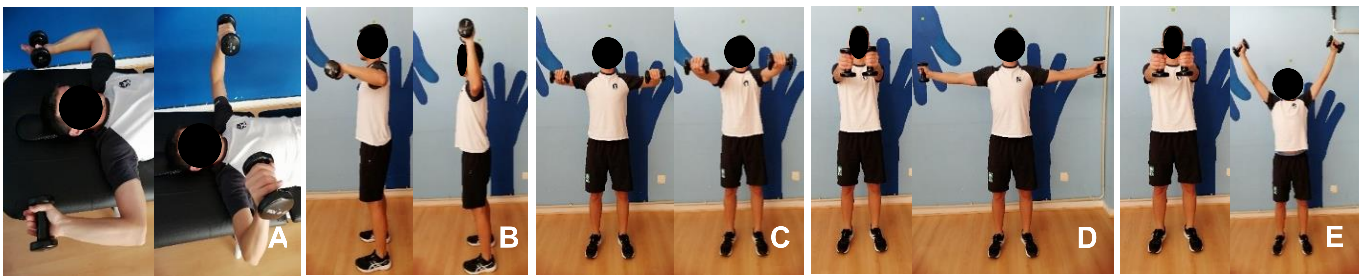

Figure 6.1. Illustration of the five exercises included in the weight program: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

Figure 6.2. Illustration of the five exercises included in the elastic band program: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

Control group

The control group carried out a sham intervention twice a week for 12 weeks. This intervention consisted of two sets of ten repetitions of five shoulder mobility exercises, commonly included as part of a warm-up before training. The sham intervention exercises were shoulder maximum flexion and extension, horizontal abduction and adduction starting from 90° of shoulder abduction, maximum IR and ER starting from 90° of shoulder abduction, circumduction of the shoulder in a clockwise direction, and circumduction of the shoulder in a counterclockwise direction (Baechle & Earle, 2008). There was no progression in the exercises over time. While the team's coach monitored the execution of the exercises, there was no individualized oversight or regular technique correction provided by a physiotherapist.

To ensure ethical equity among the sample groups and considering the potential benefits of the exercise programs tested, the control group was guaranteed access to either the weight or elastic band program after the conclusion of the trial.

Outcomes and testing procedures

Before (T0) and after 12 weeks (T1) of interventions and control procedures, the concentric and eccentric PT of IR and ER of the dominant shoulder were assessed through an isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, New York, NY, USA) (Batalha et al., 2018; Batalha et al., 2020; Batalha et al., 2015; Loureiro et al., 2013; Noffal, 2003), at 60°/s, 120°/s, and 180°/s (Shahpar et al., 2019).

Previously to strength evaluations, each swimmer completed a 10-minute warm-up that involved general upper-limb joint mobilization (Batalha et al., 2020). The isokinetic dynamometer assessment was performed with the swimmer lying (Loureiro et al., 2013; Noffal, 2003). The upper extremity was positioned with the shoulder abducted to 90° and the elbow flexed to 90° (Noffal, 2003), ensuring that the dynamometer's axis was aligned with the longitudinal axis of the humerus (Loureiro et al., 2013). The chosen evaluation position is similar to the body position of athletes during swimming. This position demonstrates better reproducibility and reliability for assessing the IR, ER, and concentric conventional ratio compared to both seated assessment and lying evaluation with the shoulder at 45° of abduction (Forthomme et al., 2011; Loureiro et al., 2013). Forthomme et al. (2011) conducted strength assessments in this position at angular velocities of 60°/s and 240°/s, showing reproducibility values of 11.8 and 10.5 for IR, 8.9 and 7.5 for ER, and 7.6 and 7.8 for the conventional concentric ratio. The reliability values were noted as 15.9 and 15.5 for IR, 9.6 and 6.6 for ER, and 0.15 and 0.13 for the conventional concentric ratio. Velcro straps were used to stabilize the athlete's trunk and the evaluated arm to prevent compensatory movements (Figure 6.3) (Batalha et al., 2020; Batalha et al., 2015; Loureiro et al., 2013). Gravity correction was not applied during this testing position because the ER and IR shoulder muscles moved with and against gravity when applying force (Ellenbecker & Mattalino, 1997; Loureiro et al., 2013; Noffal, 2003). Strength was tested through a ROM of 145°, measured from 80° of ER to 65° of IR, to capture the PT variation within the maximum available rotational ROM. The tests began with the shoulder positioned at 80° of ER (Loureiro et al., 2013). Concentric strength was tested first, followed by the eccentric strength test (Andrade et al., 2013; Noffal, 2003). The order of the angular velocity test was increased (60°/s–120°/s–180°/s) to preserve an ascending difficulty during the evaluations (Loureiro et al., 2013). A hard cushion deceleration control was chosen to give the subjects the greatest potential for achieving maximum velocity before deceleration (Brown et al., 1995; Loureiro et al., 2013). Before testing, the procedure was explained to all athletes, emphasizing the importance of exerting maximal effort within their tolerances (Batalha et al., 2020). Subsequently, swimmers performed three submaximal trials to familiarize themselves with the ROM and the accommodating resistance of the dynamometer (Noffal, 2003).

Each of the concentric and eccentric tests at varying velocities involved five maximal-effort reciprocal repetitions (Loureiro et al., 2013; Noffal, 2003). Standardized verbal instructions and encouragement were provided to all subjects (Batalha et al., 2020; Loureiro et al., 2013; Noffal, 2003), and a one-minute rest period was maintained between different tests (Batalha et al., 2018). The PT is the maximum torque produced at any point during the ROM and was used to assess the rotator cuff strength (Batalha et al., 2015). To evaluate the rotator cuff strength balance, the ER:IR ratio was calculated. This ratio is obtained by dividing the ER PT by the IR PT and multiplying the result by 100 (Batalha et al., 2015; Noffal, 2003). For this study, the conventional conER:conIR and functional eccER:conIR ratios were calculated.

Figure 6.3. Subject position and stabilizing during the isokinetic dynamometer strength assessment.

Sample size

The sample size calculation was performed using G*Power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Kiel, Germany, version 3.1.9.4). The statistical test selected was designed to compare mean differences between independent groups. The effect size used for this calculation was derived from a similar clinical trial (Batalha et al., 2015), which involved 56 participants divided into three groups: an experimental group of 20 swimmers who participated in both a preventive strength program and swimming training, a training group of 20 swimmers who only engaged in swimming training, and a control group consisting of 16 active non-swimmers. Based on this trial (Batalha et al., 2015), an effect size (Cohen's d) of 2.81 was identified, representing the smallest difference considered statistically significant between the experimental and training groups when assessing IR and ER PT at 60°/s and 180°/s of the swimmers' dominant shoulder.

Using an alpha level of 0.01, a power of 0.99, and an allocation ratio of 1:1, the software projected a minimum total sample size of 24 swimmers (8 per group). To account for potential dropouts, a final sample size of 30 swimmers (10 per group) was considered.

Randomization and blinding

The initial contact with the competitive swimmers of the two swimming teams was made through a telephone call, during which the eligibility criteria and individual consent for participation in the trial were screened. The eligible swimmers were then divided into three groups: a weight program group, an elastic band program group, and a control group. Allocation to each group was performed through stratified randomization according to the team (A or B), sex (male or female), and main swimming style (butterfly, backstroke, breaststroke, front crawl ≤ 200 m, or front crawl > 200 m). This approach aimed to balance the potential effects of these three variables on the results (Lynch et al., 2010). Participants were initially screened to determine their respective strata. The allocation process was concealed within each stratum, employing a computer-generated random number managed by a member of the research team. The participants were unaware of the existence of other sample groups. Then, all swimmers carried out the T0 assessment through the isokinetic dynamometer. To minimize fatigue bias during the assessment, half of the swimmers started with their dominant shoulder, while the other half began with their non-dominant shoulder. This order was randomized using a computer-generated random number. Following the T0 assessment, two 12-week experimental interventions were implemented and supervised by a sports physiotherapist who was external to the study and unaware of the previous procedures or the study's objectives. The first session with each athlete was conducted in person. During this session, the physiotherapist performed an individual 1RM test according to the specific equipment and explained the exercise program to the swimmer. After 6 weeks of intervention, the physiotherapist conducted a new 1RM evaluation to check any potential progress in load. All in-person and online sessions were individualized to ensure that each athlete remained unaware of the other groups. The sports physiotherapist also tracked the number of sessions completed by each athlete and did not have contact with those in the control group. At the end of the 12 weeks, all swimmers who completed the full set of proposed interventions carried out the T1 strength assessment through the isokinetic dynamometer. All T0 assessment procedures were maintained in the T1.

Data analysis

The data were filtered (smoothing option) and windowed at 95 % of the test velocity. Data analysis was performed using the AcqKnowledge 4.1 software. The mean and standard deviation of the PT in the five repetitions of different muscles (IR and ER), actions (concentric and eccentric), and angular velocities (60°/s, 120°/s, and 180°/s) were calculated. Subsequently, the conventional conER:conIR and the functional eccER:conIR ratios were calculated for three angular velocities.

All statistical analysis was carried out using IBM SPSS Statistics 27 software. Mean and standard deviation were used for sample characterization. The Shapiro–Wilk test was used to verify the normality of the sample distribution. The homogeneity of variance between the three groups was verified for the sample characterization variables and the IR and ER PT at T0, through the one-way ANOVA or the Kruskal–Wallis tests. After this, an intra-group analysis between T0 and T1 was made. The paired sample T-test or the Wilcoxon test was applied to compare differences in each group between T0 and T1. A p-value ≤ 0.05 was considered the significance level for each difference in PT, conventional, and functional ratios.

RESULTS

Participant recruitment happened in September 2022. Initial contact with the competitive swimmers was made through a phone call, during which the eligibility criteria and individual consent for participation in the trial were screened. Out of

49 athletes contacted, 30 were eligible and deemed suitable to participate. These participants were allocated through stratified randomization into three groups: a weight training program group (n = 10), an elastic band training program group (n = 10), and a control group (n = 10). The different types of swimming training according to the team or the main swimmer's style, and the strength differences between males and females were two variables that could influence the results. To minimize its impact, each group maintained equal representation, consisting of five swimmers from team A and five from team B, five men's and five women's, and two swimmers from each swimming style—butterfly, backstroke, breaststroke, front crawl ≤ 200 m, and front crawl > 200 m (Figure 6.4). The three groups exhibited homogeneity of variance (p > 0.05) regarding sample characterization (Table 6.2) and in IR and ER PT at T0 (Table 6.3). Each group performed two strength assessments: one before the intervention (T0) and one after the intervention (T1). No participant dropouts were recorded during the 12 weeks of follow-up. All participants in the experimental interventions completed the 24 individual sessions of their prevention program over 12 weeks.

Table 6.2. Sample characterization and homogeneity of variance between the groups.

Variables	**WP**	**EBP**	**Control**	***p*-value**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	
Age (years)	19.90 ± 2.92	19.60 ± 2.99	19.00 ± 3.62	0.506
Body Mass (kg)	68.86 ± 8.49	68.80 ± 14.76	65.57 ± 11.77	0.879
Height (m)	1.72 ± 0.08	1.70 ± 0.11	1.73 ± 0.09	0.774
Body Mass Index (kg/m^2)	23.19 ± 2.24	23.64 ± 3.34	21.79 ± 1.91	0.262
Fat mass (%)	17.02 ± 10.30	17.37 ± 8.65	15.40 ± 7.19	0.700
Lean mass (kg)	55.23 ± 10.60	57.66 ± 12.83	52.04 ± 13.66	0.868
Bone mass (kg)	2.91 ± 0.51	3.03 ± 0.64	2.75 ± 0.69	0.706
Swimming practice (years)	12.10 ± 4.18	9.40 ± 4.81	12.30 ± 4.17	0.274
Competitive swimming (years)	8.90 ± 3.28	6.10 ± 3.73	7.90 ± 3.38	0.206
Weekly swimming training (hours)	16.80 ± 5.01	14.20 ± 6.29	16.60 ± 6.87	0.577

SD – standard deviation; WP – weight program; EBP – elastic band program.

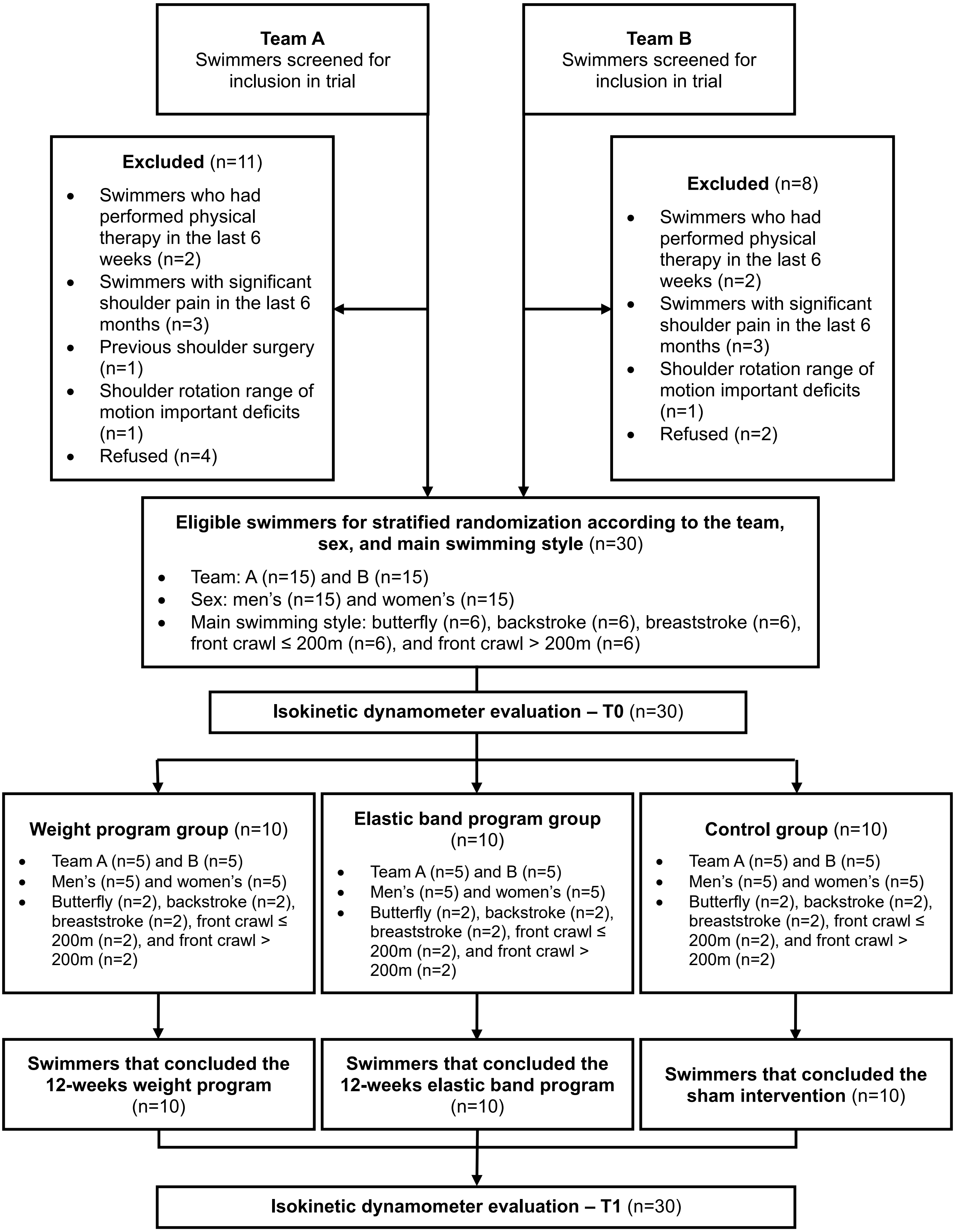

Figure 6.4. The flow of participants through the trial.

Table 6.3. The homogeneity of variance between the 3 sample groups for the PT at T0.

		WP PT (Nm)	EBP PT (Nm)	Control PT (Nm)	*p*-value
60°/s	conIR	36.06 ± 9.71	33.17 ± 9.25	37.99 ± 13.49	0.619
	eccIR	37.30 ± 7.74	38.62 ± 14.47	41.67 ± 19.08	0.790
	conER	24.98 ± 6.63	27.62 ± 7.95	25.42 ± 10.25	0.756
	eccER	31.69 ± 7.11	36.14 ± 11.61	34.51 ± 13.58	0.667
120°/s	conIR	30.84 ± 9.22	32.13 ± 11.56	34.66 ± 13.53	0.756
	eccIR	36.71 ± 8.05	36.43 ± 11.96	38.01 ± 17.24	0.959
	conER	23.95 ± 6.91	26.90 ± 8.88	23.63 ± 11.58	0.691
	eccER	29.74 ± 7.46	35.47 ± 11.95	30.79 ± 12.80	0.473
180°/s	conIR	28.63 ± 9.70	28.22 ± 10.73	32.07 ± 13.90	0.719
	eccIR	38.11 ± 6.99	39.81 ± 12.95	39.53 ± 19.00	0.958
	conER	21.33 ± 5.07	24.26 ± 9.45	22.65 ± 11.64	0.774
	eccER	31.08 ± 7.74	37.28 ± 12.10	31.26 ± 14.64	0.464

WP – weight program; EBP – elastic band program; PT – peak torque;
con – concentric; ecc – eccentric; IR - internal rotation; ER – external rotation.

Peak Torque

Firstly, an intra-group analysis of PT variation was conducted between T0 and T1 (Table 6.4). Overall, there was a decrease in PT values between the two moments. In the weight program group, there was a decrease in eight PT assessments, while the remaining groups exhibited decreases in nine assessments. A total of six differences ($p \leq 0.050$) were found in the PT values between T0 and T1, all indicating a drop in values. For the intervention groups, only one difference of −5.65 Nm in concentric IR PT at 60°/s was considered significant ($p = 0.047$) in the weight program group. The remaining five differences were observed in the control group, which included: concentric IR PT at 60°/s (p = 0.002), eccentric IR PT at 60°/s ($p = 0.036$), eccentric ER PT at 60°/s ($p = 0.048$), concentric IR PT at 120°/s ($p = 0.005$), and concentric IR PT at 180°/s ($p = 0.002$).

Table 6.4. Intra-group analyses in PT between T0 and T1.

		T0 | PT (Nm)	T1 | PT (Nm)	T1-T0 | PT (Nm)	*p*-value
Weight Program	conIR at 60°/s	36.06 ± 9.71	30.41 ± 11.93	-5.65	0.047*
	eccIR at 60°/s	37.30 ± 7.74	37.16 ± 10.80	-0.14	0.959
	conER at 60°/s	24.98 ± 6.63	25.96 ± 8.45	0.98	0.506
	eccER at 60°/s	31.69 ± 7.11	29.84 ± 7.78	-1.85	0.315
	conIR at 120°/s	30.84 ± 9.22	29.57 ± 10.77	-1.27	0.537
	eccIR at 120°/s	36.71 ± 8.05	36.91 ± 10.74	0.20	1.000
	conER at 120°/s	23.95 ± 6.91	24.41 ± 7.05	0.46	0.705
	eccER at 120°/s	29.74 ± 7.46	29.03 ± 7.54	-0.71	0.704
	conIR at 180°/s	28.63 ± 9.70	26.21 ± 9.77	-2.42	0.215
	eccIR at 180°/s	38.11 ± 6.99	37.49 ± 9.65	-0.62	0.757
	conER at 180°/s	21.33 ± 5.07	22.74 ± 7.01	1.41	0.294
	eccER at 180°/s	31.08 ± 7.74	30.02 ± 8.83	-1.06	0.642
Elastic band program	conIR at 60°/s	33.17 ± 9.25	32.65 ± 13.57	-0.52	0.445
	eccIR at 60°/s	38.62 ± 14.47	38.08 ± 19.37	-0.54	0.575
	conER at 60°/s	27.62 ± 7.95	28.42 ± 8.12	0.80	0.595
	eccER at 60°/s	36.14 ± 11.61	35.57 ± 13.38	-0.57	0.818
	conIR at 120°/s	32.13 ± 11.56	30.95 ± 15.44	-1.18	0.074
	eccIR at 120°/s	36.43 ± 11.96	36.63 ± 18.98	0.20	0.594
	conER at 120°/s	26.90 ± 8.88	26.84 ± 9.12	-0.06	0.977
	eccER at 120°/s	35.47 ± 11.95	33.03 ± 11.15	-2.44	0.386
	conIR at 180°/s	28.22 ± 10.73	27.37 ± 13.81	-0.85	0.648
	eccIR at 180°/s	39.81 ± 12.95	37.48 ± 21.51	-2.33	0.386
	conER at 180°/s	24.26 ± 9.45	24.74 ± 10.70	0.48	0.828
	eccER at 180°/s	37.28 ± 12.10	35.36 ± 13.47	-1.92	0.301
Control	conIR at 60°/s	37.99 ± 13.49	28.15 ± 10.65	-9.84	0.002*
	eccIR at 60°/s	41.67 ± 19.08	37.03 ± 16.37	-4.64	0.036*
	conER at 60°/s	25.42 ± 10.25	25.85 ± 9.38	0.43	0.788
	eccER at 60°/s	34.51 ± 13.58	30.54 ± 12.50	-3.97	0.048*
	conIR at 120°/s	34.66 ± 13.53	26.07 ± 10.35	-8.59	0.005*
	eccIR at 120°/s	38.01 ± 17.24	37.08 ± 16.05	-0.93	0.627
	conER at 120°/s	23.63 ± 11.58	24.02 ± 9.68	0.39	0.843
	eccER at 120°/s	30.79 ± 12.80	30.18 ± 12.88	-0.61	0.675
	conIR at 180°/s	32.07 ± 13.90	24.53 ± 10.46	-7.54	0.002*
	eccIR at 180°/s	39.53 ± 19.00	37.15 ± 16.10	-2.38	0.264
	conER at 180°/s	22.65 ± 11.64	22.20 ± 9.70	-0.45	0.771
	eccER at 180°/s	31.26 ± 14.64	31.61 ± 13.71	0.35	0.680

* Statistically significant difference

PT – peak torque; con – concentric; ecc – eccentric; IR – internal rotation; ER – external rotation.

Conventional and functional ratios

The conER:conIR and eccER:conIR ratios were calculated for the different assessments at T0 and T1. Each swimmer provided three values for the conventional and functional ratios during each evaluation, corresponding to the three angular velocities tested. These individual values were plotted in three graphs for each group (Figure 6.5, 6.6, and 6.7), which also marked reference values for preventing shoulder injuries (Bak & Magnusson, 1997; Drigny et al., 2020; Ellenbecker & Davies, 2000). According to Ellenbecker and Davies (2000), the optimal range for the conER:conIR ratio in swimmers is between 0.66 and 0.75. Regarding the eccER:conIR ratio, the optimal range is between 0.68 and 0.86, based on findings from Drigny et al. (2020) and Bak and Magnusson (1997). The weight program group showed an overall increase in the conER:conIR and eccER:conIR ratios from T0 to T1. This increase resulted in a higher number of T1 assessments in the optimal range of the conER:conIR ratio but a smaller number of T1 evaluations in the optimal range of the eccER:conIR compared to T0 (Figure 6.5)

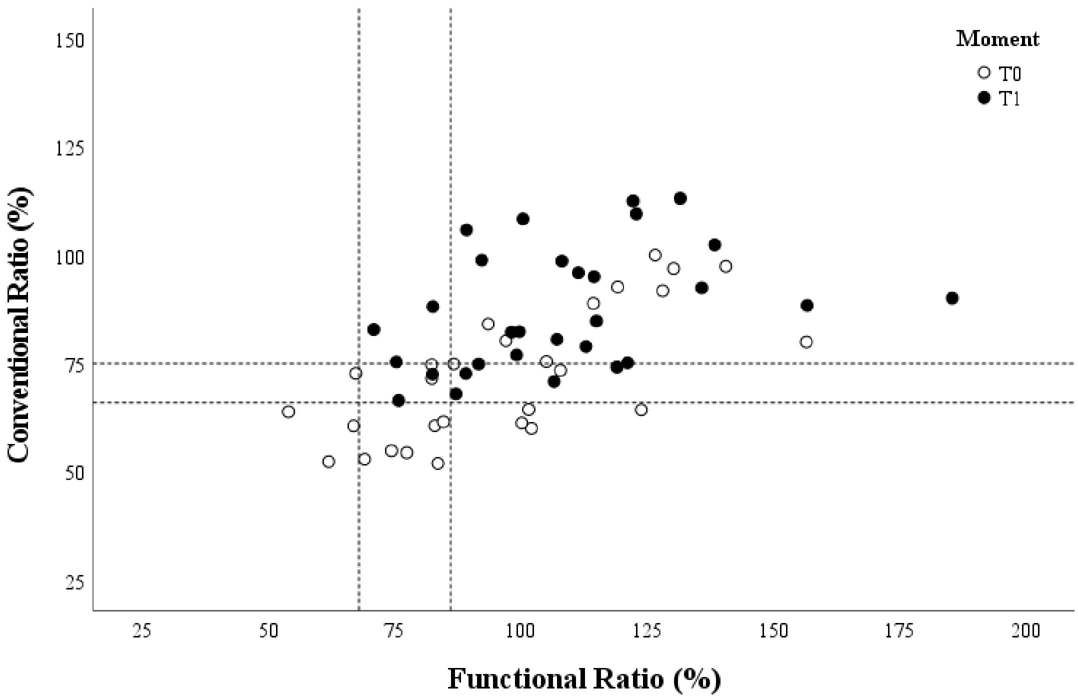

Figure 6.5. Conventional and functional ratios at 60°/s, 120°/s, and 180°/s for each swimmer in the weight program group. The reference values for preventing shoulder injuries are indicated with a dashed line.

In the elastic band program group, there was an overall increase only in the conER:conIR ratio from T0 to T1. This increase resulted in fewer T1 assessments in the optimal range of the conER:conIR ratio compared to T0. Additionally, there was no significant change in the eccER:conIR ratio between T0 and T1 (Figure 6.6).

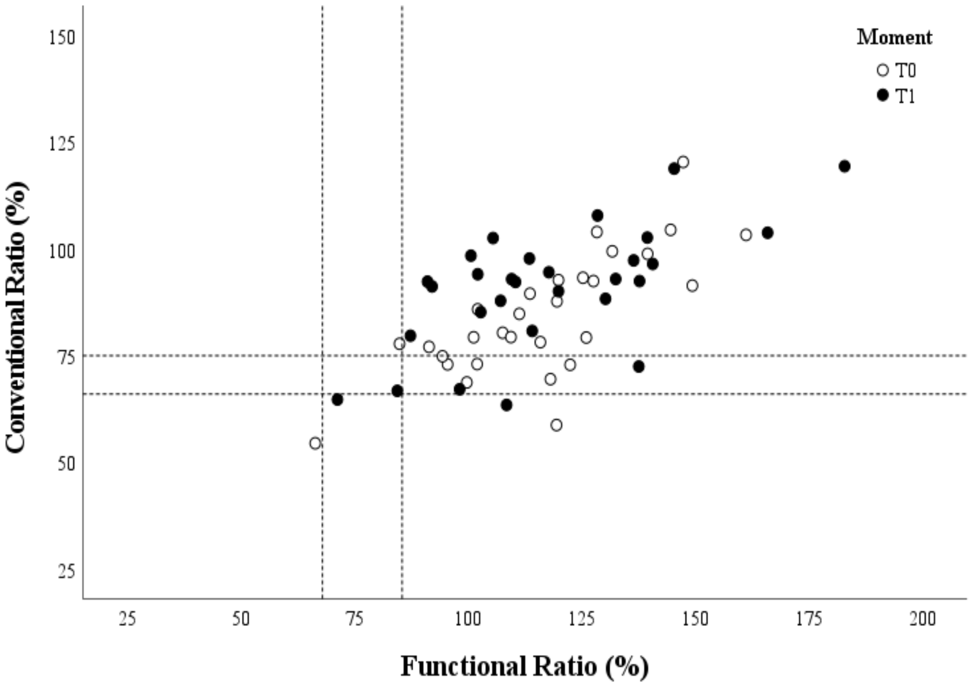

Figure 6.6. Conventional and functional ratios at 60°/s, 120°/s, and 180°/s for each swimmer in the elastic band program group. The reference values for preventing shoulder injuries are indicated with a dashed line.

In the control group, there was an increase in T1 compared to T0 for both shoulder ratios. This increase causes a move away from the optimal ranges of the conER:conIR and eccER:conIR ratios (Figure 6.7).

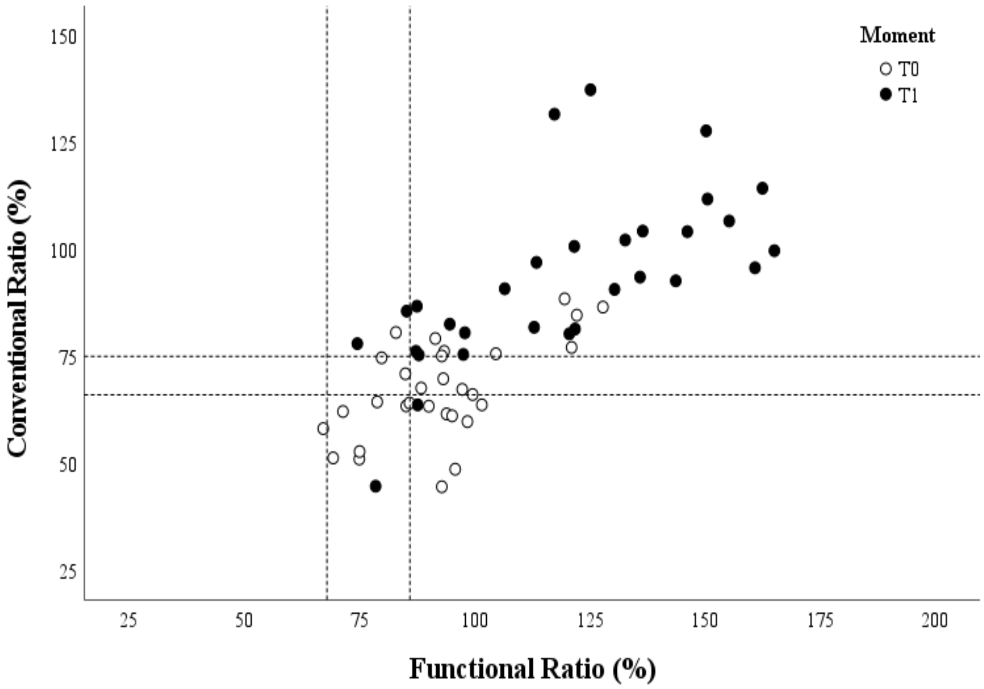

Figure 6.7. Conventional and functional ratios at 60°/s, 120°/s, and 180°/s for each swimmer in the control group. The reference values for preventing shoulder injuries are indicated with a dashed line.

In summary, a more significant decrease in the shoulder IR PT values in the control group increased the conventional and functional ratios, moving these values further away from the non-injury zone, compared to the experimental groups.

DISCUSSION

This investigation primarily aimed to assess the effectiveness of two 12-week preventive programs for swimmers' shoulder injuries, focusing on the IR and ER PTs, as well as the respective conventional and functional ratios. The findings indicated that the absence of a preventive exercise program resulted in significant decreases in PT values for both internal and external rotators, with particularly notable declines in the concentric assessment of internal rotators. Regarding rotator cuff balance, the results showed that the experimental groups demonstrated less imbalance compared to the control group.

Regarding secondary objectives, neither preventive program was more effective than the other. Both exercise programs successfully minimized the typical decrease in PT values during the swimming season. The weight program seemed to enhance the conventional concentric ratio, while the elastic program maintained the functional ratio, which includes the eccentric component. Additionally, a duration of 12 weeks for the programs seems to be sufficient to detect some effects. Lastly, individual monitoring throughout this period proved to be an effective strategy for reducing dropout rates and improving adherence to the program.

In the intra-group analysis, no significant increases were observed in any PT assessments following the experimental or control procedures. Instead, there was a general trend of decreasing PT values. This finding is consistent with some previous studies (Fredriksen et al., 2021; Hibberd et al., 2012; Swanik, Swanik, et al., 2002). This decline may be attributed to fatigue resulting from the cumulative effects of swimming training and competitions throughout the season. Some authors have observed a reduction in shoulder IR PT due to fatigue in other overhead sports immediately after training (Andrade et al., 2016) and following several weeks of training (Fredriksen et al., 2021). In contrast, some studies have reported an increase in shoulder ER PT among competitive swimmers after completing a preventive open kinetic chain program, as measured with an isokinetic dynamometer (Batalha et al., 2018; Batalha et al., 2015; Shahpar et al., 2019). The variety of exercises included in these programs could explain this difference. Notably, two of these programs (Batalha et al., 2018; Shahpar et al., 2019) incorporated more than one exercise that specifically emphasized ERs, which could account for better outcomes. Conversely, our experimental programs included only one exercise targeting the shoulder ER–ER at 90°. Furthermore, it is important to highlight that five of the six significant decreases in shoulder PT occurred in the control group. This suggests that experimental procedures may help minimize the expected declines in rotator cuff PT throughout the swimming season.

Regarding rotator cuff balance, swimmers who participated in experimental prevention programs demonstrated less imbalance after 12 weeks. The most significant differences between the initial (T0) and the final (T1) assessment were observed in the control group, which showed a marked deviation from the injury prevention ratios in both conventional and functional ratios. The experimental groups exhibited deviations in only one of the ratios. Specifically, the weight training group showed a deviation in the functional ratio, while the elastic band training group in the conventional concentric ratio. Drigny et al. (2020) and Batalha et al. (2013) observed that throughout the swimming season, there is a tendency for changes in swimmers' rotational ratios for injury risk values. Additionally, Fredriksen et al. (2021) verified that in another overhead sport, training for 8 weeks increased conventional and functional ratios.

The qualitative analysis of rotator cuff balance involved comparing conventional and functional ratio values against reference ranges for preventing shoulder injuries in athletes. While these ranges are widely cited in the literature (Batalha et al., 2018; Drigny et al., 2020; Ellenbecker & Davies, 2000), they have some limitations. The recommended range of 0.66–0.75 for the concentric conventional ratio (conER:conIR) is a general guideline for overhead athletes but is not specifically for swimmers (Bak & Magnusson, 1997). Additionally, the lower (0.68) and upper (0.86) limits of the ideal functional ratio (eccER:conIR) were established using significantly lower angular velocities than those typically encountered during swimming techniques. The lower limit was determined by Drigny et al. (2020), who monitored eighteen competitive swimmers over a season using an isokinetic dynamometer at 60°/s. Bak and Magnusson (1997) defined the upper limit by evaluating the eccER:conIR in asymptomatic Danish competitive swimmers using an isokinetic dynamometer at 30°/s. These limitations may explain why our T0 assessments of the conventional and functional ratios did not align perfectly with the optimal reference values for injury prevention.

The effects of a weight program compared to an elastic band program were not considered significantly different. A systematic review conducted in 2019 concluded that training with elastic bands promotes strength gains comparable to those from weight resistance training across different populations and using various protocols (Lopes et al., 2019). In another study involving swimmers, it was observed that there is great variability in the electromyographic activity values of the shoulder muscles from exercise to exercise when executed with different instruments (Tavares et al., 2024). When analyzing the rotator cuff balance, the weight intervention showed a more positive impact on the conventional concentric ratio, while the elastic band protocol was more effective on the functional ratio. This information may assist in determining which preventive program is most appropriate for each swimmer. Generally, both instruments had good adherence; however, swimmers reported the portability of the elastic band as a positive feature.

After 12 weeks of experimental prevention programs, there has been an observed improvement in rotator cuff strength and balance. This duration aligns with the ACSM guidelines, which suggest a minimum of 10 weeks for achieving visible effects in strength and endurance programs (ACSM, 2009). Interestingly, studies (Hibberd et al., 2012; Swanik, Swanik, et al., 2002) that reported no effects from preventive programs on strength and endurance variables in swimmers had a follow-up period of only 6 weeks, which may explain the absence of results. Similarly, another study (Fredriksen et al., 2021) conducted in a different overhead sport found no benefits from an 8-week prevention program for shoulder injuries concerning strength and endurance variables.

It is important to note that there were no dropouts in any of the experimental groups. This contrasts with findings from similar studies (Fredriksen et al., 2021; Hibberd et al., 2012). The individual monitoring and correction provided to each swimmer likely contributed positively to this high adherence over the 12 weeks of intervention.

Implementing a prevention program for swimmer’s shoulder that includes five open kinetic chain exercises performed with weights or elastic bands can help minimize the natural rotator cuff imbalances during the competitive swimming season. This program should be carried out twice a week for 12 weeks, ideally with the assistance of a physiotherapist for individual monitoring and progression. An intensity level of 75% of 1RM has proven to be effective. It is advisable to introduce this preventive program during the pre-season, allowing athletes time to establish routines for the remainder of the competitive season. By adopting these preventive measures, swimmers can reduce the impact of an important risk factor for the most common injury in swimming, decreasing the likelihood of its occurrence.

One limitation of this trial is the small sample size within each group. Additionally, the fact that the research was conducted only with athletes from two swimming teams may impact its external validity. These factors could restrict the generalization of the results obtained. Furthermore, the increase in fatigue caused by the accumulation of training and competitions throughout the season also influenced the strength assessments.

It is essential to conduct similar investigations involving a larger number of competitive swimmers and swimming teams to understand the effects of these preventive measures better. Additionally, it is important to evaluate the impact of such interventions in other sports, particularly cyclical sports that often experience overuse injuries. Moreover, it is necessary to clarify the non-injury ranges of muscular balance across various sports, while also considering the high velocities involved in sports movements. This information will assist sports clinicians in identifying athletes at high risk of injury.

CONCLUSIONS

The implementation of two 12-week preventive programs for swimmers' shoulder injuries did not result in an increase in IR and ER strength of the dominant shoulder at different tested velocities. However, the absence of a preventive program in the control group led to a reduction in strength, particularly in shoulder IRs. These preventive programs help minimize the normal rotator cuff imbalance developed during the competitive season for swimmers. No significant differences were observed in the effects of the two experimental programs, whether using weights or elastic bands. When selecting the appropriate equipment for these programs, it is essential to consider the swimmer's previous clinical assessment and individual preferences. A 12-week duration with gradual load progression is adequate to assess some effects of these preventive programs. Individual monitoring is essential for improving swimmers' adherence to this type of intervention.

Supplementary Materials

The following supporting information is at the end of Study V (Table 6.5), and can be downloaded at: https://www.mdpi.com/article/10.3390/healthcare13050538/s1

Author Contributions

Conceptualization and study design, N.T., J.P.V.-B., and M.A.C.; methodology, N.T. and M.A.C.; software, N.T. and M.A.C.; investigation, N.T.; data analysis, N.T. and M.A.C.; writing—original draft preparation, N.T.; writing—review and editing, N.T., J.P.V.-B., and M.A.C.; visualization, N.T., J.P.V.-B., and M.A.C.;

supervision, J.P.V.-B. and M.A.C. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted following the Declaration of Helsinki and approved by the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

Data are contained within the article and Supplementary Materials.

Conflicts of Interest

The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ER – External rotation
IR – Internal rotation
PT – Peak torque
con – Concentric
ecc – Eccentric
1RM – One-repetition maximum
ROM – Range of motion

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Table 6.5. CONSORT 2010 checklist of information to include when reporting a randomized trial.

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomized trial in the title.	127
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance, see CONSORT for abstracts).	128
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale.	128-131
	2b	Specific objectives or hypotheses.	131
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial), including allocation ratio.	132
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons.	Not applicable
Participants	4a	Eligibility criteria for participants.	132
	4b	Settings and locations where the data were collected.	133
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were administered.	133-135
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed.	135-137
	6b	Any changes to trial outcomes after the trial commenced, with reasons.	Not applicable
Sample size	7a	How sample size was determined.	137-138
	7b	When applicable, an explanation of any interim analyses and stopping guidelines.	Not applicable
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence.	138
	8b	Type of randomization; details of any restriction (such as blocking and block size).	138
Allocation concealment	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned.	138
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions.	138
Blinding	11a	If done, who was blinded after assignment to interventions (example: participants, care providers, those assessing outcomes) and how.	138-139
	11b	If relevant, description of the similarity of interventions.	Not applicable
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes.	139
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses.	139

Section/Topic	Item No	Checklist item	Reported on page No
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the number of participants who were randomly assigned to receive the intended treatment was analyzed for the primary outcome.	139-140 and Figure 6.4
	13b	For each group, losses and exclusions after randomization, together with reasons.	139-140 and Figure 6.4
Recruitment	14a	Dates defining the periods of recruitment and follow-up.	139
	14b	Why the trial ended or was stopped.	Not applicable
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group.	Page 140 and Table 6.2
Numbers analyzed	16	For each group, the number of participants (denominator) included in each analysis, and whether the analysis was by the original assigned groups.	139-140 and Figure 6.4
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval).	142-146 and Table 6.4
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended.	Not applicable
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory.	144-146 and Figure 6.5, 6.6, 6.7
Harms	19	All-important harms or unintended effects in each group (for specific guidance, see CONSORT for harms).	Not applicable
		Discussion	
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses.	149-150
Generalizability	21	Generalizability (external validity, applicability) of the trial findings.	149-150
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence.	146-150
		Other information	
Registration	23	Registration number and name of trial registry.	128 and 132
Protocol	24	Where the full trial protocol can be accessed, if available.	132
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders.	151

Citation: Schulz KF, Altman DG, Moher D, for the CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomized trials. BMC Medicine. 2010;8:18.

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomized trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.

STUDY VI

Randomized Controlled Trial

An Inter-Group Analysis of the Rotator Cuff Strength and Balance After Implementing Two 12-Week Preventive Exercise Programs for Swimmer's Shoulder: A Randomized Controlled Trial

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Current Status: Submitted.

ABSTRACT

Background: The rotator cuff strength and balance are modifiable factors with high predictive values for swimmer's shoulder injury. Preventive exercise programs have been implemented to minimize these risk factors. However, there is a lot of heterogeneity in the architecture and results of these programs. Objective: Verify the inter-group differences in the shoulder internal and external rotators' peak torque and conventional and functional ratios after implementing two 12-week preventive programs for swimmer's shoulder injury. Design: A randomized controlled trial with three groups performing parallel interventions, with both physiotherapists and participants blinded. Setting: Primary health care in a sports context. Participants: Competitive swimmers, aged between 16–35 years old, without previous clinical problems related to the shoulders. Interventions: Twice a week, over 12 weeks, two experimental groups carried out five strength exercises where the only difference was executing the program with weights or elastic bands, and one control group performed a sham intervention. Main outcome measures: Before (T0) and after (T1) the intervention, concentric and eccentric internal and external rotators' peak torque of both shoulders were assessed through an isokinetic dynamometer Biodex System 3, at 60°/s, 120°/s, and 180°/s. After this, the conventional and functional ratios were calculated. Results: Thirty swimmers were allocated through stratified randomization into a weight program group (n = 10), an elastic band program group (n = 10), and a control group (n = 10). In the dominant shoulder, the control group has a drop of concentric internal rotators' peak torque at 60º/s ($p = 0.040$), 120º/s ($p = 0.036$), and 180º/s ($p = 0.036$), and an increase in the conventional ratio at 120º/s ($p = 0.034$) compared with the experimental groups. In the non-dominant shoulder, the control group has a decrease of concentric internal rotators' peak torque at 60º/s ($p < 0.001$), 120º/s ($p = 0.003$), 180º/s ($p = 0.004$), and eccentric internal rotators' peak torque at 180º/s ($p = 0.015$), and an increment of both ratios at all angular velocities ($p \leq 0.05$) compared with the other groups. Conclusions: Including a swimmer’s shoulder preventive program in a weekly training routine has a positive impact on the rotator cuff strength and balance of competitive swimmers. Clinical Trial Registration number: NCT06552585.

Keywords
Swimming; Elastic band; Weight, Torque, Sports injury, Sports medicine.

INTRODUCTION

Swimming is an overhead sport characterized by cyclic and bilateral movements, in which propulsive forces are primarily produced by the upper limbs (Batalha et al., 2018; Wanivenhaus et al., 2012). It is estimated that competitive swimmers perform over 2,500 shoulder revolutions daily and 16,000 weekly (Struyf et al., 2017). This intense load, combined with the high degree of mobility that characterizes the shoulder joint complex, requires substantial muscular stability to prevent overuse injuries in this population (Batalha et al., 2018). The rotator cuff contributes significantly to this joint stability, making the strength and balance of shoulder rotators critical, modifiable factors with high predictive value for swimmer’s shoulder injuries (Feijen et al., 2021; Tavares et al., 2022).

In overhead athletes, the PT of ER and IR during concentric or eccentric actions, measured using an isokinetic dynamometer, are the primary metrics collected to evaluate rotator cuff strength (Batalha et al., 2013; Collado-Mateo et al., 2018; Drigny et al., 2020; Olivier & Daussin, 2018). Based on these measurements, unilateral conventional or functional ER:IR ratios are commonly calculated to assess rotator cuff muscle balance (Batalha et al., 2018; Cingel et al., 2007; Ellenbecker & Davies, 2000). Conventional ratios are calculated by dividing ER by IR PT in concentric (conER:conIR) or eccentric (eccER:eccIR) contraction modes. Functional ratios, on the other hand, are determined by dividing ER PT during an eccentric action by IR PT during a concentric action (eccER:conIR) or vice versa (eccIR:conER). Conventional ratios assess muscular imbalances within the rotator cuff, while functional ratios evaluate the eccentric action of rotators in maintaining dynamic glenohumeral joint stability (Drigny et al., 2020).

During the swimming season, due to the high volume of training and competition, shoulder rotator strength and balance values in competitive swimmers can fluctuate significantly (So et al., 2022). For example, Batalha et al. (2013) observed an increase of 9.33 Nm at 60°/s and 8.27 Nm at 180°/s in IR PT after a 32-week swimming season, which led to a decrease in the conventional conER:conIR ratio among competitive swimmers. This finding supports the notion that aquatic training disproportionately strengthens IR muscles relative to their antagonists, as they are more engaged during the propulsive phases of swimming (Batalha et al., 2013; Kluemper et al., 2006). Conversely, some studies have reported a reduction in shoulder IR PT due to fatigue in other overhead sports, both immediately following a training session (Lopes et al., 2019) and after several weeks of training (Fredriksen et al., 2021), resulting in an increase in the conventional conER:conIR and functional eccER:conIR ratios.

To mitigate these natural changes that increase shoulder injury risk, compensatory and preventive exercise programs are often included in swimmers' weekly training routines (Batalha et al., 2015; Chepeha et al., 2018; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002). Recent reviews suggest that strength training programs involving a few exercises, performed outside of water and in an open kinetic chain, appear to be the most effective (Tavares et al., 2022; Yoma et al., 2022). Nonetheless, there is still considerable heterogeneity in the composition and outcomes of preventive exercise programs regarding rotator cuff strength and balance (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002). In a 10-week dry-land strength program with three elastic band exercises (Batalha et al., 2018) and a 12-week program with five elastic band exercises (Manske et al., 2015), increases were observed in ER PT and, consequently, in the conventional ratio. However, other studies, such as an 8-week strength program with four weight-based exercises and another with four closed kinetic chain exercises, demonstrated notable gains in both IR and ER PT (Shahpar et al., 2019). Additionally, a 6-week strength and stretching program using 11 elastic band exercises (Hibberd et al., 2012) and a 6-week functional training program with both elastic band and weight exercises (Swanik, Swanik, et al., 2002) showed no significant improvements in IR and ER PT.

It is essential to achieve greater clarity regarding the impact of these compensatory programs on rotator cuff strength and balance, to understand their role in preventing swimmer’s shoulder injuries. Furthermore, it is necessary to clarify which program characteristics yield the best results: program duration, exercise type and intensity, optimal equipment, and monitoring.

The purpose of this study was to compare differences in shoulder rotator PT, conventional conER:conIR ratio, and functional eccER:conIR ratio after implementing two 12-week preventive programs for swimmer's shoulder in competitive swimmers. One of these programs involved weight training, while the other used elastic bands. It was hypothesized that both preventive exercise programs would increase IR and ER PT and reduce shoulder rotator imbalances over the swimming season.

METHODS

Trial design

A care provider and participant-blind, parallel, randomized controlled trial with three groups was completed from September 2022 to April 2023. This trial follows the CONSORT 2010 checklist for reporting randomized controlled trials (Table 7.5). All procedures received approval from the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022). The protocol for the randomized controlled trial has been registered on https://clinicaltrials.gov with the registration number NCT06552585.

Participants

Participants were recruited from two national competitive swimming teams in Portugal affiliated with the Portuguese Swimming Federation during the 2022/2023 season. Eligible participants met the following criteria: 16–35 years old, federated in the current season, ≥ 5 years of experience in national competitions (Batalha et al., 2015), and ≥ 8 hours of weekly swim training (Batalha et al., 2018; Batalha et al., 2015; Hibberd et al., 2012). Exclusion criteria included a history of shoulder pain within the past 6 months (Hibberd et al., 2012; Kluemper et al., 2006; Van de Velde et al., 2011), prior shoulder surgeries (Chepeha et al., 2018; Lynch et al., 2010; Manske et al., 2015; Van de Velde et al., 2011), traumatic shoulder injuries, cervical or thoracic conditions (Van de Velde et al., 2011), ROM deficits, or neurological injuries (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010). Exclusion also applied to swimmers undergoing recent treatment, such as physical therapy, injections, or medications, for at least six weeks (Chepeha et al., 2018; Lynch et al., 2010). Eligibility was verified via an individual questionnaire. Each participant provided informed consent per the Declaration of Helsinki (2013 revision) (Holt, 2014) and was then weighed using a Tanita RD-953 scale and measured with a stadiometer. Participant identities were protected according to the EU General Data Protection Regulation – Regulation (EU) 2016/679. This trial took place at the RoboCorp Laboratory, Polytechnic Institute of Coimbra.

Intervention programs

Twice a week, over 12 weeks (Baechle & Earle, 2008; Manske et al., 2015), the two intervention groups performed a strength training program with the five open kinetic chain exercises most often reported in the literature to prevent swimmer's shoulder (Batalha et al., 2018; Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Tavares et al., 2022; Van de Velde et al., 2011): IR at 90°, ER at 90°, scapular punches, T's, and Y's. The weight program group performed these five exercises with two Domyos dumbbells with 1, 2, 3, 4, or 5 kg (Figure 7.1), and the elastic band program group with an elastic band Bodytone Power Band with 10, 15, 20, 25, or 30 kg (Figure 7.2). The load used to perform the programs with elastic bands and weights was previously assessed and adjusted for each swimmer, corresponding to 75 % of 1RM (Ellenbecker & Mattalino, 1997). After 6 weeks of program execution, each swimmer carried out another 1RM test assessment to verify the possibility of a load instrument progression (Shahpar et al., 2019; Van de Velde et al., 2011).

Each exercise was performed in 2 sets of 10 valid repetitions, which were defined as reaching the target ROM for each movement previously described (Table 7.1). The concentric and eccentric phases of each exercise were performed for 5 seconds (Ekstrom et al., 2003). A Tabata Timer mobile application controlled this time. One minute of rest was preserved between different exercises and sets (Baechle & Earle, 2008).

A certified sports physiotherapist, blinded to the study objectives, supervised all sessions, provided individualized corrections, and monitored progress through WhatsApp or Zoom after the initial in-person session.

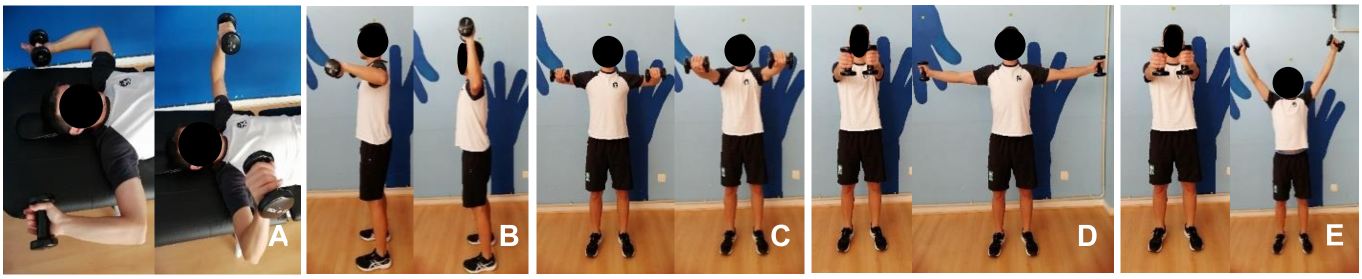

Figure 7.1. Illustration of the five exercises included in the weight program: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

Figure 7.2. Illustration of the five exercises included in the elastic band program: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

Control group

The control group performed a sham intervention twice a week for 12 weeks. This intervention consisted of 2 sets of 10 repetitions of five shoulder mobility exercises, without preventive aim, normally carried out in warm-up before training: shoulder maximum flexion and extension, horizontal abduction and adduction starting from 90º of shoulder abduction, maximum IR and ER starting from 90º of shoulder abduction, circumduction of the shoulder in a clockwise direction and circumduction of the shoulder in a counterclockwise direction (Baechle & Earle, 2008) (Figure 7.3). There was no progression after 6 weeks of this sham intervention. The coach of the respective team checked the execution of the exercises, but there was no individualized monitoring with a regular exercise technique correction by a physiotherapist.

To ensure ethical equity among the sample groups and considering the potential benefits of the exercise programs tested, the control group was guaranteed access to either the weight or elastic band program after the conclusion of the trial.

Figure 7.3. Illustration of the sham intervention program: (A) Flexion-extension, (B) Horizontal abduction-adduction, (C) Internal-external rotation, (D) Clockwise circumductions, (E) Counterclockwise circumductions.

Outcomes and testing procedures

At baseline (T0) and after 12 weeks (T1) of interventions and control procedures, concentric and eccentric PT of IR and ER for both dominant and non-dominant shoulders was assessed using an isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, New York), at 60°/s, 120°/s, and 180°/s (Shahpar et al., 2019).

Swimmers completed a 10-minute warm-up, followed by testing in a randomized sequence of shoulder dominance to minimize fatigue bias. Testing was performed in the supine position with the shoulder abducted to 90° and the elbow flexed to 90°, stabilizing both the trunk and arm with velcro straps (Ellenbecker & Mattalino, 1997; Loureiro et al., 2013; Noffal, 2003). ROM limits were set between 80° ER and 65° IR to capture maximal PT within the shoulder's functional range (Loureiro et al., 2013). The concentric test was conducted first, followed by the eccentric test, with the angular velocity increasing from 60°/s to 180°/s (Loureiro et al., 2013). Each test included five maximal-effort repetitions, following three submaximal practice repetitions. Standardized instructions and encouragement were provided (Batalha et al., 2020; Loureiro et al., 2013; Noffal, 2003). A minute rest period between different tests was preserved (Batalha et al., 2018).

The ER:IR ratio was calculated as the ratio of the ER to IR PT multiplied by 100 (Batalha et al., 2015; Noffal, 2003). Both conventional, conER:conIR ratio, and functional, eccER:conIR, were calculated at all angular velocities.

Sample size

The calculation of the sample size was conducted using G*Power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Kiel, Germany, version

3.1.9.4). The selected statistical test aimed to compare mean differences between independent groups. The effect size for this calculation was derived from a similar clinical trial performed by Batalha et al. (2015), which included 56 participants divided into three groups: an experimental group of 20 swimmers who participated in both a preventive strength program and swimming training, a training group of 20 swimmers who only engaged in swimming training, and a control group of 16 active non-swimmers. From this trial, an effect size (Cohen's d) of 2.81 was identified, indicating the minor difference considered statistically significant between the experimental and training groups when assessing IR and ER PT at 60°/s and 180°/s of the swimmers' dominant shoulder. Using an alpha level of 0.01, a power of 0.99, and an allocation ratio of 1:1, the software determined a minimum total sample size of 24 swimmers (8 per group). To account for potential dropouts, a final sample size of 30 swimmers (10 per group) was established.

Randomization and blinding

The initial contact with the competitive swimmers from two swimming teams was established through a telephone call, during which the eligibility criteria and individual consent for participation in the trial were screened. The eligible swimmers were then divided into three groups: a weight program group, an elastic band program group, and a control group. Allocation to each group was conducted through stratified randomization based on the team (A or B), sex (male or female), and main swimming style (butterfly, backstroke, breaststroke, front crawl ≤ 200 m, or front crawl > 200 m). This approach aimed to balance the potential effects of these three variables on the results (Lynch et al., 2010). Participants were initially screened to determine their respective strata. The allocation process was concealed within each stratum, employing a computer-generated random number managed by a member of the research team. The participants were unaware of the existence of other sample groups. All swimmers underwent a T0 assessment using an isokinetic dynamometer. To minimize fatigue bias during the assessment, half of the swimmers began with their dominant shoulder, while the other half started with their non-dominant shoulder. This order was randomized using a computer-generated random number. Following the T0 assessment, two 12-week experimental interventions were implemented and supervised by a sports physiotherapist who was external to the study and unaware of the previous procedures or the study's objectives. The first session with each athlete was conducted in person. During this session, the physiotherapist performed an individual 1RM test according to the specific equipment and explained the exercise program to the swimmer. After 6 weeks of intervention, the physiotherapist conducted a new 1RM evaluation to assess any potential progress in load. All in-person and online sessions were individualized to ensure that each athlete remained unaware of the other groups. The sports physiotherapist also tracked the number of sessions completed by each athlete and did not have contact with those in the control group. At the end of the 12 weeks, all swimmers who completed the full set of proposed interventions underwent a T1 strength assessment using the isokinetic dynamometer. The procedures for the T0 assessment were maintained for the T1 assessment.

Data analysis

The data was filtered (smoothing option) and windowed at 95 % of the test velocity. Data analysis was performed using the AcqKnowledge 4.1 software. The mean and SD of the PT in the five repetitions of different muscles (IR and ER), actions (concentric and eccentric), and angular velocities (60º/s, 120º/s, and 180º/s) for both sides were calculated. Subsequently, the conventional conER:conIR ratio and the functional eccER:conIR ratio were verified for these three angular velocities.

All statistical analysis was carried out using IBM SPSS Statistics 27 software. Means and SD were used for sample characterization. The Shapiro-Wilk test was used to verify the normality of the sample distribution. The homogeneity of variance between the three groups was verified for the sample characterization variables and the IR and ER PT at T0, through the One-Way ANOVA or the Kruskal-Wallis tests. After this, an inter-group analysis in T0 and T1 was made for dominant and non-dominant shoulders. For an inter-group analysis, the One-Way ANOVA or the Kruskal-Wallis tests were applied to compare differences between all groups in T0 and T1, and the Independent Sample T-test or the Mann-Whitney U-test were used to compare differences between two of the groups in T0 and T1. A p-value ≤ 0.05 was considered the level of significance for each difference in PT and ER:IR ratios.

RESULTS

Participants were recruited in September 2022. Initial contact with the competitive swimmers was made through a phone call, during which eligibility criteria and individual consent for participation in the trial were screened. Out of 49 athletes contacted, 30 were deemed eligible and suitable for participation. These participants were then allocated through stratified randomization into three groups: a weight program group (n = 10), an elastic band program group (n = 10), and a control group (n = 10). To account for variables that could influence the results, such as differences in swimming training, main swimming style, and variations in strength between males and females, the distribution was carefully balanced. Each group included five swimmers from Team A and five from Team B, comprising an equal number of men and women, as well as two swimmers from each swimming style: butterfly, backstroke, breaststroke, front crawl ≤ 200 m, and front crawl > 200 m (Figure 7.4). The three groups have homogeneity of variance ($p > 0.05$) regarding the sample characterization (Table 7.2) and in IR and ER PT at T0 (Table 7.3). Each group performed two strength assessment moments: before (T0) and after (T1) the respective intervention. No participant dropouts were recorded during the 12 weeks of follow-up. All participants in the experimental interventions completed the 24 individual sessions of their prevention program over 12 weeks.

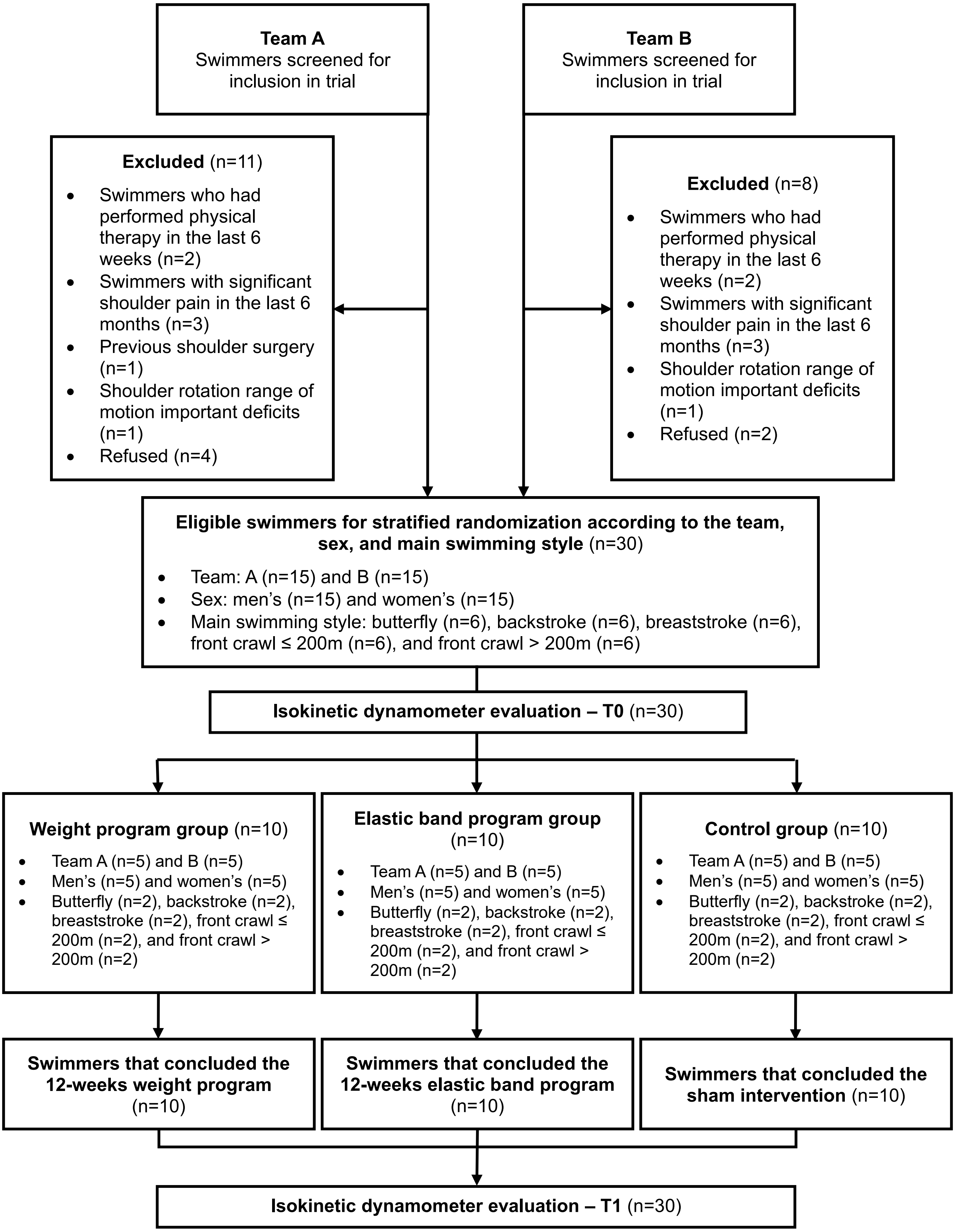

Figure 7.4. The flow of participants through the trial.

Table 7.1. Sample characterization and respective homogeneity of variance between the three groups.

Variables	WP Mean ± SD	EBP Mean ± SD	Control Mean ± SD	*p*-value
Age (years)	19.90 ± 2.92	19.60 ± 2.99	19.00 ± 3.62	0.506
Body Mass (kg)	68.86 ± 8.49	68.80 ± 14.76	65.57 ± 11.77	0.879
Height (m)	1.72 ± 0.08	1.70 ± 0.11	1.73 ± 0.09	0.774
Body Mass Index (kg/m^2)	23.19 ± 2.24	23.64 ± 3.34	21.79 ± 1.91	0.262
Fat mass (%)	17.02 ± 10.30	17.37 ± 8.65	15.40 ± 7.19	0.700
Lean mass (kg)	55.23 ± 10.60	57.66 ± 12.83	52.04 ± 13.66	0.868
Bone mass (kg)	2.91 ± 0.51	3.03 ± 0.64	2.75 ± 0.69	0.706
Swimming practice (years)	12.10 ± 4.18	9.40 ± 4.81	12.30 ± 4.17	0.274
Competitive swimming (years)	8.90 ± 3.28	6.10 ± 3.73	7.90 ± 3.38	0.206
Weekly swimming training (hours)	16.80 ± 5.01	14.20 ± 6.29	16.60 ± 6.87	0.577

SD – standard deviation; WP – weight program; EBP – elastic band program.

Table 7.2. The homogeneity of variance between the three sample groups for the PT at T0 in dominant and non-dominant shoulders.

			WP PT (Nm)	EBP PT (Nm)	Control PT (Nm)	*p*-value
Dominant shoulder	60°/s	conIR	36.06 ± 9.71	33.17 ± 9.25	37.99 ± 13.49	0.619
		eccIR	37.30 ± 7.74	38.62 ± 14.47	41.67 ± 19.08	0.790
		conER	24.98 ± 6.63	27.62 ± 7.95	25.42 ± 10.25	0.756
		eccER	31.69 ± 7.11	36.14 ± 11.61	34.51 ± 13.58	0.667
	120°/s	conIR	30.84 ± 9.22	32.13 ± 11.56	34.66 ± 13.53	0.756
		eccIR	36.71 ± 8.05	36.43 ± 11.96	38.01 ± 17.24	0.959
		conER	23.95 ± 6.91	26.90 ± 8.88	23.63 ± 11.58	0.691
		eccER	29.74 ± 7.46	35.47 ± 11.95	30.79 ± 12.80	0.473
	180°/s	conIR	28.63 ± 9.70	28.22 ± 10.73	32.07 ± 13.90	0.719
		eccIR	38.11 ± 6.99	39.81 ± 12.95	39.53 ± 19.00	0.958
		conER	21.33 ± 5.07	24.26 ± 9.45	22.65 ± 11.64	0.774
		eccER	31.08 ± 7.74	37.28 ± 12.10	31.26 ± 14.64	0.464
Non-dominant shoulder	60°/s	conIR	25.95 ± 7.60	29.14 ± 12.54	35.73 ± 12.71	0.157
		eccIR	33.12 ± 6.76	35.26 ± 13.23	38.64 ± 15.99	0.907
		conER	25.73 ± 7.49	29.26 ± 8.43	29.53 ± 10.83	0.582
		eccER	26.86 ± 7.81	32.92 ± 11.26	30.63 ± 12.32	0.449

	120°/s	conIR	26.58 ± 8.07	26.88 ± 11.26	33.17 ± 11.03	0.348
		eccIR	32.58 ± 8.15	35.14 ± 15.28	37.64 ± 17.15	0.983
		conER	24.87 ± 6.44	26.81 ± 8.21	27.73 ± 11.33	0.765
		eccER	27.31 ± 8.90	32.50 ± 12.27	30.12 ± 12.29	0.593
	180°/s	conIR	24.34 ± 8.52	23.31 ± 10.01	29.82 ± 9.60	0.267
		eccIR	34.73 ± 6.64	34.47 ± 15.03	38.16 ± 16.19	0.790
		conER	23.35 ± 7.55	24.67 ± 7.69	26.01 ± 10.93	0.800
		eccER	29.74 ± 8.62	32.75 ± 11.06	30.91 ± 12.02	0.818

WP – weight program; EBP – elastic band program; PT – peak torque; con – concentric; ecc – eccentric; IR - internal rotation; ER – external rotation.

<u>Inter-group analysis of the peak torque variation</u>

Regarding the PT variation of the dominant shoulder over the 12 weeks, it is possible to verify that there are differences between the 3 groups in the IR strength tested concentrically at 60º/s (p = 0.040), 120º/s (p = 0.036), and 180º/s (p = 0.036). Performing an elastic band program leads to a lower loss of IR PT tested concentrically at 60º/s (p = 0.014), 120º/s (p = 0.019), and 180º/s (p = 0.017) compared to a sham intervention. In turn, executing a weight program leads to a lower loss of concentric IR PT at 60º/s (p = 0.041) compared to the control group (Table 7.4).

In an inter-group analysis of the PT variation over 12 weeks in the non-dominant shoulder, a significant drop of PT is visible in the control group compared with the experimental groups. This decrease occurs in the concentric IR PT at 60º/s (p < 0.001), 120º/s (p = 0.003), and 180º/s (p = 0.004), and in the eccentric IR PT at 180º/s (p = 0.015) (Table 7.4).

Table 7.3. Inter-group analyses of the PT in the dominant and non-dominant shoulders between T0 and T1.

			PT difference T1-T0 (Nm)			***p*-value**			
			WB	EBP	CP	WB | EBP	WB | CP	EBP | CP	WB | EBP | CP
Dominant shoulder	**IR**	con at 60º/s	-5.65	-0.52	-9.84	0.173	0.223	**0.014***	**0.040***
		ecc at 60º/s	-0.14	-0.54	-4.64	0.922	0.098	0.337	0.413
		con at 120º/s	-1.27	-1.18	-8.59	0.705	**0.041***	**0.019***	**0.036***
		ecc at 120º/s	0.20	0.20	-0.93	0.999	0.657	0.813	0.950
		con at 180º/s	-2.42	-0.85	-7,54	0.548	0.060	**0.017***	**0.036***
		ecc at 180º/s	-0.62	-2.33	-2.38	0.713	0.538	0.992	0.887

	ER	con at 60º/s	0.98	0.80	0.43	0.880	0.880	0.597	0,924
		ecc at 60º/s	-1.85	-0.57	-3.97	0.668	0.396	0.261	0.475
		con at 120º/s	0.46	-0.06	0.39	0.880	0.762	0.545	0.852
		ecc at 120º/s	-0.71	-2.44	-0.61	0.364	0.545	0.762	0.648
		con at 180º/s	1.41	0.48	-0.45	0.711	0.354	0.726	0.736
		ecc at 180º/s	-1.06	-1.92	0.35	0.763	0.556	0.262	0.637
Non-dominant shoulder	IR	con at 60º/s	4.67	0.92	-8.81	0.109	**<0.001***	**0.003***	**<0.001***
		ecc at 60º/s	-0.23	1.84	-4.32	0.562	0.218	0.143	0.217
		con at 120º/s	1.78	1.48	-7.65	0.886	**0.007***	**0.008***	**0.003***
		ecc at 120º/s	0.95	-0,62	-5.35	0.684	0.190	0.190	0.272
		con at 180º/s	2.17	3.21	-5,88	0.645	**0.015***	**0.005***	**0.004***
		ecc at 180º/s	-0.13	2.44	-7.51	0.474	**0.012***	**0.014***	**0.015***
	ER	con at 60º/s	-0.97	-2.35	-5.36	0.527	0.074	0.173	0,143
		ecc at 60º/s	0.09	-0.73	-0.19	0.711	0.890	0.698	0.905
		con at 120º/s	-1.76	-2.69	-4.93	0.589	0.160	0.277	0.268
		ecc at 120º/s	-1.32	-1.70	-1.18	0.887	0.954	0.803	0.975
		con at 180º/s	-1.60	-1.40	-4.60	0.901	0.140	0.133	0.173
		ecc at 180º/s	-3.12	-1.02	-3.43	0.796	0.739	0.247	0.581

* Statistically significant difference

PT – peak torque; WB – Weight program; EBP – Elastic band program; CP – Control procedure; IR – internal rotation; ER – external rotation; con – concentric; ecc – eccentric.

Inter-group analysis of the variation of the conventional and functional ratios

In the dominant shoulder, practically all groups and assessments have an increase in the conventional conER:conIR ratio and the functional eccER:conIR ratio, due to the decrease in concentric IR PT between T0–T1 already seen in Table 4. However, only the increment of 65.82 ± 11.56 to 93.46 ± 19.98 in the conventional conER:conIR ratio at 120º/s in the control group compared to the experimental groups was considered significant ($p = 0.034$) (Table 7.5).

There are different results about the variation of ratios in the non-dominant shoulder. In both experimental groups, there is a drop in conventional conER:conIR and functional eccER:conIR ratios at the three angular velocities, due to a superior increase in the concentric IR PT, compared to the eccentric IR and ER PT. In the control group, the opposite occurred. The fact that there is a superior loss of concentric IR PT compared to eccentric IR and ER PT promoted an increment in both shoulder ratios. Thus, in the non-dominant shoulder, both ratio variations between the control and experimental groups are significant ($p \leq 0.05$) at all angular velocities tested (Table 7.5).

Table 7.4. Inter-group analyses of the CR and FR in the dominant and non-dominant shoulders between T0 and T1.

			WP		EBP		CP		*p*-value
			T0	T1	T0	T1	T0	T1	
DS	CR (%)	60º/s	71.41 ± 18.15	87.69 ±16.77	84.47 ± 17.20	91.05 ± 15.93	66.88 ± 12.99	93.82 ± 18.41	0.065
		120º/s	83.12 ± 33.09	85.12 ± 14.96	85.18 ± 12.59	91.45 ± 13.40	65.82 ± 11.56	93.46 ± 19.98	**0.034***
		180º/s	81.92 ± 35.77	88.99 ± 10.74	86.71 ± 18.28	95.93 ± 23.99	68.20 ± 10.36	91.97 ± 22.55	0.364
	FR (%)	60º/s	91.64 ± 24.17	102.36 ± 18.98	110.16 ± 23.91	112.03 ± 22.30	91.59 ± 19.17	110.31 ± 25.47	0.280
		120º/s	105.30 ± 43.31	101.52 ± 15.91	112.55 ± 21.38	115.24 ± 30.65	89.48 ± 16.10	117.07 ± 25.94	0.084
		180º/s	120.12 ± 49.48	120.63 ± 33.92	137.25 ± 32.71	143.35 ± 55.79	96.54 ± 10.49	131.56 ± 28.94	0.074
NDS	CR (%)	60º/s	100.89 ± 22.18	79.92 ± 10.02	106.23 ± 16.95	90.46 ± 8.50	83.48 ± 15.28	90.98 ± 14.82	**0.001***
		120º/s	96.56 ± 22.81	80.65 ± 8.38	105.57 ± 17.40	85.88 ± 6.92	82.65 ± 22.95	88.73 ± 16.36	**<0.001***
		180º/s	99.01 ± 23.92	82.59 ± 9.21	112.30 ± 19.02	86.67 ± 10.70	85.25 ± 26.14	91.56 ± 16.58	**0.013***
	FR (%)	60º/s	104.86 ± 17.82	87.60 ± 20.08	118.27 ± 21.31	108.90 ± 8.63	88.95 ± 27.55	113.70 ± 26.59	**0.002***
		120º/s	103.32 ± 16.63	90.45 ± 16.92	127.23 ± 29.73	111.90 ± 13.76	92.18 ± 24.43	112.67 ± 20.37	**0.020***
		180º/s	126.17 ± 25.30	101.78 ± 19.12	150.01 ± 36.04	122.40 ± 16.64	103.66 ± 23.69	122.73 ± 36.19	**0.032***

CR – Conventional ratio; FR – Functional ratio; WP – weight program; EBP – elastic band program; PT – peak torque; con – concentric; ecc – eccentric; IR - internal rotation; ER – external rotation.

DISCUSSION

This study examines the differences between two experimental groups and one control group in the shoulder rotator's PT, conventional conER:conIR ratio, and functional eccER:conIR ratio. The experimental groups performed a 12–week preventive program for swimmer's shoulder with weights or an elastic band, and a control group did a sham intervention. Analyzing the differences between the three groups, in control, there is a decrease in rotator cuff strength, which is more visible in the concentric IR, leading to an increase in the shoulder balance ratios. No differences were visible between the two experimental groups in the rotator cuff strength and balance over the 12 weeks.

Regarding shoulder IR strength, a reduction ($p \leq 0.05$) was observed in the control group compared to the experimental groups in both shoulders, across slow and fast angular velocities, and especially in concentric tests. Fatigue from cumulative swimming training and competitions may account for this decrease, aligning with findings from other overhead sports that report a reduction in IR PT due to fatigue both immediately after training (Lopes et al., 2019) and over several weeks of training (Fredriksen et al., 2021). The preventive programs seem to mitigate some IR strength losses, with similar effects achieved through both weight and elastic band exercises.

Unlike findings from Batalha et al. (2018), Manske et al. (2015), and Shahpar et al. (2019), there was no evident increase in the shoulder ER strength in competitive swimmers who performed the preventive programs compared to the controls. One explanation could be that our intervention's ER exercises focused solely on ER at 90º, potentially limiting strength gains. Consequently, our results align with those of Fredriksen et al. (2021), Hibberd et al. (2012), and Swanik, Swanik, et al. (2002), who also reported no significant increases in ER strength following compensatory exercise programs.

In quantitative and statistical analyses of ratios results, the IR strength drop ($p < 0.05$) reported in the control group caused an increase ($p < 0.05$) in all conventional conER:conIR and functional eccER:conIR ratios, which was more distinct from the experimental groups in the non-dominant shoulder.

For the qualitative and clinical analysis of the conventional ratio, the range 0.66–0.75 was considered the optimal zone of rotator cuff muscle balance, based on Ellenbecker and Davies (2000) and corroborated by Batalha et al. (2018) and Drigny et al. (2020). Globally, all conventional conER:conIR ratios in this trial were higher in comparison with the values of the optimal zone. It is important to note that the range 0.66–0.75 is a generalized conventional conER:conIR ratio for overhead athletes and not specific for swimmers, which may explain this difference. In the dominant shoulder, the conventional conER:conIR ratio of all groups moves away from the optimal zone, with the control group having more variation. In the non-dominant shoulder, the conventional conER:conIR ratio of the experimental groups approaches from the optimal zone, while the values of the control group move away from it. Therefore, strength programs with a preventive aim appear to have a positive influence on rotator cuff muscle balance in competitive swimmers.

The functional eccER:conIR ratio between 0.68–0.86 was considered the optimal range for swimmers based on Bak and Magnusson (1997) and Drigny et al. (2020). Once again, in our clinical trial, the functional eccER:conIR ratio values are higher than the optimal zone. A possible explanation for the observed difference could be that the reference range based on two studies that performed swimmer's dynamometer isokinetic assessments at 30º/s (Bak & Magnusson,

1997) and 60º/s (Drigny et al., 2020), lower angular velocities compared to the present investigation. Both experimental groups have low oscillation in the dominant shoulder and an approximation to the optimal functional eccER:conIR ratio zone in the non-dominant shoulder. On the other side, the control swimmers have moved away from the optimal interval, which possibly means more imbalance in the eccentric action of rotators in dynamic glenohumeral joint stability.

It is also worth highlighting that there were no subject dropouts in any experimental group (Figure 7.4), different from what occurred in similar studies (Fredriksen et al., 2021; Hibberd et al., 2012). The fact that there was individual monitoring and correction for each swimmer seems to have contributed very positively to the absence of dropouts over the 12 weeks of interventions.

The primary limitation of this type of study is that fatigue is always unavoidable with the progress of the swimming season, which will have some impact on strength measurements. Furthermore, it would be interesting to have a greater number of swimmers in each group.

CONCLUSIONS

Swimmers participating in a 12-week preventive exercise program experienced less shoulder IR strength loss compared to controls, though no differences were observed between groups in ER strength variation. The experimental groups demonstrated improved rotator cuff muscle balance, particularly in the non-dominant shoulder, while the control group showed greater deviation from the optimal balance range. No significant differences were found between programs using weights versus elastic bands.

Integrating a preventive exercise program into a swimmer's weekly routine appears beneficial for maintaining rotator cuff strength and balance—factors critical in reducing the risk of swimmer's shoulder injuries. Future research should explore these interventions' effects on other risk factors for swimmer's shoulder injuries and consider extending this approach to other sports.

Supplementary Materials

The following supporting information is at the end of Study VI (Table 7.5).

Protocol

The full trial protocol can be accessed in: https://clinicaltrials.gov/study/NCT06552585

Author Contributions

Conceptualization and study design, N.T.; J.P.V-B.; M.A.C.; methodology, N.T.; M.A.C.; software, N.T.; M.A.C.; investigation, N.T.; data analysis, N.T.; M.A.C.; writing – original draft preparation, N.T.; writing – review and editing, N.T.; J.P.V-B.; M.A.C.; visualization, N.T.; J.P.V-B.; M.A.C.; supervision, J.P.V-B.; M.A.C. All authors have read and agreed to the published version of the manuscript.

Data availability

Data are available from the authors upon reasonable request.

Ethical approval

This trial was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022).

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Conflict of interest

None.

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Table 7.5. CONSORT 2010 checklist of information to include when reporting a randomized trial.

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomized trial in the title.	161
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance, see CONSORT for abstracts).	162
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale.	163-164
	2b	Specific objectives or hypotheses.	165
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial), including allocation ratio.	165
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons.	Not applicable
Participants	4a	Eligibility criteria for participants.	165
	4b	Settings and locations where the data were collected.	166
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were administered.	166-168
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed.	168
	6b	Any changes to trial outcomes after the trial commenced, with reasons.	Not applicable
Sample size	7a	How sample size was determined.	168-169
	7b	When applicable, an explanation of any interim analyses and stopping guidelines.	Not applicable
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence.	169
	8b	Type of randomization; details of any restriction (such as blocking and block size).	169
Allocation concealment	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned.	169
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions.	169-170
Blinding	11a	If done, who was blinded after assignment to interventions (example: participants, care providers, those assessing outcomes) and how.	169-170
	11b	If relevant, description of the similarity of interventions.	Not applicable
Statistical methods	12a	Statistical methods are used to compare groups for primary and secondary outcomes.	170-171
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses.	170-171

Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the number of participants who were randomly assigned received the intended treatment and were analyzed for the primary outcome.	171-172 and Figure 7.4
	13b	For each group, losses and exclusions after randomization, together with reasons.	171-172 and Figure 7.4
Recruitment	14a	Dates defining the periods of recruitment and follow-up.	171
	14b	Why the trial ended or was stopped.	Not applicable
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group.	173 and Table 7.1
Numbers analyzed	16	For each group, the number of participants (denominator) included in each analysis, and whether the analysis was by the original assigned groups.	171-172 and Figure 7.4
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as a 95% confidence interval).	174-176 and Table 7.3, 7.4
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended.	Not applicable
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory.	174-176 and Table 7.3, 7.4
Harms	19	All-important harms or unintended effects in each group (for specific guidance, see CONSORT for harms).	Not applicable
		Discussion	
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses.	178
Generalizability	21	Generalizability (external validity, applicability) of the trial findings.	177-178
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence.	176-178
		Other information	
Registration	23	Registration number and name of trial registry.	162 and 165
Protocol	24	Where the full trial protocol can be accessed, if available.	165
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders.	179

Citation: Schulz KF, Altman DG, Moher D, for the CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomized trials. BMC Medicine. 2010;8:18.

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomized trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.

STUDY VII

Randomized Controlled Trial

Influence of Dry-Land Exercise Programs on Symmetry of Shoulder Rotator Cuff Strength and Balance in Competitive Swimmers – A Randomized Controlled Trial

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ABSTRACT

Background: The high volume of swimming training can lead to body imbalances that increase the risk of overuse injuries, particularly in swimmers' shoulders. Dry-land exercise programs improve some swimmers' shoulder musculoskeletal risk factors. However, no information has been found about the effects of these preventive programs on strength symmetry between the dominant and non-dominant sides. Objective: To analyze the impact of two 12-week dry-land exercise programs on the symmetry of shoulder rotator cuff strength and rotational muscle balance between dominant and non-dominant shoulders in competitive swimmers. Design: A randomized controlled trial with three groups performing parallel interventions, with both physiotherapists and participants blinded. Setting: Primary health care in a sports context. Participants: Competitive swimmers aged 16 to 35 years, with no prior clinical issues related to the shoulders. Interventions: Over 12 weeks, two experimental groups participated in twice-weekly sessions focusing on five strength exercises. The only difference between these groups was that one executed the program with weights and the other utilized elastic bands. A third group served as a control and performed a sham intervention. Main outcome measures: Concentric and eccentric internal and external rotators peak torque for both shoulders were assessed before (T0) and after (T1) the intervention using an isokinetic dynamometer Biodex System 3, at 60°/s, 120°/s, and 180°/s. Following these assessments, conventional and functional ratios were calculated. Results: Thirty swimmers were allocated through stratified randomization into a weight program group ($n = 10$), an elastic band program group ($n = 10$), and a control group ($n = 10$). After 12 weeks of the respective interventions, all groups showed an overall reduction in the right/left asymmetries observed during the initial measurements. Furthermore, neither group exhibited differences ($p < 0.05$) between the dominant and non-dominant shoulders in the conventional and functional ratios. Conclusions: A preventive exercise program has a limited effect on the strength symmetry of shoulder rotators between sides compared to the impact of water training volume in competitive swimmers. However, its implementation is fundamental in improving the muscle balance of the rotator cuff to align with the recommended preventive values. Clinical Trial Registration number: NCT06552585.

Keywords
Symmetry, Rotator cuff, Dry-land exercise program, Swimming.

INTRODUCTION

Approximately 96% of the human population presents levels of body asymmetry (Annett, 1998; Carvalho et al., 2019), which negatively influences the performance of cycling and continuous sports such as swimming (Carvalho et al., 2019; Sanders et al., 2012; Toubekis et al., 2010). Applying similar force between the right and left sides can positively affect the swimmer's performance, particularly by promoting better body alignment, reducing drag, and lowering intracycle velocity variations (Carvalho et al., 2019; Sanders et al., 2011; Santos et al., 2024). Due to the competitive swimmers' high training volume, the presence of body imbalances is an important risk factor for increasing the probability of overuse injuries, with the shoulder being the most affected locally (Batalha, Marmeleira, et al., 2015; Carvalho et al., 2019). It is estimated that 91% of these subjects experience swimmer's shoulder injuries during their sports career (Feijen et al., 2020; Struyf et al., 2017).

Recent reviews (Tavares et al., 2022; Yoma et al., 2022) suggest that dry-land exercise programs have a positive influence on musculoskeletal risk factors for swimmer shoulder injuries, such as rotator cuff strength and endurance (Batalha, Raimundo, et al., 2015; Manske et al., 2015; Swanik, Lephart, et al., 2002), shoulder posture (Kluemper et al., 2006; Lynch et al., 2010), proprioception (Swanik, Lephart, et al., 2002), and shoulder rotational ROM (Chepeha et al., 2018). Only one study analyzes the symmetry between the dominant and non-dominant shoulder before and after dry-land exercise programs. Swimmers performed an 8-week stretching program that improved the symmetry between different sides in shoulder rotational ROM (Chepeha et al., 2018). To our knowledge, no studies have evaluated the influence of dry-land exercise programs on side symmetry in other musculoskeletal risk factors for swimmer shoulder injuries. There were only cross-sectional assessments of the swimming symmetry index and their correlation with other risk factors, such as sex or technique (Formosa et al., 2013) or different forms of evaluating this body symmetry (Carvalho et al., 2019).

The strength and endurance of the shoulder rotator muscles are a modifiable musculoskeletal risk factor with high predictive value for a swimmer's shoulder injury (Feijen et al., 2021; Tavares et al., 2022). The isokinetic dynamometer is the gold standard instrument for assessing asymmetries and imbalances in force production, permitting analysis of specific muscle groups such as the rotator cuff (Batalha, Marmeleira, et al., 2015; Batalha et al., 2013; Collado-Mateo et al., 2018; Drigny et al., 2020; Olivier & Daussin, 2018; Rupp et al., 1995; Secchi et al., 2011). Usually, the ER and the IR PT in concentric or eccentric action are the main outcomes collected to evaluate this risk factor (Batalha et al., 2013; Drigny et al., 2020; So et al., 2022). Based on these measurements, conventional or functional ER:IR ratios are commonly calculated to assess rotator cuff muscle balance (Batalha et al., 2018; Cingel et al., 2007; Ellenbecker & Davies, 2000). Conventional ratios are calculated by dividing ER by IR PT in concentric (conER:conIR) or eccentric (eccER:eccIR) contraction modes. Functional ratios, on the other hand, are determined by dividing ER PT during an eccentric action by IR PT during a concentric action (eccER:conIR) or vice versa (eccIR:conER). Conventional ratios assess muscular imbalances within the rotator cuff, while functional ratios evaluate the eccentric action of rotators in maintaining dynamic glenohumeral joint stability (Drigny et al., 2020).

This study aimed to analyze the influence of two 12-week dry-land exercise programs on symmetry between dominant and non-dominant shoulder rotator cuff strength and rotational muscle balance in competitive swimmers. One of these programs involved weight training, while the other used elastic bands. It was hypothesized that both dry-land exercise programs would increase the symmetry in the analyzed variables compared to the control group.

METHODS

Trial design

A care provider and participant-blind, parallel, randomized controlled trial with three groups was completed from September 2022 to April 2023. This trial follows the CONSORT 2010 checklist for reporting randomized controlled trials (Table 8.6). All procedures received approval from the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022). The protocol for the randomized controlled trial has been registered on https://clinicaltrials.gov with the registration number NCT06552585.

Participants

Participants were recruited from two national competitive swimming teams in Portugal affiliated with the Portuguese Swimming Federation during the 2022/2023 season. Eligible participants met the following criteria: 16–35 years old, federated in the current season, ≥ 5 years of experience in national competitions (Batalha, Raimundo, et al., 2015), and ≥ 8 hours of weekly swim training (Batalha et al., 2018; Batalha, Raimundo, et al., 2015; Hibberd et al., 2012). Exclusion criteria included a history of shoulder pain within the past 6 months (Hibberd et al., 2012; Kluemper et al., 2006; Van de Velde et al., 2011), prior shoulder surgeries (Chepeha et al., 2018; Lynch et al., 2010; Manske et al., 2015; Van de Velde et al., 2011), traumatic shoulder injuries, cervical or thoracic conditions (Van de Velde et al., 2011), ROM deficits, or neurological injuries (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010). Exclusion also applied to swimmers undergoing recent treatment, such as physical therapy, injections, or medications, for at least six weeks (Chepeha et al., 2018; Lynch et al., 2010). Eligibility was verified via an individual questionnaire. Each participant provided informed consent per the Declaration of Helsinki (2013 revision) (Holt, 2014) and was then weighed using a Tanita RD-953 scale and measured with a stadiometer. Participant identities were protected according to the EU General Data Protection Regulation – Regulation (EU) 2016/679. This trial took place at the RoboCorp Laboratory, Polytechnic Institute of Coimbra.

Intervention programs

Twice a week, over 12 weeks (Baechle & Earle, 2008; Manske et al., 2015), the two intervention groups performed a strength training program with the five open kinetic chain exercises most often reported in the literature to prevent swimmer's shoulder (Batalha et al., 2018; Batalha, Raimundo, et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Shahpar et al., 2019; Swanik, Lephart, et al., 2002; Swanik, Swanik, et al., 2002; Tavares et al., 2022; Van de Velde et al., 2011): IR at 90°, ER at 90°, scapular punches, T's, and Y's (Table 8.1). The weight program group performed these five exercises with two Domyos dumbbells with 1, 2, 3, 4, or 5 kg, and the elastic band program group with an elastic band Bodytone Power Band with 10, 15, 20, 25, or 30 kg. The load used to perform the programs with elastic bands and weights was previously assessed and adjusted for each swimmer, corresponding to 75 % of 1RM (Ellenbecker & Mattalino, 1997). After 6 weeks of program execution, each swimmer carried out another 1RM test assessment to verify the possibility of a load instrument progression (Shahpar et al., 2019; Van de Velde et al., 2011).

Each exercise was performed in 2 sets of 10 valid repetitions, which were defined as reaching the target ROM for each movement previously described (Table 8.1). The concentric and eccentric phases of each exercise were performed for 5 seconds (Ekstrom et al., 2003). A Tabata Timer mobile application controlled this time. One minute of rest was allowed between different exercises and sets (Baechle & Earle, 2008).

A certified sports physiotherapist, blinded to the study objectives, supervised all sessions, provided individualized corrections, and monitored progress through WhatsApp or Zoom after the initial in-person session.

Table 8.1. Description of five exercises that constitute weight and elastic band programs.

Exercise	Weight program	Elastic band program
IR at 90°	Started in a supine position, 90° shoulder ABD, 90° ER, and 90° elbow FLX. Movement: 90° shoulder IR and return to the starting position (5 s).	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: 90° shoulder IR (5 s) and return to the starting position (5 s).
ER at 90°	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. Movement: 90° shoulder ER (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder ABD, 90 elbow FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: 90° shoulder ER (5 s) and return to the starting position (5 s).
Scapular punches	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. Movement: Elbow EXT (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder ABD, 90° elbow FLX, and hands at the same height as the shoulders. The elastic band should be fixed at shoulder height. Movement: Elbow EXT (5 s) and return to the starting position (5 s).

T's	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. Movement: 90° shoulder HABD (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. The elastic band should be fixed at shoulder height. Movement: 90° shoulder HABD (5 s) and return to the starting position (5 s).
Y's	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. Movement: 90° shoulder HABD and maximum shoulder FLX (5 s) and return to the starting position (5 s).	Started in a SP, 90° shoulder FLX, and maximum elbow EXT. The elastic band should be fixed at shoulder height. Movement: 90° shoulder HABD and maximum shoulder FLX (5 s) and return to the starting position (5 s).

SP – standing position; s – seconds; ABD – Abduction; ER – External rotation; IR – Internal rotation; FLX – Flexion; EXT – Extension; HABD – Horizontal abduction.

Control group

The control group performed a sham intervention twice a week for 12 weeks. This intervention consisted of 2 sets of 10 repetitions of five shoulder mobility exercises, without preventive aim, normally carried out in warm-up before training: shoulder maximum flexion and extension, horizontal abduction and adduction starting from 90º of shoulder abduction, maximum IR and ER starting from 90º of shoulder abduction, circumduction of the shoulder in a clockwise direction and circumduction of the shoulder in a counterclockwise direction (Baechle & Earle, 2008). There was no progression after 6 weeks of this sham intervention. The coach of the respective team checked the execution of the exercises, but there was no individualized monitoring with a regular exercise technique correction by a physiotherapist.

To ensure ethical equity among the sample groups and considering the potential benefits of the exercise programs tested, the control group was guaranteed access to either the weight or elastic band program after the conclusion of the trial.

Outcomes and testing procedures

At baseline (T0) and after 12 weeks (T1) of interventions and control procedures, concentric and eccentric PT of IR and ER for both dominant and non-dominant shoulders was assessed using an isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, New York), at 60°/s, 120°/s, and 180°/s (Shahpar et al., 2019).

Swimmers completed a 10-minute warm-up, followed by testing in a randomized sequence of shoulder dominance to minimize fatigue bias. Testing was performed in the supine position with the shoulder abducted to 90° and the elbow flexed to 90°, stabilizing both the trunk and arm with a velcro strap (Ellenbecker & Mattalino, 1997; Loureiro et al., 2013; Noffal, 2003). ROM limits were set between 80° ER and 65° IR to capture maximal PT within the shoulder's functional range (Loureiro et al., 2013). The concentric test was conducted first, followed by the eccentric test, with the angular velocity increasing from 60°/s to 180°/s (Loureiro et al., 2013). Each test included five maximal-effort repetitions, following three submaximal practice repetitions. Standardized instructions and encouragement were provided (Batalha et al., 2018; Batalha et al., 2020; Loureiro et al., 2013; Noffal, 2003). A minute rest period between different tests was preserved

The ER:IR ratio was calculated as the ratio of the ER to IR PT multiplied by 100 (Batalha, Raimundo, et al., 2015; Noffal, 2003). Both conventional, conER:conIR ratio, and functional, eccER:conIR, were calculated at all angular velocities.

Sample size

The sample size calculation was performed using G*Power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Kiel, Germany, version 3.1.9.4). The selected statistical test aimed to compare mean differences between independent groups. The effect size used for this calculation was derived from a similar clinical trial conducted by Batalha et al. (2015), which involved 56 participants divided into three groups: an experimental group of 20 swimmers who participated in both a preventive strength program and swimming training, a training group of 20 swimmers who only engaged in swimming training, and a control group of 16 active non-swimmers. From this trial, an effect size (Cohen's d) of 2.81 was identified, indicating the minor difference considered statistically significant between the experimental and training groups when assessing IR and ER PT at 60°/s and 180°/s of the swimmers' dominant shoulder. Using an alpha level of 0.01, a power of 0.99, and an allocation ratio of 1:1, the software calculated a minimum total sample size of 24 swimmers (8 per group). To account for potential dropouts, a final sample size of 30 swimmers (10 per group) was established.

Randomization and blinding

The first contact with the swimmers was established through a telephone call, during which the eligibility criteria and individual consent for participation in the trial were screened. The eligible competitive swimmers were divided into three groups: a weight program group, an elastic band program group, and a control group. This design aimed to balance the potential effects of these three variables on the results (Lynch et al., 2010) and was executed by a member of the research team in a computer-generated random number. The participants were unaware of the existence of other sample groups. Following this, all swimmers underwent the T0 assessment using an isokinetic dynamometer. To minimize fatigue bias during the assessments, half of the swimmers began the evaluation with their dominant shoulder, while the other half started with their non-dominant shoulder. This order was randomized using a computer-generated random number. After the T0 assessment, two 12-week experimental interventions were implemented and supervised by a sports physiotherapist who was external to the study and unaware of the previous procedures or the study's objectives. The first session with each athlete was conducted in person. During this session, the physiotherapist performed an individual 1RM test according to the specific equipment and explained the exercise program to the swimmer. After 6 weeks of intervention, the physiotherapist carried out a new 1RM evaluation to assess any potential progress in load. All in-person and online sessions were individualized to ensure that each athlete remained unaware of the other groups. The sports physiotherapist also tracked the number of sessions completed by each athlete and did not have contact with those in the control group. At the end of the 12 weeks, all swimmers who completed the full set of proposed interventions underwent a T1 strength assessment using the isokinetic dynamometer. The T0 assessment procedures were preserved in the T1 evaluation moment.

Data analysis

The data was filtered (smoothing option) and windowed at 95% of the test velocity. Data analysis was performed using the AcqKnowledge 4.1 software. The mean and SD of the PT in the 5 repetitions of different muscles (IR and ER), actions (concentric and eccentric), and angular velocities (60º/s, 120º/s, and 180º/s) for both sides were calculated. Subsequently, the conventional conER:conIR ratio and the functional eccER:conIR ratio were verified for these three angular velocities.

All statistical analysis was carried out using IBM SPSS Statistics 27 software. Means and SD were used for sample characterization. The Shapiro-Wilk test was used to verify the normality of the sample distribution. The homogeneity of variance between the three groups was verified for the sample characterization variables and the IR and ER PT at T0, through the One-Way ANOVA or the Kruskal-Wallis tests. Following this, the differences between the dominant and non-dominant shoulders at T0 and T1 were assessed using either an independent sample t-test or the Mann-Whitney U test. The variables analyzed included IR PT, ER PT, the conventional conER:conIR ratio, and the functional eccER:conIR ratio. A p-value ≤ 0.05 was considered the level of significance for each difference in PT and ER:IR ratios.

RESULTS

Participants were recruited in September 2022. Out of 49 athletes contacted, 30 were deemed eligible and suitable for participation. These participants were then allocated through stratified randomization into three groups: a weight program group (n = 10), an elastic band program group (n = 10), and a control group (n = 10). Each group consisted of five swimmers from Team A and five from Team B, with equal representation of men and women. Additionally, each group included two swimmers specializing in each swimming technique: butterfly, backstroke, breaststroke, front crawl (≤ 200 m), and front crawl (> 200 m), as shown in Figure 8.1. The three groups demonstrated homogeneity of variance (p > 0.05) regarding the sample characterization (Table 8.2) and in IR and ER PT at the initial assessment (T0) (Table 8.3). There were no recorded participant dropouts during the 12 weeks of follow-up.

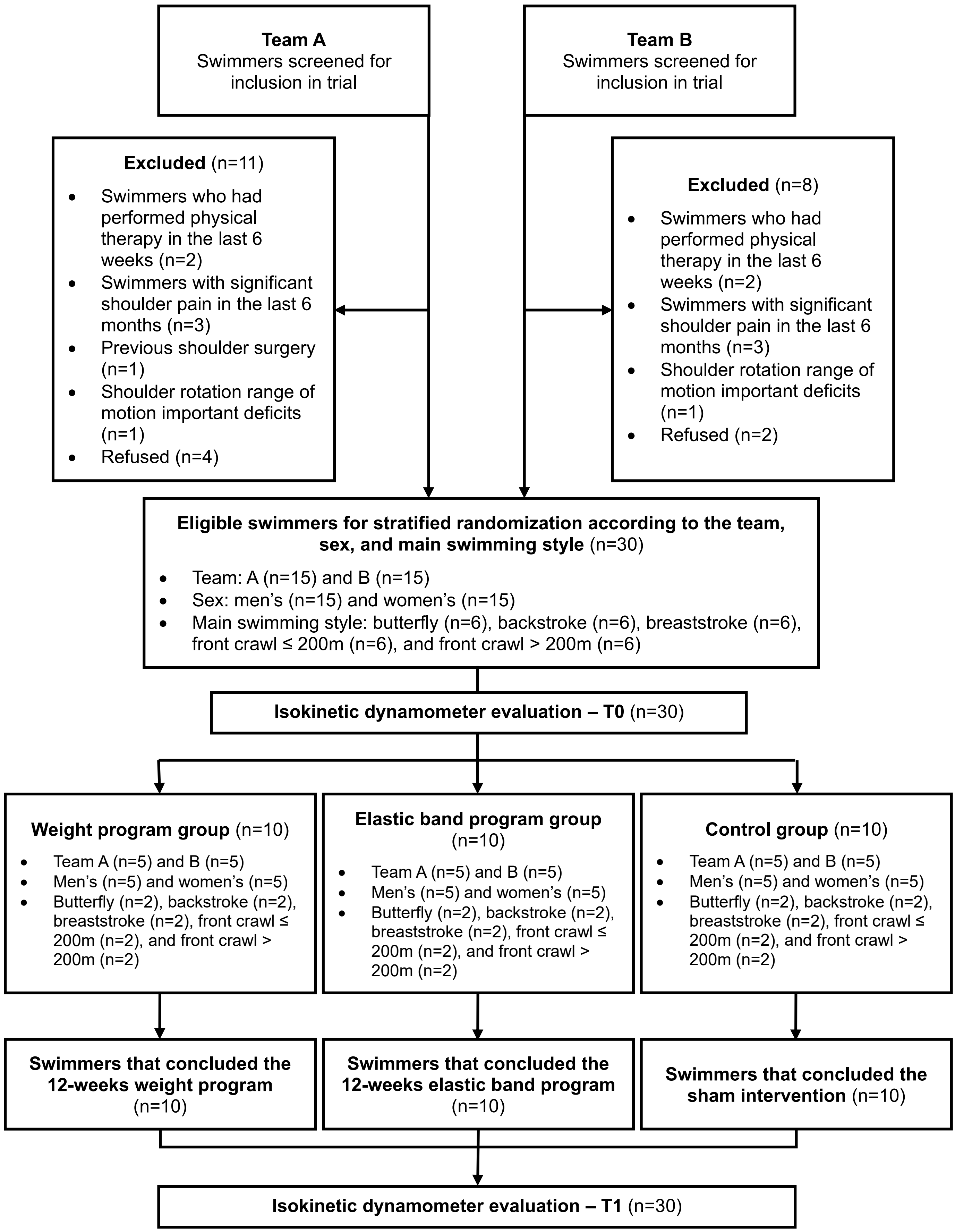

Figure 8.1. The flow of participants through the trial.

Table 8.2. Sample characterization and homogeneity of variance between the groups.

Variables	WP Mean ± SD	EBP Mean ± SD	Control Mean ± SD	*p*-value
Age (years)	19.90 ± 2.92	19.60 ± 2.99	19.00 ± 3.62	0.506
Body Mass (kg)	68.86 ± 8.49	68.80 ± 14.76	65.57 ± 11.77	0.879
Height (m)	1.72 ± 0.08	1.70 ± 0.11	1.73 ± 0.09	0.774
Body Mass Index (kg/m^2)	23.19 ± 2.24	23.64 ± 3.34	21.79 ± 1.91	0.262
Fat mass (%)	17.02 ± 10.30	17.37 ± 8.65	15.40 ± 7.19	0.700
Lean mass (kg)	55.23 ± 10.60	57.66 ± 12.83	52.04 ± 13.66	0.868
Bone mass (kg)	2.91 ± 0.51	3.03 ± 0.64	2.75 ± 0.69	0.706
Swimming practice (years)	12.10 ± 4.18	9.40 ± 4.81	12.30 ± 4.17	0.274
Competitive swimming (years)	8.90 ± 3.28	6.10 ± 3.73	7.90 ± 3.38	0.206
Weekly swimming training (hours)	16.80 ± 5.01	14.20 ± 6.29	16.60 ± 6.87	0.577

SD – standard deviation; WP – weight program; EBP – elastic band program.

Table 8.3. The homogeneity of variance between the three sample groups for the PT at T0 in dominant and non-dominant shoulders.

			WP PT (Nm)	EBP PT (Nm)	Control PT (Nm)	*p*-value
Dominant shoulder	60°/s	conIR	36.06 ± 9.71	33.17 ± 9.25	37.99 ± 13.49	0.619
		eccIR	37.30 ± 7.74	38.62 ± 14.47	41.67 ± 19.08	0.790
		conER	24.98 ± 6.63	27.62 ± 7.95	25.42 ± 10.25	0.756
		eccER	31.69 ± 7.11	36.14 ± 11.61	34.51 ± 13.58	0.667
	120°/s	conIR	30.84 ± 9.22	32.13 ± 11.56	34.66 ± 13.53	0.756
		eccIR	36.71 ± 8.05	36.43 ± 11.96	38.01 ± 17.24	0.959
		conER	23.95 ± 6.91	26.90 ± 8.88	23.63 ± 11.58	0.691
		eccER	29.74 ± 7.46	35.47 ± 11.95	30.79 ± 12.80	0.473
	180°/s	conIR	28.63 ± 9.70	28.22 ± 10.73	32.07 ± 13.90	0.719
		eccIR	38.11 ± 6.99	39.81 ± 12.95	39.53 ± 19.00	0.958
		conER	21.33 ± 5.07	24.26 ± 9.45	22.65 ± 11.64	0.774
		eccER	31.08 ± 7.74	37.28 ± 12.10	31.26 ± 14.64	0.464
Non-dominant shoulder	60°/s	conIR	25.95 ± 7.60	29.14 ± 12.54	35.73 ± 12.71	0.157
		eccIR	33.12 ± 6.76	35.26 ± 13.23	38.64 ± 15.99	0.907
		conER	25.73 ± 7.49	29.26 ± 8.43	29.53 ± 10.83	0.582
		eccER	26.86 ± 7.81	32.92 ± 11.26	30.63 ± 12.32	0.449
	120°/s	conIR	26.58 ± 8.07	26.88 ± 11.26	33.17 ± 11.03	0.348
		eccIR	32.58 ± 8.15	35.14 ± 15.28	37.64 ± 17.15	0.983
		conER	24.87 ± 6.44	26.81 ± 8.21	27.73 ± 11.33	0.765
		eccER	27.31 ± 8.90	32.50 ± 12.27	30.12 ± 12.29	0.593

180°/s	conIR	24.34 ± 8.52	23.31 ± 10.01	29.82 ± 9.60	0.267
	eccIR	34.73 ± 6.64	34.47 ± 15.03	38.16 ± 16.19	0.790
	conER	23.35 ± 7.55	24.67 ± 7.69	26.01 ± 10.93	0.800
	eccER	29.74 ± 8.62	32.75 ± 11.06	30.91 ± 12.02	0.818

WP – weight program; EBP – elastic band program; PT – peak torque; con – concentric; ecc – eccentric; IR - internal rotation; ER – external rotation.

Table 8.4. Differences in IR and ER PT between the dominant and non-dominant shoulders at T0 and T1.

			WP dif (Nm)	*p*	EBP dif (Nm)	*p*	Control dif (Nm)	*p*
T0	60°/s	conIR	10.11	**<0.001***	4.03	0.095	2.26	0.187
		eccIR	4,17	**0.028***	3.36	0.387	3.03	0.262
		conER	-0.75	0.610	-1.64	0.115	-4.11	**0.037***
		eccER	4.82	0.058	3.22	**0.022***	3.88	**0.011***
	120°/s	conIR	4.26	**0.028***	5.26	**0.001***	1.50	0.581
		eccIR	4.12	**0.047***	1.29	0.689	0.37	0.909
		conER	-0.92	0.382	0.09	0.947	-4.10	0.069
		eccER	2.43	0.405	2.97	**0.007***	0.66	0.640
	180°/s	conIR	4.29	**0.024***	4.91	**0.002***	2.25	0.431
		eccIR	3.38	0.076	5.33	0.109	1.37	0.584
		conER	-2.03	0.093	-0.41	0.730	-3.36	0.136
		eccER	1,34	0.649	4.53	**0.008***	0.35	0.853
T1	60°/s	conIR	-0.22	0.646	2.59	0.241	1.23	0.522
		eccIR	4.27	**0.037***	0.97	0.959	2.71	0.275
		conER	1.20	0.220	1.51	0.352	1.68	**0.009***
		eccER	2.89	**0.012***	3.39	0.266	0.09	0.960
	120°/s	conIR	1.21	0.494	2.60	0.284	0.55	0.745
		eccIR	3.38	0.074	2.11	0.878	4.79	0.074
		conER	1.31	0.173	2.73	**0.035***	1.21	0.181
		eccER	3.05	**0.045***	2.22	0.285	1.24	0.247
	180°/s	conIR	-0.30	0.818	0.84	0.640	0.60	0.723
		eccIR	2.89	0.241	0.56	0.878	6.50	0.112
		conER	0.98	0.386	1.47	0.362	0.79	0.167
		eccER	3.40	**0.032***	3.63	0.098	4.13	0.122

WP – weight program; EBP – elastic band program; dif – peak torque difference between dominant and non-dominant shoulder; *p* – *p*-value; con – concentric; ecc – eccentric; IR - internal rotation; ER – external rotation.

At the initial assessment (T0), the weight program group obtained five differences ($p \leq 0.05$) between the dominant and non-dominant shoulder. All of them occurred due to the superiority of the IR PT of the swimmers' dominant shoulder. Similarly, the elastic band program group also evidenced five differences ($p \leq 0.05$), which were due to higher PT values in the dominant shoulder—three in ER and two in IR. The control group revealed only two differences ($p \leq 0.05$) in the ER PT values at 60º/s.

After 12 weeks of the respective interventions, there was an overall reduction in the right-left asymmetries observed in the three sample groups at the initial measurement (Table 8.4). The elastic band program group obtained more symmetrical gains between the dominant and non-dominant shoulders. Only one difference ($p \leq 0.05$) was noted in the concentric evaluation of ER PT at 120º/s, where the dominant shoulder exhibited higher values. In the weight program group, four differences ($p \leq 0.05$) were observed, all showing greater PT values for the dominant shoulder—three in ER and one in IR. The control group showed just one difference ($p \leq 0.05$) in the concentric evaluation of ER at 60º/s, with the dominant shoulder demonstrating superior values to the other side.

Table 8.5. Differences in CR and FR between the shoulders at T0 and T1.

			WP (Nm)			EBP (Nm)			Control (Nm)		
			DS	**NDS**	***p***	**DS**	**NDS**	***p***	**DS**	**NDS**	***p***
T0	60°/s	CR	71.41 ± 18.15	100.89 ± 22.18	**0.001***	84.47 ± 17.20	106.23 ± 16.95	**0.034***	66.88 ± 12.99	83.48 ± 15.28	**0.009***
		FR	91.64 ± 24.17	104.86 ± 17.82	0.133	110.16 ± 23.91	118.27 ± 21.31	0.440	91.59 ± 19.17	88.95 ± 27.55	0.682
	120°/s	CR	83.12 ± 33.09	96.56 ± 22.81	**0.047***	85.18 ± 12.59	105.57 ± 17.40	**0.018***	65.82 ± 11.56	82.65 ± 22.95	**0.013***
		FR	105.30 ± 43.31	103.32 ± 16.63	0.856	112.55 ± 21.38	127.23 ± 29.73	0.105	89.48 ± 16.10	92.18 ± 24.43	0.701
	180°/s	CR	81.92 ± 35.77	99.01 ± 23.92	**0.028***	86.71 ± 18.28	112.30 ± 19.02	**0.015***	68.20 ± 10.36	85.25 ± 26.14	**0.022***
		FR	120.12 ± 49.48	126.17 ± 25.30	0.386	137.25 ± 32.71	150.01 ± 36.04	0.333	96.54 ± 10.49	103.66 ± 23.69	0.275
T1	60°/s	CR	87.69 ±16.77	79.92 ± 10.02	0.087	91.05 ± 15.93	90.46 ± 8.50	0.923	93.82 ± 18.41	90.98 ± 14.82	0.705
		FR	102.36 ± 18.98	87.60 ± 20.08	0.112	112.03 ± 22.30	108.90 ± 8.63	0.700	110.31 ± 25.47	113.70 ± 26.59	0.752
	120°/s	CR	85.12 ± 14.96	80.65 ± 8.38	0.381	91.45 ± 13.40	85.88 ± 6.92	0.307	93.46 ± 19.98	88.73 ± 16.36	0.542
		FR	101.52 ± 15.91	90.45 ± 16.92	0.131	115.24 ± 30.65	111.90 ± 13.76	0.732	117.07 ± 25.94	112.67 ± 20.37	0.668
	180°/s	CR	88.99 ± 10.74	82.59 ± 9.21	0.083	95.93 ± 23.99	86.67 ± 10.70	0.336	91.97 ± 22.55	91.56 ± 16.58	0.966
		FR	120.63 ± 33.92	101.78 ± 19.12	0.093	143.35 ± 55.79	122.40 ± 16.64	0.285	131.56 ± 28.94	122.73 ± 36.19	0.606

WP – weight program; EBP – elastic band program; DS – dominant shoulder; NDS – non-dominant shoulder; *p* – *p*-value; CR – conventional ratio; FR – functional ratio.

After the initial assessment (T0), three differences ($p \leq 0.05$) were observed in the conventional concentric ratio between the dominant and non-dominant shoulders across all sample groups, with the non-dominant consistently exhibiting higher values. After 12 weeks of follow-up, improvements in shoulder rotational muscle balance symmetry were noted in all groups. Neither group showed significant differences between the dominant and non-dominant shoulders (Table 8.5).

DISCUSSION

This research aimed to investigate the potential impact of dry-land preventive exercise programs for swimmers' shoulder injuries, on the symmetry between the dominant and non-dominant shoulders in four variables: IR PT, ER PT, the conventional conER:conIR ratio, and the functional eccER:conIR ratio. To achieve this objective, we analyzed the differences ($p \leq 0.05$) between the dominant and non-dominant shoulders in three homogeneous groups (Tables 8.2 and 8.3) before and after 12 weeks of follow-up. During this time, two groups participated in a specific exercise program, while the third group received a sham intervention.

After 12 weeks of the respective interventions, an overall reduction was observed in shoulder rotators' PT symmetries. All three groups demonstrated a smaller number of differences ($p \leq 0.05$) between the dominant and non-dominant sides when compared to the initial measurement (Table 8.4). The weight program group showed fewer differences in IR PT values, while the elastic band program group exhibited fewer differences in IR and ER PT values. However, the control group also exhibited reduced differences between sides in ER PT values. It may suggest that the observed reduction in the right-left symmetry of shoulder rotators' PT is likely more attributable to the large volume of swimming training performed by the athletes rather than the specific interventions they received. The cyclical and symmetrical nature of swimming (Struyf et al., 2017) appears to be a significant factor contributing to the symmetry gains observed. It's important to note that the initial assessment of these swimmers occurred during the pre-season, following a break from water training. This absence may have contributed to the higher levels of asymmetry recorded in the first evaluation.

To our knowledge, only one study examines the symmetry between dominant and non-dominant shoulders following an 8-week stretching program (Chepeha et al., 2018). The variables analyzed were the IR and the horizontal adduction ROM. In contrast to the present study, the intervention by Chepeha et al. (2018) increased the symmetry between sides compared to the control group, particularly in the IR ROM. It is important to note that the sample included a mix of athletes: 24 volleyball players, 5 tennis players, and 8 swimmers. The predominance of participants from asymmetric sports most likely influences the results. Additionally, the variables and the exercise program differ significantly from the present study, which may lead to different results.

All studies that analyzed the impact of an exercise program on shoulder strength and compared the results with a control group do not focus on symmetry between the dominant and non-dominant sides before and after the intervention (Batalha, Raimundo, et al., 2015; Manske et al., 2015; Swanik, Lephart, et al., 2002). Batalha, Raimundo, et al. (2015) conducted a strength analysis on both shoulders of swimmers in three homogeneous groups at the initial assessment. Although a symmetry analysis was not performed, it's possible to verify that after 16 weeks, experimental, training, and control groups exhibited similar changes in IR and ER PT when comparing the dominant and non-dominant shoulders at the two tested angular velocities: 60º/s and 180º/s. The remaining studies only assess the strength of the dominant shoulder, making it impossible to compare with the opposite side (Manske et al., 2015; Swanik, Lephart, et al., 2002).

In the initial assessment of rotational muscle balance, all groups showed significant asymmetries ($p < 0.05$) in the conventional conER:conIR ratios while demonstrating symmetrical values in the functional eccER:conIR ratios across all tested angular velocities. After 12 weeks, all groups demonstrated improvement in the symmetry of the conventional conER:conIR ratios, with no differences ($p < 0.05$) observed between sides at three angular velocities. Additionally, symmetry in the functional eccER:conIR ratio was preserved (Table 8.5). The alignment of the control group with the experimental groups suggests that the volume of water training influenced the strength symmetry between the shoulders. The repetitive and predominantly concentric nature of the swimming techniques likely contributed to the improvement in symmetry in the concentric assessment of the rotators, generating similar conventional ratio values between both sides.

Over 12 weeks, all groups exhibited more modifications in the conventional conER:conIR and functional eccER:conIR ratios of the non-dominant shoulder compared to the dominant side. This suggests that the non-dominant shoulder is more susceptible to changes in rotator cuff strength when swimmers return to normal training routines following a rest period.

The optimal conventional conER:conIR ratio range for swimmers was identified as 0.66–0.75, according to Ellenbecker and Davies (2000). For the functional eccER:conIR ratio, the optimal range was found to be 0.68–0.86 based on Bak and Magnusson (1997) and Drigny et al. (2020). When examining the significance of the ratios in our study and not just the symmetry, it becomes evident that the experimental groups approached the recommended intervals for injury prevention in both ratios, especially on the non-dominant side. In contrast, the control group deviated from these optimal values on both shoulders (Table 8.5). Although preventive exercise programs have a limited effect on side symmetry, they are fundamental for improving the muscle balance of the rotator cuff to align with the recommended preventive values.

One limitation of this study is that the initial assessment occurred during the pre-season, after a rest period, which may have resulted in more asymmetry at the first evaluation moment.

CONCLUSION

An injury prevention exercise program has a limited impact on enhancing shoulder rotators' strength symmetry between the dominant and non-dominant sides. However, its implementation plays a significant role in improving muscle balance in swimmers' rotator cuff.

The volume of water training combined with the cyclical and symmetrical nature of swimming are two factors that possibly explain the increase in strength symmetry and rotational ratios during the first 12 weeks of the swimming season. Side asymmetry in musculoskeletal variables, such as strength, range of motion, and proprioception, is a significant risk factor for injuries, particularly in cyclic and symmetrical sports. Further studies are needed to explore how an athlete's body symmetry changes during the sports season and to determine the impact of specific interventions on this symmetry.

Supplementary Materials

The following supporting information is at the end of Study VII (Table 8.6).

Protocol

The full trial protocol can be accessed in: https://clinicaltrials.gov/study/NCT06552585

Author Contributions

Conceptualization and study design, N.T.; J.P.V-B.; M.A.C.; methodology, N.T.; M.A.C.; software, N.T.; M.A.C.; investigation, N.T.; data analysis, N.T.; M.A.C.; writing – original draft preparation, N.T.; writing – review and editing, N.T.; J.P.V-B.; M.A.C.; visualization, N.T.; J.P.V-B.; M.A.C.; supervision, J.P.V-B.; M.A.C. All authors have read and agreed to the published version of the manuscript.

Data availability

Data are available from the authors upon reasonable request.

Ethical approval

This trial was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (CEIPC 6/2022).

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Conflict of interest

None.

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Table 8.6. CONSORT 2010 checklist of information to include when reporting a randomized trial.

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomized trial in the title.	187
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance, see CONSORT for abstracts).	188
		Introduction	
Background and objectives	2a	Scientific background and explanation of rationale.	189-190
	2b	Specific objectives or hypotheses.	190
		Methods	
Trial design	3a	Description of trial design (such as parallel, factorial), including allocation ratio.	190
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons.	Not applicable
Participants	4a	Eligibility criteria for participants.	191
	4b	Settings and locations where the data were collected.	191
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were administered.	191-193
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed.	193 and 194
	6b	Any changes to trial outcomes after the trial commenced, with reasons.	Not applicable
Sample size	7a	How sample size was determined.	194
	7b	When applicable, an explanation of any interim analyses and stopping guidelines.	Not applicable
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence.	195
	8b	Type of randomization; details of any restriction (such as blocking and block size).	195
Allocation concealment	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned.	195
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions.	195
Blinding	11a	If done, who was blinded after assignment to interventions (example: participants, care providers, those assessing outcomes) and how.	195
	11b	If relevant, description of the similarity of interventions.	Not applicable
Statistical methods	12a	Statistical methods are used to compare groups for primary and secondary outcomes.	195-196
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses.	195-196

Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the number of participants who were randomly assigned received the intended treatment and were analyzed for the primary outcome.	196-197 and Figure 8.1
	13b	For each group, losses and exclusions after randomization, together with reasons.	196-197 and Figure 8.1
Recruitment	14a	Dates defining the periods of recruitment and follow-up.	196
	14b	Why the trial ended or was stopped.	Not applicable
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group.	198 and Table 8.2
Numbers analyzed	16	For each group, the number of participants (denominator) included in each analysis, and whether the analysis was by the original assigned groups.	196-197 and Figure 8.1
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as a 95% confidence interval).	199-201 and Table 8.4, 8.5
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended.	Not applicable
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory.	199-201 and Table 8.4, 8.5
Harms	19	All-important harms or unintended effects in each group (for specific guidance, see CONSORT for harms).	Not applicable
		Discussion	
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses.	203
Generalizability	21	Generalizability (external validity, applicability) of the trial findings.	203
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence.	201-203
		Other information	
Registration	23	Registration number and name of trial registry.	188 and 190-191
Protocol	24	Where the full trial protocol can be accessed, if available.	190-191
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders.	204

Citation: Schulz KF, Altman DG, Moher D, for the CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomized trials. BMC Medicine. 2010;8:18.

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomized trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.

CHAPTER V

- **Study VIII –** Effect of Two 12-Week Prevention Exercise Programs on Swimmers' Shoulder Epidemiology in Competitive Swimmers.

STUDY VIII

Observational Study

Effect of Two 12-Week Prevention Exercise Programs on Swimmers' Shoulder Epidemiology in Competitive Swimmers

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ABSTRACT

Background: Strength programs with few exercises, performed out of the water and in an open kinetic chain, have shown good results in minimizing some musculoskeletal risk factors related to swimmer's shoulder. However, there is no information about the epidemiology of this injury after its implementation. Objective: To evaluate the effect of two 12-week strength exercise programs on swimmer's shoulder epidemiology indicators in competitive swimmers. Design: Observational study. Setting: A survey of swimmer's shoulder episodes and respective characterization was collected every 6 weeks through telephone contact with swimmers and their coaches, over 24 weeks after the start of the interventions. Participants: Thirty competitive Portuguese swimmers with a mean age of 19.5 ± 3.1 years, divided through stratified randomization according to team, sex, and main swimming style into three groups. Interventions: Group A performed a 12-week program of five exercises with weights two times per week, group B performed a 12-week program of 5 exercises with elastic band 2 times per week, and group C did a sham exercise intervention two times per week. Outcomes measurements: Retrospective assessment of the swimmer's shoulder episodes, laterality, moment of occurrence, duration, and maximum intensity of pain, physiotherapy sessions needed, and number of modified and failed trainings. Results: The groups that performed a preventive program had a lower number of episodes and consequently a smaller number of modified swimming trainings and physiotherapy sessions performed due to swimmer's shoulder. On the other hand, no significant differences were found between groups in the mean duration and intensity of shoulder pain episodes. Conclusions: A 12-week preventive strength exercise program seems to reduce the number of episodes of swimmer's shoulder and their consequences in competitive swimmers during the season. However, carrying out these programs does not seem to change the severity of pain episodes when they appear.

INTRODUCTION

The most common type of injuries in swimming are overuse injuries, which result from the repetitive cyclical movements characteristic of this sport (Struyf et al., 2017). In contrast, the likelihood of traumatic injuries is low due to the absence of external impacts and contact with opponents (Pyne et al., 2014; Trinidad et al., 2021). The incidence of overuse injuries tends to be higher during competitions than in training (Trinidad et al., 2021). Factors contributing to this increase include the high pressure on athletes (Hootman et al., 2007), heightened intensity (Prien et al., 2017; Trinidad et al., 2021), and limited recovery time during competitions (Pyne et al., 2014). Additionally, these injuries are higher in women compared to men (Trinidad et al., 2021) due to anatomical, biomechanical, and physiological differences (Costa et al., 2012; Ferreira et al., 2015; Jesús et al., 2011). For instance, women typically have lower strength levels and require more strokes to cover the same distance, which increases stress on their joints and leads to greater muscle fatigue (Trinidad et al., 2021). The principal anatomical location of these overuse injuries is the shoulder (Gaunt et al., 2012; Hill et al., 2015; Struyf et al., 2017; Trinidad et al., 2021). The term "swimmer's shoulder" is commonly used to describe a painful syndrome that occurs in the anterior region of the shoulder, resulting from the excessive use of specific anatomical structures during swimming (Hill et al., 2015; Struyf et al., 2017).

To mitigate some modifiable risk factors associated with swimmer's shoulder injury (SSI), several preventive measures have been tested. Incorporating strength programs that include dry-land exercises into athletes' weekly routines has proven to be an effective preventive strategy (Batalha et al., 2018; Tavares et al., 2022; Yoma et al., 2022). However, existing literature on this topic only reports the effects of these preventive programs on specific injury risk factors (Tavares et al., 2022; Yoma et al., 2022). To our knowledge, no studies have conducted an epidemiological analysis following the implementation of such interventions. It's essential to recognize that even if a preventive measure has a positive impact on injury risk factors, it does not necessarily lead to a significant change in injury incidence. This discrepancy occurs because multiple modifiable and non-modifiable risk factors contribute to the occurrence of SSI.

This study aimed to evaluate the impact of two 12-week preventive strength exercise programs on the SSI epidemiological indicators, over 24 weeks, among

Portuguese competitive swimmers. It was hypothesized that both dry-land exercise programs would reduce the frequency and severity of SSI throughout the evaluation period.

METHODS

Thirty competitive swimmers, consisting of 15 men and 15 women, with a mean age of 19.5 ± 3.1 years, were recruited from two national competitive swimming teams in Portugal to participate in this study. Athletes were required to be between 16 and 35 years old, have ≥ 5 years of experience in national competitions (Batalha et al., 2015), and perform ≥ 8 hours of weekly swim training (Batalha et al., 2015; Batalha et al., 2018; Hibberd et al., 2012). Exclusion criteria included a history of shoulder pain within the past 6 months (Hibberd et al., 2012; Kluemper et al., 2006; Van de Velde et al., 2011), previous shoulder surgeries (Chepeha et al., 2018; Lynch et al., 2010; Manske et al., 2015; Van de Velde et al., 2011), traumatic shoulder injuries, cervical or thoracic conditions (Van de Velde et al., 2011), ROM deficits, or neurological injuries (Ekstrom et al., 2003; Myers et al., 2005; Oyama et al., 2010). Exclusion also applied to swimmers who had recently received treatment, including physical therapy, injections, or medications for at least six weeks (Chepeha et al., 2018; Lynch et al., 2010). Eligibility criteria were verified through an individual questionnaire, and each participant provided informed consent in accordance with the Declaration of Helsinki (2013 revision) (Holt, 2014).

The participants were divided into three groups through stratified randomization based on their team, sex, and main swimming style. Group A participated in a weight training program consisting of five exercises, performed twice a week for 12 weeks (Figure 9.1). Group B engaged in an elastic band program, also with five exercises, conducted twice a week for 12 weeks (Figure 9.2). Group C carried out a sham exercise intervention twice a week for the same duration of 12 weeks (Figure 9.3).

The load used for the elastic band and weight exercises was assessed and adjusted for each swimmer, corresponding to 75 % of 1RM (Ellenbecker & Mattalino, 1997). After 6 weeks of exercise program execution, each swimmer underwent another 1RM test to evaluate potential progression in load (Shahpar et al., 2019; Van de Velde et al., 2011). Each exercise was performed in 2 sets of

10 valid repetitions, where valid repetitions were defined as achieving the target range of motion (ROM) for each movement. The concentric and eccentric phases of each exercise were performed for 5 seconds (Ekstrom et al., 2003). A Tabata Timer mobile application controlled this time. One minute of rest was preserved between different exercises and sets (Baechle & Earle, 2008). A sports physiotherapist, blinded to the study objectives, supervised all sessions, providing individualized corrections and monitoring progress through WhatsApp or Zoom after the initial in-person session.

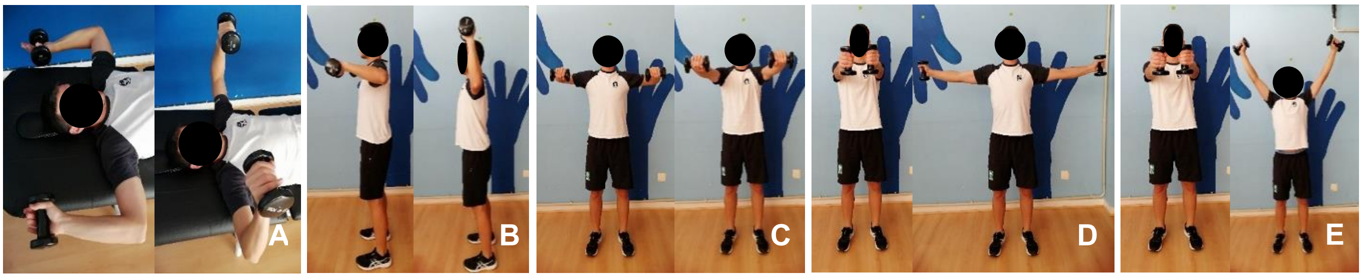

Figure 9.1. Group A weights program: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

.

Figure 9.2. Group B elastic band program: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

The control group intervention consisted of 2 sets of 10 repetitions of five shoulder mobility exercises, without a preventive aim, normally carried out in a warm-up before training. There was no progression after 6 weeks of this sham intervention. The coach of the respective team checked the execution of the exercises, but there was no individualized monitoring or correction of exercise technique provided by a physiotherapist.

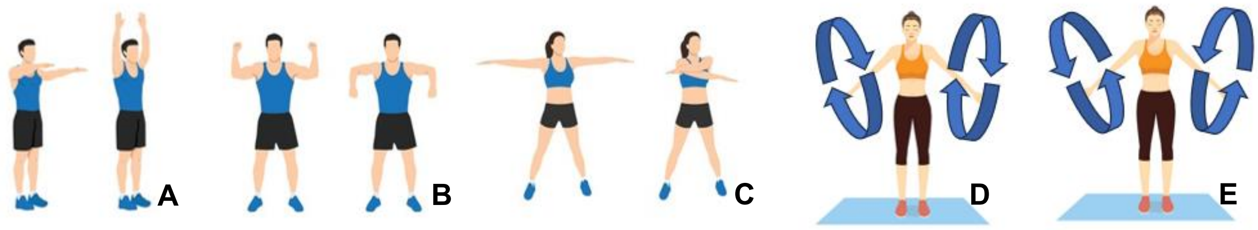

Figure 9.3. Group C sham intervention: (A) Flexion-extension, (B) Horizontal abduction-adduction, (C) Internal-external rotation, (D) Clockwise circumductions, (E) Counterclockwise circumductions.

After initiating the intervention procedures, a survey and characterization of SSI episodes were conducted every 6 weeks over 24 weeks. This assessment was performed through telephone contact. According to the International Olympic Committee Consensus Statement, a valid SSI episode was considered whenever the athlete experienced shoulder pain during a technical swimming gesture that necessitated modification of their training or competition (Bahr et al., 2020).

All statistical analyses were conducted using IBM SPSS Statistics 27 software. Means and standard deviations (SD) were used to characterize the sample. The Shapiro-Wilk test was employed to verify the normality of the sample distribution. The homogeneity of variance among the three groups was assessed using either One-Way ANOVA or Kruskal-Wallis tests for the characterization variables.

After a global characterization of SSI episodes over 24 weeks, two analyses were performed. The first was a quantitative analysis of discrete variables, which evaluated the number of SSI episodes, the number of modified and failed trainings, and the physical therapy sessions required due to an SSI episode. The second analysis was qualitative, focusing on the characterization of SSI episodes. This analysis measured the duration of SSI episodes, defined as the number of days until the Visual Analog Scale (VAS) score reached 0, as well as the maximum pain intensity for each SSI episode, rated on a VAS from 0 to 10. The Independent Samples t-test or the Mann-Whitney U-test was used to compare differences between two groups in the second analysis. A p-value of ≤ 0.05 was considered the level of significance for differences in qualitative measures.

RESULTS

At the beginning of the epidemiological data collection, the three groups showed homogeneity of variance ($p > 0.05$) across all sample characterization variables (Table 9.1).

Table 9.1. Sample characterization and homogeneity of variance between the groups.

Variables	WP Mean ± SD	EBP Mean ± SD	Control Mean ± SD	*p*-value
Age (years)	19.90 ± 2.92	19.60 ± 2.99	19.00 ± 3.62	0.506
Body Mass (kg)	68.86 ± 8.49	68.80 ± 14.76	65.57 ± 11.77	0.879
Height (m)	1.72 ± 0.08	1.70 ± 0.11	1.73 ± 0.09	0.774
Body Mass Index (kg/m^2)	23.19 ± 2.24	23.64 ± 3.34	21.79 ± 1.91	0.262
Fat mass (%)	17.02 ± 10.30	17.37 ± 8.65	15.40 ± 7.19	0.700
Lean mass (kg)	55.23 ± 10.60	57.66 ± 12.83	52.04 ± 13.66	0.868
Bone mass (kg)	2.91 ± 0.51	3.03 ± 0.64	2.75 ± 0.69	0.706
Swimming practice (years)	12.10 ± 4.18	9.40 ± 4.81	12.30 ± 4.17	0.274
Competitive swimming (years)	8.90 ± 3.28	6.10 ± 3.73	7.90 ± 3.38	0.206
Weekly swimming training (hours)	16.80 ± 5.01	14.20 ± 6.29	16.60 ± 6.87	0.577

SD – standard deviation; WP – weight program; EBP – elastic band program.

Over a 24-week data collection period, a total of 30 SSI episodes were recorded among competitive swimmers. Of these, 18 SSI were reported by female swimmers and 12 by male swimmers. Notably, 8 occurrences of SSI happened during or immediately after swimming competitions. In 6 instances, athletes experienced bilateral symptoms, while the remaining 24 episodes were unilateral, with 80 % affecting the dominant shoulder.

When analyzing the distribution of injuries among different groups, it was found that 46.67 % of the SSI occurred in the control group. This resulted in 78 modified trainings, 5 missed trainings, and 11 physiotherapy appointments. In Group A, the weight program group, 30 % of the total SSI were recorded, leading to 46 modified trainings, and 6 physiotherapy sessions due to this sports injury. Lastly, Group B, the elastic band group, reported only 23.33 % of the total SSI, which resulted in 34 modified training sessions, 3 missed trainings, and 5 physiotherapy sessions (Table 9.2).

Table 9.2. Quantification of discrete variables in the following 24 weeks after the start of the intervention.

	Group A n=10	**Group B** n=10	**Group C** n=10
SSI episodes	10	6	14
Modified swimming trainings due to SSI	46	34	78
Missed swimming trainings due to SSI	0	3	5
Physiotherapy sessions for SSI	6	5	11

SSI – Swimmer's shoulder injury.

Regarding the characterization of SSI, two indicators were used: the duration of the SSI, measured from its onset until the athlete reported a pain intensity of 0/10 on the VAS, and the maximum pain experienced during the injury, also quantified from 0 to 10 using the VAS. The analysis revealed no statistically significant differences (*p* > 0.05) among the three groups for either of these variables.

Table 9.3. Continuous variables and their significance in the following 24 weeks after the start of the intervention.

	Group A n=10	**Group B** n=10	**Group C** n=10	***p*-value**
Average of SSI episode duration (days until VAS = 0)	10.80	13.83	10.79	A ↔ B: 0.423 B ↔ C: 0.406 A ↔ C: 0.995
Average of maximum pain intensity in each SSI episode (VAS 0-10)	5.00	5.00	4.71	A ↔ B: 1.000 B ↔ C: 0.765 A ↔ C: 0.682

SSI – Swimmer's shoulder injury; VAS – Visual Analogue Scale.

DISCUSSION

This epidemiological study aimed to track a sample of competitive swimmers over half a season to quantify and classify episodes of SSI. It was built on the sequence of the randomized controlled trial conducted by Tavares et al. (2025), which evaluated the effectiveness of two preventive programs in rotator cuff strength and balance—two modifiable musculoskeletal risk factors for SSI. While some studies have demonstrated improvements in these risk factors following such interventions (Batalha et al., 2015; Chepeha et al., 2018; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002; Tavares et al., 2022; Tavares et al., 2025; Yoma et al., 2022), there is no information available on their impact on the epidemiology of SSI. The lengthy duration required for longitudinal studies is likely to contribute to this gap in research. Therefore, this study aims to make a significant and innovative contribution by examining the impact of these two preventive programs on the epidemiology of SSI.

Consistent with previous studies (Costa et al., 2012; Ferreira et al., 2015; Jesús et al., 2011; Trinidad et al., 2021), a higher incidence of SSI was observed in female athletes, typically presenting a unilateral pattern predominantly on the dominant side. Epidemiological follow-up indicated that SSI occurred more frequently during training, which contrasts with the findings of Trinidad et al. (2021), who reported that injuries are more common in a competitive context.

In the quantitative analysis, it was observed that swimmers in the control group had more episodes of SSI, resulting in a greater number of modified and missed training sessions and an increased requirement for physiotherapy due to these injuries. This could be attributed to the improvement in rotator cuff balance observed in the experimental groups following the preventive interventions (Tavares et al., 2025). Additionally, the athletes' awareness that participating in an injury prevention program likely provides a greater sense of safety during training and competition may further contribute to the reduction in SSI occurrences.

In contrast, the qualitative analysis of SSI episodes showed no significant difference ($p > 0.05$) in episode duration and maximum pain intensity between the experimental and control groups. This indicates that the implementation of preventive exercise programs has limited effectiveness on the severity and duration of the SSI once it has occurred.

This observational study has several limitations. First, the small sample size of competitive swimmers limits the external validity of the conclusions drawn. Additionally, the study was conducted within a specific timeframe, resulting in a limited observation period of only 6 months for data collection. Finally, to improve the characterization and analysis of SSI, it would be essential to provide more detailed information about the anatomical structures that experienced tissue damage for each injury. This limitation arises from the inability to evaluate all SSI episodes using imaging resources.

CONCLUSION

A 12-week preventive strength exercise program appears to reduce the number of swimmer's shoulder episodes and their consequences in competitive swimmers during the season. This improvement may be associated with a better rotator cuff balance and an increased sense of security among athletes who engage in these preventive programs. Although the improvement in these modifiable risk factors from the preventive program implementation is evident, it does not seem to affect the severity of pain episodes when they occur. In this specific context, SSI were more common during training, particularly among female athletes, and primarily affected the dominant shoulder.

This is the first known epidemiological study conducted following the implementation of preventive exercise interventions for swimmers. Future research is needed to involve larger sample sizes, longer observation periods, and more detailed injury characterization to effectively assess the impact of these preventive programs on the incidence of SSI among competitive swimmers.

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CHAPTER VI

- General discussion and main conclusions

The organization of this thesis follows a conceptual model proposed by van Mechelen et al. (1992), which consists of four steps: exploring sports injuries, examining the mechanisms and risk factors associated with them, introducing preventive measures, and assessing the effectiveness of these measures. Although the model is straightforward, it is widely recognized by the scientific community as a framework for evaluating preventive interventions in the context of sports medicine (Bahr & Krosshaug, 2005; Cools et al., 2021; van Mechelen et al., 1992).

The swimmer's shoulder was selected for analysis in this thesis following a thorough exploration of swimming injuries (Hill et al., 2015; Struyf et al., 2017; Trinidad et al., 2021). This decision was based on its status as the most common injury among competitive swimmers, which is likely to generate significant interest in the topic.

Several risk factors associated with swimmer's shoulder were analyzed. Due to the numerous factors linked to sports injuries, particularly overuse injuries, it is impossible to examine all of them in detail. This thesis focused on variables related to rotator cuff strength, including peak torque, external/internal rotator balance, and symmetry between the right and left sides. This selection was based on three main reasons: these factors are modifiable, they have a high predictive value for swimmer's shoulder injury, and they fall within the category of musculoskeletal risk factors prioritized in physical therapy (Feijen et al., 2021; Feijen et al., 2020; Gaunt & Maffulli, 2012; Hill et al., 2015; Schlueter et al., 2021; Struyf et al., 2017; Wanivenhaus et al., 2012).

After selecting the injury and identifying the relevant risk factors for analysis, the next step was to determine the appropriate intervention to test. This was the aim of the systematic review presented in this thesis. The review concluded that a dry-land program consisting of five or fewer strength exercises appears to result in greater improvements in the strength and endurance of the rotator cuff (Tavares et al., 2022). However, several limitations were identified after this step:

- There is significant heterogeneity and a lack of clarity regarding the structure of the exercise programs examined. The studies do not provide detailed explanations for the inclusion of specific exercises and often fail to specify important criteria, such as the intensity of the exercises.

- The overall results indicate positive results for preventive exercise programs. However, some authors note that these interventions may lack effectiveness, particularly in programs of shorter duration (Fredriksen et al., 2021) or those involving a greater number of exercises (Hibberd et al., 2012).
- Previous studies only focused on variables related to musculoskeletal risk factors (Batalha et al., 2015; Chepeha et al., 2018; Hibberd et al., 2012; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002). However, there is no documentation regarding the impact of these exercise programs on the incidence of swimmer's shoulder injuries. It is important to note that while addressing a specific risk factor may lead to improvements, this does not always result in a reduction in sports injuries.

Globally, the results observed after implementing preventive interventions are consistent with studies that demonstrate positive results in rotator cuff strength and endurance variables (Batalha et al., 2015; Chepeha et al., 2018; Kluemper et al., 2006; Lynch et al., 2010; Manske et al., 2015; Swanik, Lephart, et al., 2002; Tavares et al., 2022; Yoma et al., 2022). Furthermore, this thesis presents important new data on this topic:

- Using elastic bands or weights enables better control over the intensity of preventive exercise programs, making them more personalized and suitable for each swimmer. Another aspect to consider is that different equipment activates distinct shoulder muscles. This should be a key consideration when selecting the appropriate tool for preventive interventions.
- A 12-week dry-land program consisting of five open kinetic chain strength exercises positively impacted the rotator cuff strength and balance. However, these exercises did not seem to influence the symmetry of the rotator's peak torque between the right and left sides.
- Continuous individual monitoring throughout the program, combined with the implementation of progressions over the 12 weeks, resulted in no dropouts among swimmers who participated in the preventive interventions.
- The implementation of preventive interventions has reduced the incidence of swimmer's shoulder injuries and their related consequences over a period of

6 months. However, these exercise programs do not appear to affect the severity of pain episodes when they occur.

Limitations and recommendations

Although specific limitations of each study were presented in the corresponding study chapter, some relevant limitations are described below.

The exercise programs analyzed throughout the thesis were selected with the utmost care. Based on the existing literature, we chose the exercises most frequently referenced in the studies reviewed, particularly those that demonstrated the most significant effects on musculoskeletal risk factors for swimmer's shoulder. Additionally, we assessed each exercise using EMG to provide more robust data. However, as noted in the systematic review, the foundation of our analysis is rooted in highly heterogeneous studies with poor methodological quality. The analysis of these exercise programs does not mean that other exercises with a similar or better effect cannot be chosen for the swimmer's shoulder injury prevention. For example, incorporating sensorimotor training into a preventive program may lead to greater variability in results and potentially offer a more comprehensive approach compared to programs that focus solely on strength training. In the future, it will be essential to continue developing logical and well-justified exercise programs to assess and compare their impacts on this sports injury.

One limitation of this thesis is the small sample size of the studies involving competitive swimmers. Additionally, the research was conducted solely with athletes from two swimming teams, which may affect its external validity. These factors could limit the ability to generalize the results. The challenge of accessing competitive swimmers was due to their intense training and competition schedule, combined with the limited number of researchers involved in this investigation, which created this limitation. It is important to replicate these studies with a larger sample and include more teams from various geographic areas.

Another limitation identified in the implementation of preventive interventions was related to the fatigue that athletes naturally experience throughout the swimming season. Fatigue levels can vary depending on the specific phase of the competitive cycle. This fatigue may affect certain risk factors, such as strength.

To minimize its impact on the results, all swimmers were evaluated during the same period of the swimming season, ensuring they theoretically had similar fatigue levels. Future studies are encouraged to assess the effect of fatigue on swimmers' shoulder musculoskeletal risk factors.
The thesis could have been improved with a longer follow-up period to track additional episodes of the swimmer's shoulder. Furthermore, conducting a new assessment of rotator cuff strength 12 weeks after the conclusion of intervention programs would help determine whether the effects of the exercise programs were sustained. Some time constraints during the research process influenced these decisions. It is recommended that future studies include these two suggestions, as they would provide more comprehensive insights into the impact of strength programs on preventing swimmer's shoulder injuries.

Practical implications

The implementation of targeted exercise programs has proven to be an effective strategy for minimizing sports injuries throughout the season. This thesis focuses on analyzing this theme in the specific context of swimming and the swimmer's shoulder.
The thesis findings indicate that an individualized program consisting of five open kinetic chain exercises using weights or elastic bands can significantly reduce the strength imbalance of the rotator cuff in competitive swimmers over the season. This intervention should be conducted twice a week for 12 weeks and incorporate a progression in load in the sixth week. The exercises included in this program specifically target the shoulder rotators and scapular stabilizing muscles. In addition to minimizing this important injury risk factor, the implementation of targeted programs also led to a reduction in the prevalence of swimmer's shoulder among competitive swimmers over 6 months. This resulted in fewer modified or failed trainings, as well as a decrease in the number of physiotherapy sessions required.

Final conclusion

The main conclusions resulting from each study are described below.

- **Chapter II:** This chapter presents several conclusions drawn from a detailed analysis of existing scientific literature. Firstly, therapeutic exercise is an effective and safe tool that should be used to prevent swimmer's shoulder. This intervention reduces crucial modifiable musculoskeletal risk factors, such as rotator cuff strength and balance. Implementing strength programs consisting of five or fewer exercises performed out of the water and in OKC yields better results for these risk factors. These programs are most effective when conducted 2 to 3 times per week for more than 6 weeks. While there are some studies on this topic, they exhibit high heterogeneity and low methodological quality, highlighting the need for further research to clarify the conclusions of this review.

- **Chapter III:** The EMG analysis of the suggested exercises for the intervention programs revealed significant variability in muscle activation depending on whether performed with weights or elastic bands. When exercises were performed with an elastic band, there was increased EMG activity in the posterior shoulder muscles. In contrast, exercises with weights resulted in the highest EMG activity in the lateral and anterior shoulder muscles. Therefore, both training methods can positively influence the stabilizing muscles of the shoulder joint complex. Furthermore, it was observed that there are very few studies on this type of analysis, indicating that many exercises are applied in clinical practice without a strong understanding of their effects on muscle activation.
- **Chapter IV:** The principal part of the dissertation assessed the impact of two preventive exercise programs for swimmers' shoulder injuries on modifiable musculoskeletal risk factors. Although the programs did not increase rotator cuff strength, not implementing them resulted in a reduction of this strength, particularly in internal rotators. This decrease adversely affected the shoulder rotator cuff balance. Implementing the preventive programs helped minimize the common rotator cuff imbalance during a swimmer's competitive season. A 12-week duration with gradual load progression is adequate to assess some effects of these preventive exercise programs. Individual monitoring is essential for improving swimmers' adherence to this type of intervention. Furthermore, there are no significant differences between the weights program and the elastic band program regarding their effects on rotator cuff strength and balance. Finally, it can be concluded that these programs should be specific according to the target risk factor intended to be modified. When

investigating their influence on muscular symmetry between sides—an important modifiable musculoskeletal risk factor—these programs showed limited impact compared to other risk factors, such as training volume and the symmetrical nature of swimming.

- **Chapter V:** In addition to assessing the effects of these preventive programs on risk factors, we aimed to evaluate their impact on the prevalence of swimmer's shoulder injuries. The final part of the dissertation concludes that swimmers who participated in the preventive exercise programs experienced a lower occurrence of swimmer's shoulder episodes and fewer consequences from this injury over six months. However, preventive interventions did not seem to affect the severity of pain episodes.

As a **general conclusion**, a preventive routine performed twice a week, consisting of five specific open kinetic chain strength exercises for shoulder stabilizing muscles, can positively influence key modifiable musculoskeletal risk factors associated with swimmer's shoulder, such as rotator cuff strength and balance. These programs have demonstrated positive results, whether performed with weights or elastic bands. Over 6 months, this type of routine can lead to a reduction in the incidence of swimmer's shoulder injuries. These programs must be individualized and specific to each swimmer, considering the risk factors that need to be addressed. Their implementation reduces the probability of injury but does not eliminate it or alter the severity of the problem when it occurs.

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Appendices

APPENDIX A – Oral presentation

Effectiveness of a 12-week Elastic Band Exercise Program for Swimmer's Shoulder on Rotator Cuff Strength and Balance in Competitive Swimmers

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INTRODUCTION

Due to many training and competition events, there is a normal tendency during the season for a progressive imbalance of shoulder rotator ratios in elite swimmers (Drigny et al., 2020; So et al., 2022). Regarding swimmers, the interval between 0.66–0.75 was considered the non-injury conventional concentric ratio (conER:conIR) (Bak & Magnusson, 1997), and the interval between 0.68–0.86 was considered the non-injury functional ratio (eccER:conIR) (Drigny et al., 2020).

To minimize these natural changes that increase the probability of a swimmer's shoulder injury, compensatory and preventive exercise programs have been implemented in swimmers' weekly training routines (Schlueter et al., 2021; Tavares et al., 2022). Although recent reviews indicate that strength programs with a few exercises performed out of the water and in an open kinetic chain appear to have better results, there continues to be a lot of heterogeneity about the constitution of preventive exercise programs and their results in rotator cuff strength and balance (Tavares et al., 2022; Yoma et al., 2022).

The study aimed to verify the differences in the shoulder rotator's peak torque, conventional conER:conIR ratio, and functional eccER:conIR ratio after implementing a 12-week preventive elastic band program for swimmer's shoulder injury in competitive swimmers.

METHODS

A physiotherapist and participant-blind, parallel, randomized controlled trial with two groups was completed from September 2022 to April 2023.

The sample consisted of 20 Portuguese competitive swimmers with a mean age of 19.30 ± 3.25 years, divided through stratified randomization according to the team, sex, and main swimming style into two groups: the experimental group performed an elastic band program with five preventive exercises for swimmer's shoulder, twice a week, over 12 weeks, and the control group carried out a sham intervention consisted of five shoulder mobility exercises without preventive aim, twice a week, over 12 weeks.

Before (T0) and after (T1) the intervention, concentric and eccentric internal and external rotation peak torques of the non-dominant shoulder were assessed through an isokinetic dynamometer Biodex System 3, at 60°/s, 120°/s, and

180°/s, and subsequently the conventional and functional ratios were calculated. Collected data was filtered, windowed, and processed using the AcqKnowledge 4.1 software. The Independent Sample T-test or the Mann-Whitney U-test was used to compare differences between the two groups in T0 and T1.

RESULTS

Table 1. Differences in peak torque of internal and external shoulder rotators between T0 and T1.

		Experimental group (Nm)	**Control group** (Nm)	***p*-value**
Internal rotation	concentric at 60º/s	0.92	-8.81	0.003*
	eccentric at 60º/s	1.84	-4.32	0.143
	concentric at 120º/s	1.48	-7.65	0.008*
	eccentric at 120º/s	-0,62	-5.35	0.190
	concentric at 180º/s	3.21	-5,88	0.005*
	eccentric at 180º/s	2.44	-7.51	0.014*
External rotation	concentric at 60º/s	-2.35	-5.36	0.173
	eccentric at 60º/s	-0.73	-0.19	0.698
	concentric at 120º/s	-2.69	-4.93	0.277
	eccentric at 120º/s	-1.70	-1.18	0.803
	concentric at 180º/s	-1.40	-4.60	0.133
	eccentric at 180º/s	-1.02	-3.43	0.247

* Statistically significant difference

Table 2. Differences in conventional and functional shoulder ratios between T0 and T1.

		Experimental T0 (%)	**Experimental T1** (%)	**Control T0** (%)	**Control T1** (%)	***p*-value**
CR	60º/s	106.23 ± 16.95	90.46 ± 8.50	83.48 ± 15.28	90.98 ± 14.82	0.001*
	120º/s	105.57 ± 17.40	85.88 ± 6.92	82.65 ± 22.95	88.73 ± 16.36	0.004*
	180º/s	112.30 ± 19.02	86.67 ± 10.70	85.25 ± 26.14	91.56 ± 16.58	0.005*
FR	60º/s	118.27 ± 21.31	108.90 ± 8.63	88.95 ± 27.55	113.70 ± 26.59	0.002*
	120º/s	127.23 ± 29.73	111.90 ± 13.76	92.18 ± 24.43	112.67 ± 20.37	0.011*
	180º/s	150.01 ± 36.04	122.40 ± 16.64	103.66 ± 23.69	122.73 ± 36.19	0.029*

* Statistically significant difference; CR – Conventional Ratio; FR – Functional Ratio.

CONCLUSION

The swimmers who performed the sham intervention lost more shoulder internal rotation than the experimental group. No differences were found between groups in the variation of external rotation strength over 12 weeks. Considering the non-injury ratio intervals, the experimental group shows an improvement in the rotator cuff balance of the non-dominant shoulder. In turn, the control swimmers have a deviation of the non-injury shoulder ratio intervals. Including a preventive program in a swimmer's weekly routine has good results in rotator cuff strength and balance, important musculoskeletal risk factors for swimmer's shoulder injury.

Acknowledge

Researcher M.A.C. acknowledges the sponsor of FCT – Fundação para a Ciência e a Tecnologia, under the project UIDB/00285/2020 and LA/P/0112/2020. The CIFI2D research unit received funding through the reference UIDB/05913/2020, with the DOI 10.54499/UIDB/05913/2020.

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Yoma, M., Herrington, L., & Mackenzie, T. A. (2022). The effect of exercise therapy interventions on shoulder pain and musculoskeletal risk factors for shoulder pain in competitive swimmers: a scoping review. *J Sport Rehabil*, 1-12. https://doi.org/10.1123/jsr.2021-0403

APPENDIX B – Poster presentation I

Effectiveness of Exercise Programs for Swimmer's Shoulder Prevention on the Torque, Conventional, and Functional Ratios of the Non-Dominant Shoulder in Competitive Swimmers: A Randomized Controlled Trial

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Current Status: Presented at the World Physiotherapy Congress 2025 (Tokyo, Japan, 2025).

INTRODUCTION

Rotator cuff imbalances are a modifiable musculoskeletal risk factor and one of the strongest predictors of swimmer's shoulder injury (Tavares et al., 2022; Yoma et al., 2022). Due to the numerous training and competition events throughout the season, there is a tendency for a progressive imbalance in shoulder ratios among swimmers (So et al., 2022).

To prevent shoulder injuries in swimmers, it is essential to maintain a conventional concentric ratio between 0.66 and 0.75, while the functional ratio should range from 0.68 to 0.86 (Drigny et al., 2020; Ellenbecker & Davies, 2000).

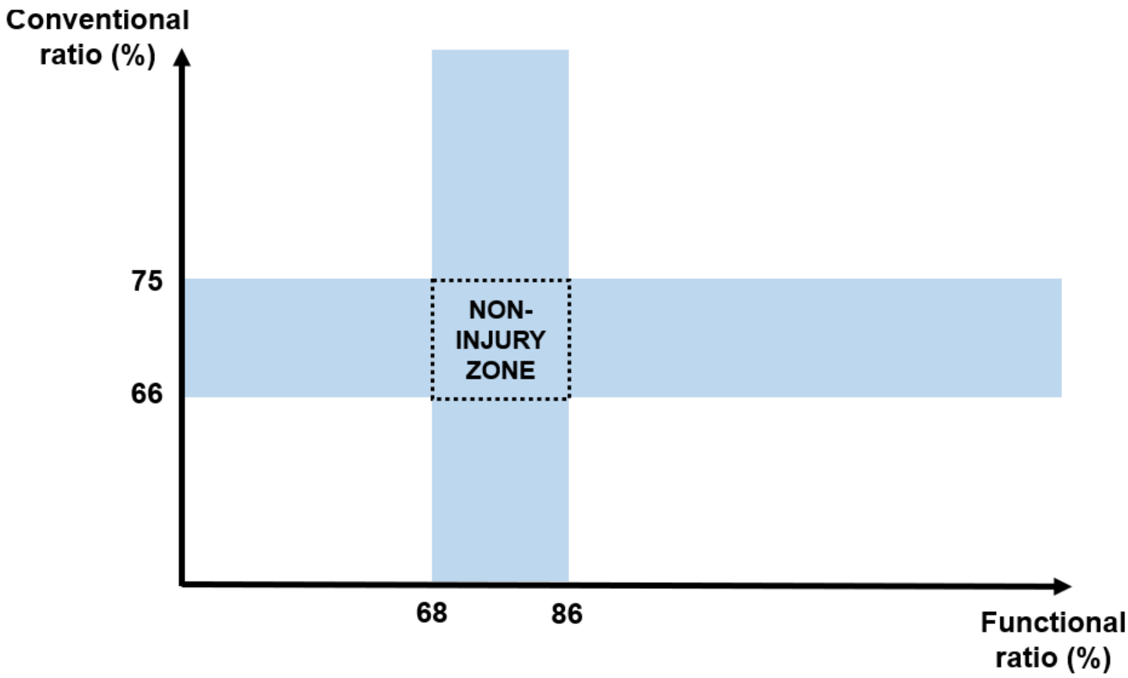


Figure 1. The reference ratios for preventing shoulder injuries in swimmers.

Strength programs that include a few exercises out of the water and in an open kinetic chain can minimize this risk factor and prevent this sports injury. However, research on this topic shows significant variability and poor methodological quality (Tavares et al., 2022; Yoma et al., 2022). Therefore, it is crucial to accurately evaluate the impact of such programs on this swimmer's shoulder risk factor.

METHODS

Participants

The sample consisted of 30 competitive swimmers with a mean age of 19.5 ± 3.1 years from two teams affiliated with the Portuguese Swimming Federation during the 2022/2023 season. The participants were randomly divided through stratified randomization according to the team, sex, and main swimming style into three groups: weights training program group (n = 10), elastic band training program group (n = 10), and control group (n = 10). The three groups exhibited homogeneity of variance ($p > 0.05$) concerning sample characterization and shoulder internal and external rotation peak torque at T0.

Experimental interventions

- Duration: 2x a week for 12 weeks.
- Characterization: 2 sets of 10 repetitions of 5 exercises with 30 seconds of rest time between sets.
- Performing moment: Out of swimming training or before water training. Material: Domyos weights or Bodytone Power elastic bands.
- Load: 75 % of 1RM.
- Sessions: Individual and monitored by a physiotherapist.
- Progressions: 6th week. Based on the quality of movement and RPE < 4.

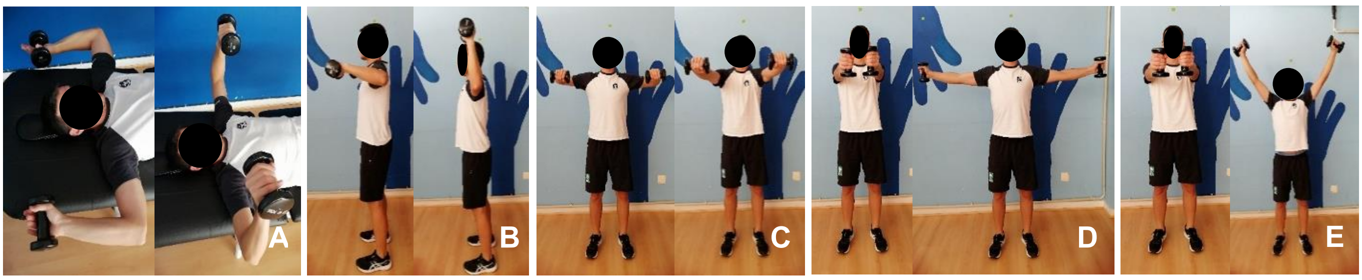


Figure 2. Weights program group: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

Figure 3. Elastic band program group: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

Control sham intervention

- Duration: 2x a week for 12 weeks.
- Characterization: 2 sets of 10 repetitions of 5 exercises with 30 seconds of rest time between sets.
- Moment of realization: Out of swimming training or before water training.
- Sessions: Coach-led group sessions.
- Progressions: No.

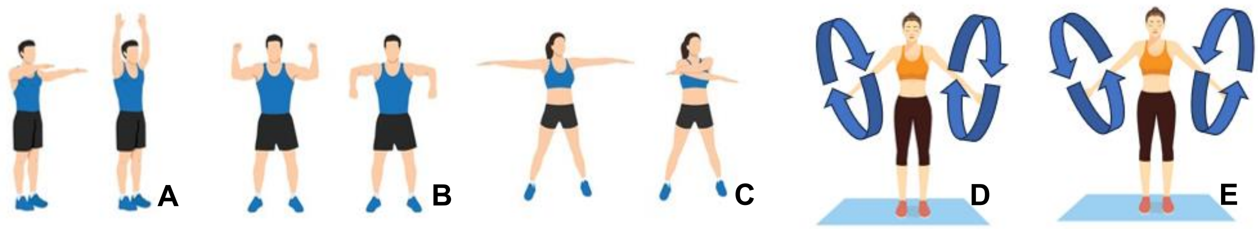


Figure 4. Control sham intervention: (A) Flexion-extension, (B) Horizontal abduction-adduction, (C) Internal-external rotation, (D) Clockwise circumductions, (E) Counterclockwise circumductions.

Data collection

- Instrument: Isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, NY, USA).
- Evaluation moments: Before (T0) and after (T1) 12 weeks of interventions and control procedures.
- Tested side: Non-dominant shoulder.
- Start position: Lying, 90º shoulder abduction, 90º elbow flexion, and with the hand palm facing the ceiling.

- Analyzed movement: 145º shoulder internal rotation followed by 145º shoulder external rotation (5 repetitions).
- Analyzed actions: Concentric and eccentric.
- Angular velocity tests: 60°/s, 120º/s, and 180°/s.
- Main outcomes: Peak torque (Nm) and conventional/functional ratios (%).

Data analysis

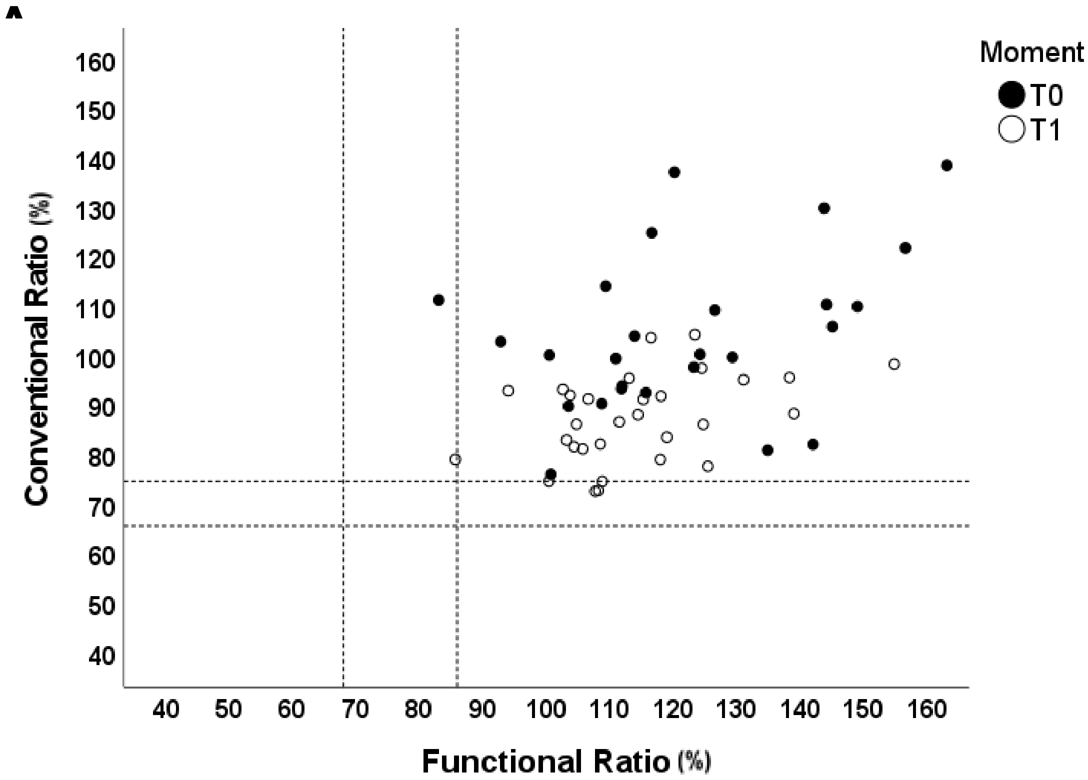
The collected data were filtered, windowed, and processed using AcqKnowledge 4.1 software. All statistical analyses were conducted using IBM SPSS Statistics 27 software.

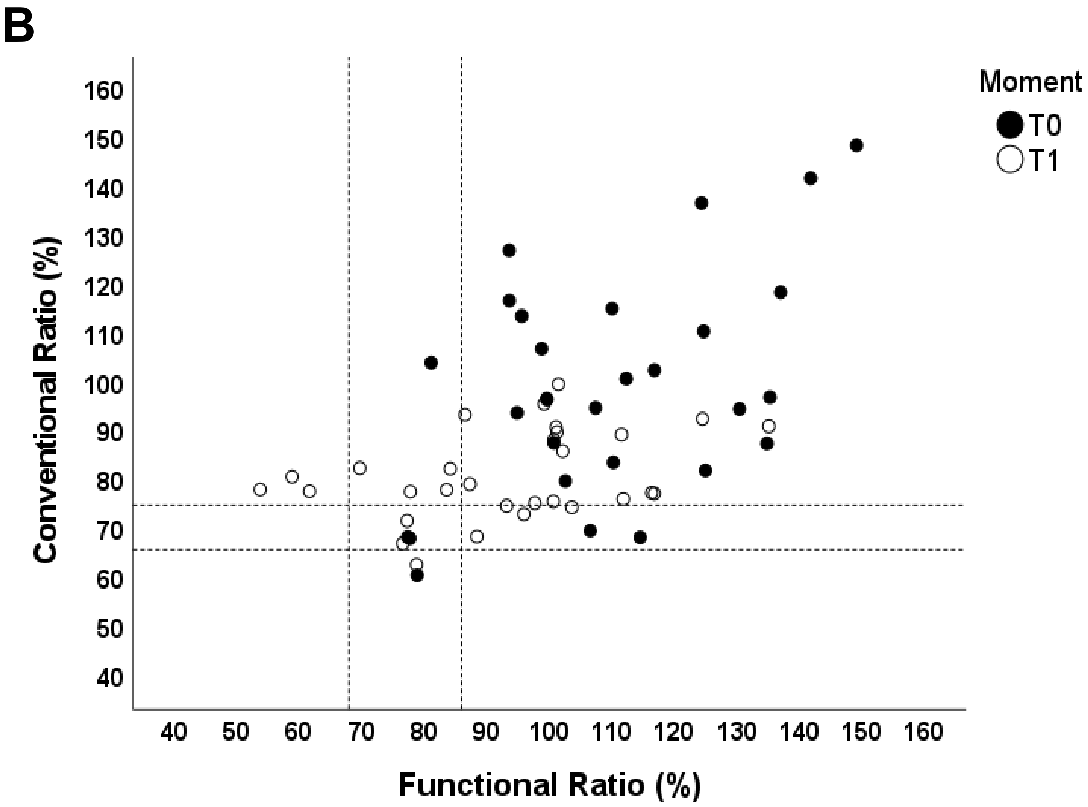
RESULTS

Table 1. Intra-group analyses of peak torque between T0 and T1.

	Weights group		**Elastic band group**		**Control group**	
	T0-T1 (Nm)	***p*-value**	**T0-T1 (Nm)**	***p*-value**	**T0-T1 (Nm)**	***p*-value**
IR | con | 60º/s	4.67	0.028*	0.92	0.582	-8.81	0.005*
IR | ecc | 60º/s	-0.23	0.878	1.84	0.434	-4.32	0.167
IR | con | 120º/s	1.78	0.333	1.48	0.329	-7.65	0.019*
IR | ecc | 120º/s	0.95	0.721	-0,62	0.827	-5.35	0.151
IR | con | 180º/s	2.17	0.231	3.21	0.053	-5,88	0.040*
IR | ecc | 180º/s	-0.13	0.799	2.44	0.448	-7.51	0.005*
ER | con | 60º/s	-0.97	0.569	-2.35	0.118	-5.36	0.009*
ER | ecc | 60º/s	0.09	0.963	-0.73	0.554	-0.19	0.799
ER | con | 120º/s	-1.76	0.386	-2.69	0.029*	-4.93	0.018*
ER | ecc | 120º/s	-1.32	0.532	-1.70	0.326	-1.18	0.352
ER | con | 180º/s	-1.60	0.203	-1.40	0.259	-4.60	0.022*
ER | ecc | 180º/s	-3.12	0.239	-1.02	0.533	-3.43	0.052

*Statistically significant difference.
IR – Internal rotation; ER – External rotation; con – concentric; ecc – eccentric.


A
Moment
T0
T1
Conventional Ratio (%)
160
150
140
130
120
110
100
90
80
70
60
50
40
Functional Ratio (%)


B
Moment
T0
T1
Conventional Ratio (%)
160
150
140
130
120
110
100
90
80
70
60
50
40
Functional Ratio (%)

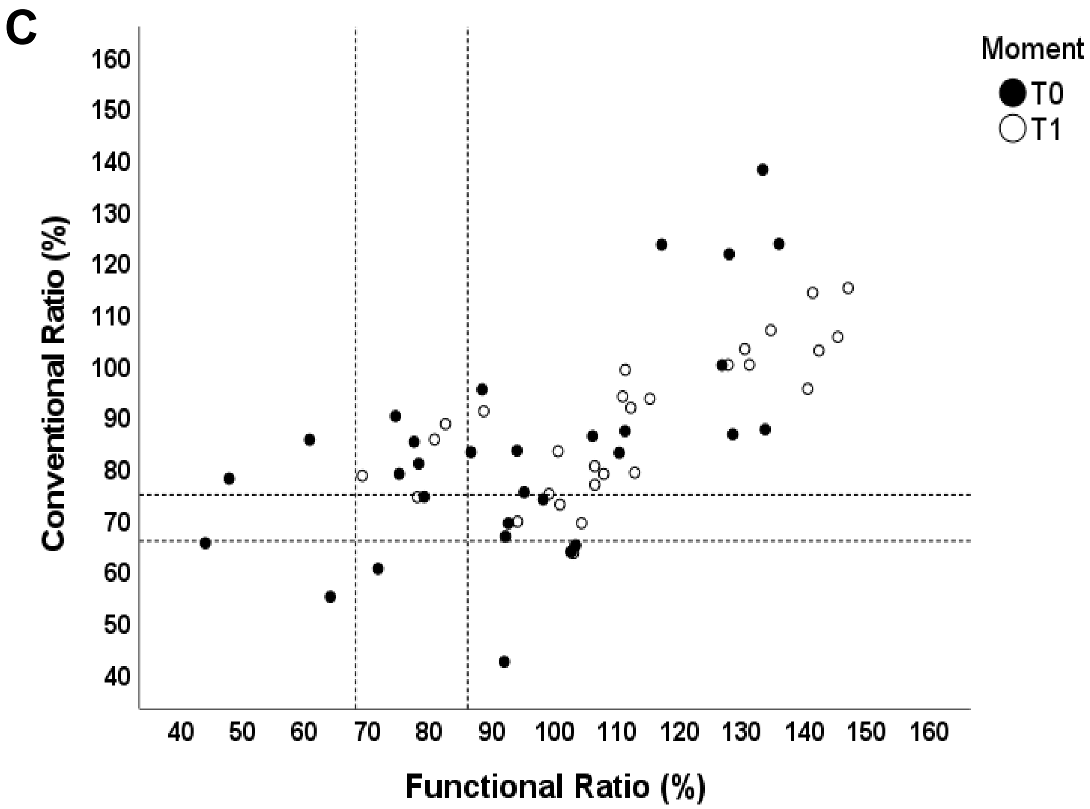


Figure 5. Conventional/functional ratios for each swimmer in: (A) weights program group, (B) elastic band program group, and (C) control group. The reference values for preventing shoulder injuries are indicated with a dashed line.

CONCLUSION

- The absence of a preventive program in the control group produces a strength reduction in the internal and external shoulder rotators.
- Implementing a 12-week preventive program for swimmer's shoulder minimizes the progressive rotator cuff imbalance throughout the competitive season.
- No significant differences were observed in the effects of the two experimental programs, whether using weights or elastic bands.

RECOMMENDATIONS

Preventive exercise programs are a fundamental part of a swimmer's weekly routines as they minimize the progressive shoulder rotational imbalance over the season in competitive swimmers.

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Drigny, J., Gauthier, A., Reboursière, E., Guermont, H., Gremeaux, V., & Edouard, P. (2020). Shoulder muscle imbalance as a risk for shoulder injury in elite adolescent swimmers: a prospective study. *J Hum Kinet*, *75*, 103-113. https://doi.org/10.2478/hukin-2020-0041

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PRESENTED AT:

World Physiotherapy Congress2025

U.PORTO FACULDADE DE DESPORTO UNIVERSIDADE DO PORTO · CIAFEL · RoboCorp Laboratório · CEMMPRE

Effectiveness of exercise programs for swimmer's shoulder prevention on the torque, conventional, and functional ratios of the non-dominant shoulder in competitive swimmers: a randomized controlled trial.

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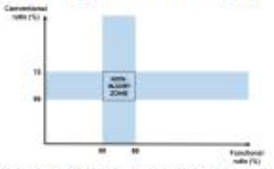
[4] RoboCorp, 12A, Polytechnic Institute of Coimbra, Coimbra, Portugal
[5] Centre of Mechanical Engineering, Materials and Processes (CEMMPRE), University of Coimbra, Coimbra, Portugal

Introduction

Rotator cuff imbalances are a modifiable musculoskeletal risk factor and one of the strongest predictors of a swimmer's shoulder injury [1,2]. Due to the numerous training and competition events throughout the season, there is a tendency for a progressive imbalance in shoulder ratios among swimmers [3].
To prevent shoulder injuries in swimmers, it is essential to maintain a conventional concentric ratio between 0.66 and 0.75, while the functional ratio should range from 0.68 to 0.86 [4,5].



The reference ratios for preventing shoulder injuries in swimmers.

Strength programs that include a few exercises out of the water and in an open kinetic chain can minimize this risk factor and prevent this sports injury. However, research on this topic shows significant variability and poor methodological quality [1,2]. Therefore, it is crucial to accurately evaluate the impact of such programs on this swimmer's shoulder risk factor.

Purpose

Verify the effectiveness of two 12-week preventive programs on the shoulder rotators' peak torque, and conventional/functional ratios.

Methods

- **Participants**

The sample consisted of 30 competitive swimmers with a mean age of 19.5 ± 3.1 years from 2 teams affiliated with the Portuguese Swimming Federation during the 2022/2023 season. The participants were randomly divided through stratified randomization according to the team, sex, and main swimming style into 3 groups: weights training program group (n = 10), elastic band training program group (n = 10), and control group (n = 10). The 3 groups exhibited homogeneity of variance ($p > 0.05$) concerning sample characterization and shoulder internal/external rotation peak torque at T0.

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[1] Yona, M.; Harrington, L.; Mackenzie, T.A. The effect of exercise therapy interventions on shoulder pain and musculoskeletal risk factors for shoulder pain in competitive swimmers: A scoping review. J. Sport Rehabil. 2022, 31, 617–628. [2] Tavares, N.; Dias, G.; Carvalho, P.; Vilas-Boas, J.P.; Castro, M.A. Effectiveness of therapeutic exercise in musculoskeletal risk factors related to swimmer's shoulder. Eur. J. Invest. Health Psychol. Educ. 2022, 12, 601–615. [3] Ho, R.C.L.; Lau, R.C.T.; Kwok, W.Y.; Tse, D.H.T.; Man, S.S. Investigating the association between supraspinatus tendon abnormality, shoulder pain and isokinetic strength in elite swimmers: A cross-sectional study. J. Sports Sci. Med. 2023, 22, 17–27. [4] Drigny, J.; Gauthier, A.; Reboursière, E.; Guermont, H.; Gremeaux, V.; Edouard, P. Shoulder muscle imbalance as a risk for shoulder injury in elite adolescent swimmers: A prospective study. J. Hum. Kinet. 2020, 75, 103–113. [5] Ellenbecker, T.S.; Davies, G.J. The application of isokinetics in testing and rehabilitation of the shoulder complex. J. Athl. Train. 2000, 35, 338–350.

Methods

- **Experimental interventions**

Duration: 2x a week for 12 weeks.
Characterization: 2 sets of 10 reps of 5 exercises with 30 s of rest time between sets.
Moment of realization: Out of swimming training or before water training. **Material:** Domyos weights or Bodytone Power elastic bands. **Load:** 75% of 1RM. **Sessions:** Individual and monitored by a physiotherapist. **Progressions:** 6th week. Based on the quality of movement and RPE < 4.

Weights program group: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

Elastic band program group: (A) IR at 90°, (B) ER at 90°, (C) Scapular punches, (D) T's, (E) Y's.

- **Control sham intervention**

Duration: 2x a week for 12 weeks.
Characterization: 2 sets of 10 reps of 5 exercises with 30 s of rest time between sets.
Moment of realization: Out of swimming training or before water training. **Sessions:** Coach-led group sessions. **Progressions:** No.

Control sham intervention: (A) Flexion-extension, (B) Horizontal abduction-adduction, (C) Internal-external rotation, (D) Clockwise circumductions, (E) Counterclockwise circumductions.

- **Data collection**

Instrument: Isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, NY, USA).
Evaluation moments: Before (T0) and after (T1) 12 weeks of interventions and control procedures.
Tested side: Non-dominant shoulder. **Start position:** Lying, 90° shoulder abduction, 90° elbow flexion, and with the hand palm facing the ceiling. **Analyzed movement:** 145° shoulder internal rotation followed by 145° shoulder external rotation (5 reps). **Analyzed actions:** Concentric and eccentric. **Angular velocity tests:** 60°/s, 120°/s, and 180°/s. **Main outcomes:** Peak torque (N.m) and conventional/functional ratios (%).

- **Data analysis**

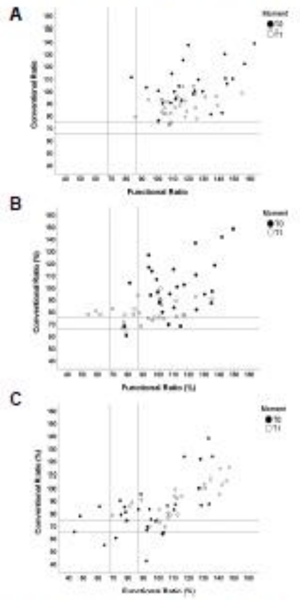
The collected data was filtered, windowed, and processed using Acqknowledge 4.1 software. All statistical analyses were conducted using IBM SPSS Statistics 27 software.

Results

	Weights group		Elastic band group		Control group	
	T1-T0 (%)	p	T1-T0 (%)	p	T1-T0 (%)	p
IR | con | 60°/s	4.07	0.028*	3.90	0.582	-8.41	0.005*
IR | ecc | 60°/s	-0.20	0.876	1.88	0.436	-4.32	0.167
IR | con | 120°/s	1.79	0.333	1.48	0.329	-7.85	0.019*
IR | ecc | 120°/s	0.95	0.721	-0.82	0.827	-0.35	0.131
IR | con | 180°/s	2.17	0.331	3.21	0.052	-5.89	0.049*
IR | ecc | 180°/s	-0.13	0.798	2.44	0.448	-7.51	0.005*
ER | con | 60°/s	-0.97	0.589	-2.30	0.118	-5.38	0.009*
ER | ecc | 60°/s	3.09	0.863	-0.73	0.554	-0.19	0.798
ER | con | 120°/s	-1.78	0.346	-2.89	0.029*	-4.80	0.016*
ER | ecc | 120°/s	-1.32	0.532	-1.70	0.326	-1.19	0.302
ER | con | 180°/s	-1.82	0.303	-1.40	0.238	-4.80	0.012*
ER | ecc | 180°/s	-0.12	0.239	-1.02	0.533	-2.43	0.052

*Statistically significant difference; IR – Internal rotation; ER – External rotation; con – concentric; ecc – eccentric.

Intra-group analyses in peak torque between T0 and T1.



Conventional/functional ratios for each swimmer in: (A) weights program group, (B) elastic band program group, and (C) control group. The reference values for preventing shoulder injuries are indicated with a dashed line.

Conclusions

- The absence of a preventive program in the control group produces a strength reduction in the internal and external shoulder rotators.
- Implementing a 12-week preventive program for swimmer's shoulder minimizes the progressive rotator cuff imbalance throughout the competitive season.
- No significant differences were observed in the effects of the two experimental programs, whether using weights or elastic bands.

Recommendations

Preventive exercise programs are a fundamental part of a swimmer's weekly routines as they minimize the progressive shoulder rotational imbalance over the season in competitive swimmers.

APPENDIX C – Poster presentation II

Effect of Two 12-Week Prevention Exercise Programs on Swimmers' Shoulder Epidemiology in Competitive Swimmers

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Current Status: Presented at the 7th International Olympic Committee World Conference on Prevention of Injury and Illness in Sport (Monaco, 2024).

BACKGROUND

Swimmer's shoulder is a common painful syndrome that occurs in the anterior region of the shoulder and results from the excessive use of certain anatomical structures during the technical gesture of swimming (Hill et al., 2015; Struyf et al., 2017). Strength programs, with few exercises, performed out of the water and in an open kinetic chain seem to have better results in the prevention of swimmer's shoulder (Tavares et al., 2022; Yoma et al., 2022). Although the impact of these programs on swimmer's shoulder risk factors has been studied (Tavares et al., 2022), there is no information about the epidemiology of this injury after its implementation.

OBJECTIVE

To evaluate the effect of two 12-week strength exercise programs on 24 weeks of SS epidemiology indicators in Portuguese competitive swimmers.

DESIGN METHOD

- A survey and characterization of swimmer's shoulder episodes was carried out every 6 weeks over 24 weeks, through telephone contact, after the start of the implementation of two 12-week prevention strength exercise programs.
- The sample consisted of 30 competitive Portuguese swimmers with a mean age of 19.5 ± 3.1 years, divided through stratified randomization according to the team, sex and main swimming style into three groups: Group A – weights program, five exercises, 2x per week (Figure 1); Group B – elastic band program, five exercises, 2x per week (Figure 2); and Group C – sham exercise intervention, 2x per week.
- A valid swimmer's shoulder episode was considered whenever the athlete felt shoulder pain in a technical gesture of swimming that forced them to modify the training or competition (Bahr et al., 2020).
- Programs were supervised by a sports physiotherapist independent of the study.
- The statistical analysis was performed using IBM SPSS Statistics 27.

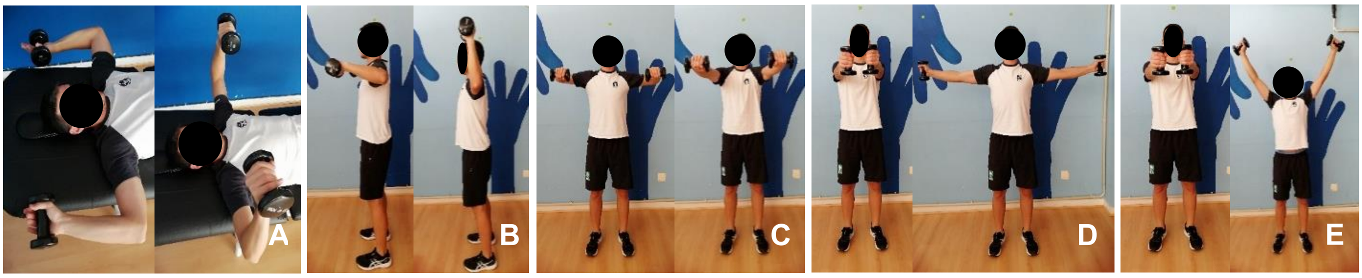

Figure 1. Group A weights program: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

Figure 2. Group B elastic band program: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

RESULTS

Table 1. Quantification of discrete variables in the following 24 weeks after the start of the intervention.

	Group A n=10	**Group B** n=10	**Group C** n=10
SSI episodes	10	6	14
Modified swimming trainings due to SSI	46	34	78
Failed swimming trainings due to SSI	0	3	5
Physiotherapy sessions for SSI	6	5	11

SSI – Swimmer's shoulder injury.

Table 2. Continuous variables and their significance in the following 24 weeks after the start of the intervention.

	Group A n=10	Group B n=10	Group C n=10	*p*-value
Average of SSI episode duration (days until VAS = 0)	10.80	13.83	10.79	A ↔ B: 0.423 B ↔ C: 0.406 A ↔ C: 0.995
Average of maximum pain intensity in each SSI episode (VAS 0–10)	5.00	5.00	4.71	A ↔ B: 1.000 B ↔ C: 0.765 A ↔ C: 0.682

SSI – Swimmer's shoulder injury; VAS – Visual Analogue Scale.

CONCLUSIONS

A 12-week preventive strength exercise program seems to reduce the number of episodes of swimmer's shoulder and their consequences in competitive swimmers during the season. However, carrying out these programs does not seem to change the severity of pain episodes when they appear.

Take-home message

Specific strength programs with a preventive aim are a fundamental part of a swimmer's weekly routines as they reduce the number of shoulder pain episodes over the season and, consequently, lead to fewer modifications to water training.

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Effect of two 12-week prevention exercise programs on swimmers' shoulder epidemiology in competitive swimmers

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MEP133

TAKE HOME MESSAGE

Specific strength programs with a preventive aim are a fundamental part of a swimmer's weekly routines as they reduce the number of shoulder pain episodes over the season and, consequently, lead to fewer modifications to the water training.

Background

Swimmer's shoulder (SS) is a common painful syndrome that occurs in the anterior region of the shoulder and results from the excessive use of certain anatomical structures during the technical gesture of swimming (1,2). Strength programs, with few exercises, performed out of the water and in an open kinetic chain seem to have better results in the prevention of SS (3, 4). Although the impact of these programs on SS risk factors has been studied (3), there is no information about the epidemiology of this injury after its implementation.

Objective

To evaluate the effect of two 12-week strength exercise programs on 24 weeks of SS epidemiology indicators in Portuguese competitive swimmers.

Design Method

- A survey and characterization of SS episodes was carried out every 6 weeks over 24 weeks, through telephone contact, after the start of the implementation of two 12-week prevention strength exercise programs.
- The sample consisted of 30 competitive Portuguese swimmers with a mean age of 19.5 ± 3.1 years, divided through stratified randomization according to the team, sex and main swimming style into 3 groups:
  - > Group A – Weights program; 5 exercises; 2x per week (Figure 1).
  - > Group B – Elastic band program; 5 exercises; 2x per week (Figure 2).
  - > Group C – Sham exercise intervention; 2x per week.
- A valid SS episode was considered whenever the athlete felt shoulder pain in a technical gesture of swimming that forced them to modify the training or competition(5).
- Programs were supervised by a sports physiotherapist independent of the study.
- The statistical analysis was performed using IBM SPSS Statistics 27.

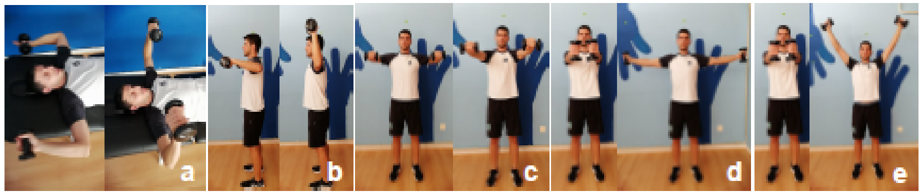

Figure 1: Group A weights program: a) IR at 90º, b) ER at 90º, c) Scapular punches, d) T's, e) Y's.

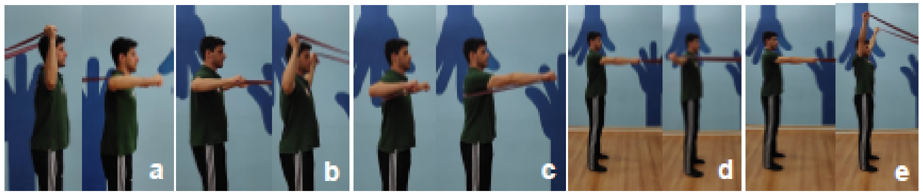

Figure 2: Group B elastic band program: a) IR at 90º, b) ER at 90º, c) Scapular punches, d) T's, e) Y's.

Results

Table 1: Quantification of discrete variables in the following 24 weeks after the start of the intervention.

	A n=10	B n=10	C n=10
SS injury episodes	10	6	14
Modified swimming trainings due to SS	46	34	78
Failed swimming trainings due to SS	0	3	5
Physiotherapy sessions for SS	6	5	11

Table 2: Continuous variables and their significance in the following 24 weeks after the start of the intervention.

	A n=10	B n=10	C n=10	*p-value*
Average of SS episode duration (days until VAS = 0)	10,80	13,83	10,79	A↔B: 0,423 B↔C: 0,406 A↔C: 0,995
Average of maximum pain intensity in each SS episode (VAS 0-10)	5,00	5,00	4,71	A↔B: 1,000 B↔C: 0,765 A↔C: 0,682

Conclusions

A 12-week preventive strength exercise program seems to reduce the number of episodes of swimmer's shoulder and their consequences in competitive swimmers during the season. However, carrying out these programs does not seem to change the severity of pain episodes when they appear.

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APPENDIX D – Poster presentation III

Impact of Two Dry-Land Exercise Programs on the Symmetry of Shoulder Rotator Cuff Strength and Rotational Muscle Balance Between Dominant and Non-Dominant Shoulders in Swimmers

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Current Status: Presented at the Biomechanics – Sport and Clinics 2025, Porto, Portugal.

INTRODUCTION

Applying similar force between the right and left sides can positively affect the swimmer's performance, particularly by promoting better body alignment, reducing drag, and lowering intracycle velocity variations (Carvalho et al., 2019; Santos et al., 2024). Due to the competitive swimmers' high training volume, the presence of body imbalances is an important risk factor that increases the risk of overuse injuries, particularly in swimmers' shoulders (Batalha et al., 2015; Carvalho et al., 2019; Struyf et al., 2017). Dry-land exercise programs improve some swimmers' shoulder musculoskeletal risk factors (Yoma et al., 2022). However, no information has been found about the effects of these preventive programs on strength symmetry between the dominant and non-dominant sides.

PURPOSE

To analyze the impact of two 12-week dry-land exercise programs on the symmetry of shoulder rotator cuff strength and rotational muscle balance between dominant and non-dominant shoulders in competitive swimmers.

METHODS

- **Participants:** The sample consisted of 30 competitive swimmers with a mean age of 19.5 ± 3.1 years from two teams affiliated with the Portuguese Swimming Federation during the 2022/2023 season. The participants were randomly divided through stratified randomization according to the team, sex, and main swimming style into three groups: weights training program group (n = 10), elastic band training program group (n = 10), and control group (n = 10). The three groups exhibited homogeneity of variance ($p > 0.05$) concerning sample characterization and shoulder internal/external rotation peak torque at T0.
- **Experimental interventions** (Figures 1 and 2)**:** Duration: 2x a week for 12 weeks. Characterization: 2 sets of 10 repetitions of five exercises with 30 seconds of rest time between sets. Moment of realization: Out of swimming training or before water training. Material: Domyos weights or Bodytone Power elastic bands. Load: 75 % of 1RM. Sessions: Individual and monitored by a physiotherapist. Progressions: 6^{th} week. Based on the quality of movement and RPE < 4.

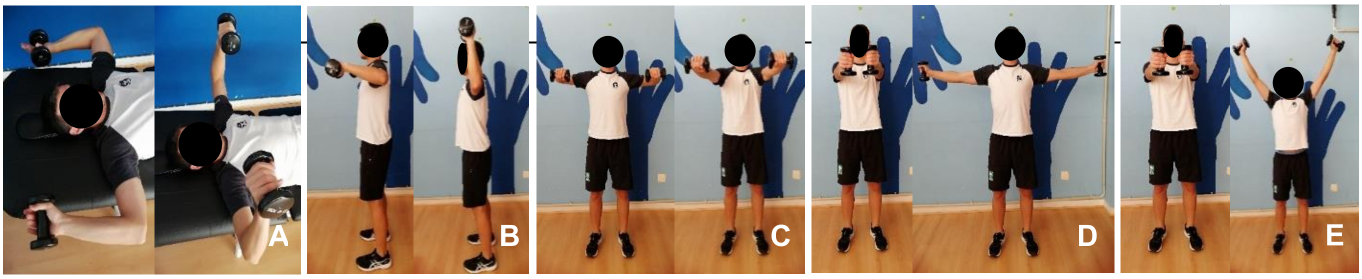

Figure 1. Weights program group: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

Figure 2. Elastic band program group: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

- **Control sham intervention** (Figure 3)**:** Duration: 2x a week for 12 weeks. Characterization: 2 sets of 10 repetitions of five exercises with 30 seconds of rest time between sets. Moment of realization: Out of swimming training or before water training. Sessions: Coach-led group sessions. Progressions: No.

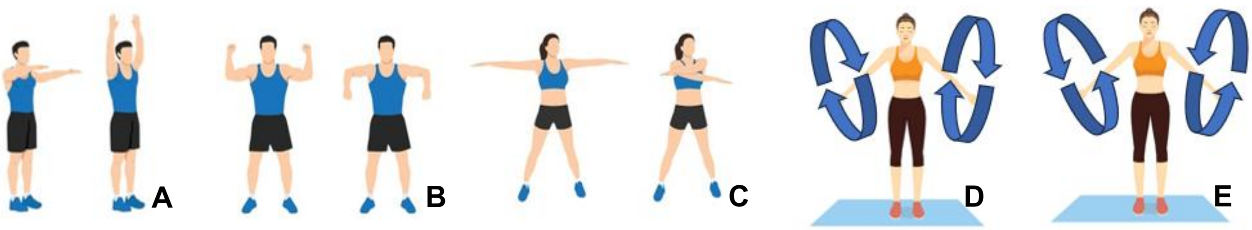

Figure 3. Control sham intervention: (A) Flexion-extension, (B) Horizontal abduction-adduction, (C) Internal-external rotation, (D) Clockwise circumductions, (E) Counterclockwise circumductions.

- **Data collection:** Instrument: Isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, NY, USA). Evaluation moments: Before (T0) and after (T1) 12 weeks of interventions and control procedures. Start position:

Lying, 90º shoulder abduction, 90º elbow flexion, and with the hand palm facing the ceiling. Analyzed movement: 145º shoulder internal rotation followed by 145º shoulder external rotation (5 repetitions). Analyzed actions: Concentric and eccentric. Angular velocity tests: 60°/s, 120º/s, and 180°/s. Main outcomes: Peak torque (Nm) and conventional/functional ratios (%).

- **Data analysis:** The collected data was filtered, windowed, and processed using AcqKnowledge 4.1 software. All statistical analyses were conducted using IBM SPSS Statistics 27 software.

RESULTS

T0	Weights group		Elastic band group		Control group	
	DS-NDS (Nm)	p	DS-NDS (Nm)	p	DS-NDS (Nm)	p
IR | con | 60º/s	10.11	**<0.001***	4.03	0.095	2.26	0.187
IR | ecc | 60º/s	4,17	**0.028***	3.36	0.387	3.03	0.262
IR | con | 120º/s	4.26	**0.028***	5.26	**0.001***	1.50	0.581
IR | ecc | 120º/s	4.12	**0.047***	1.29	0.689	0.37	0.909
IR | con | 180º/s	4.29	**0.024***	4.91	**0.002***	2.25	0.431
IR | ecc | 180º/s	3.38	0.076	5.33	0.109	1.37	0.584
ER | con | 60º/s	-0.75	0.610	-1.64	0.115	-4.11	**0.037***
ER | ecc | 60º/s	4.82	0.058	3.22	**0.022***	3.88	**0.011***
ER | con | 120º/s	-0.92	0.382	0.09	0.947	-4.10	0.069
ER | ecc | 120º/s	2.43	0.405	2.97	**0.007***	0.66	0.640
ER | con | 180º/s	-2.03	0.093	-0.41	0.730	-3.36	0.136
ER | ecc | 180º/s	1,34	0.649	4.53	**0.008***	0.35	0.853

***Statistically significant difference**

DS – Dominant shoulder; NDS – Non-dominant shoulder; IR – Internal rotation; ER – External rotation; con – concentric; ecc – eccentric

Table 1. Differences in the rotators' peak torque between the dominant and non-dominant shoulders at T0.

T1	Weights group DS-NDS (Nm)	p	Elastic band group DS-NDS (Nm)	p	Control group DS-NDS (Nm)	p
IR | con | 60º/s	-0.22	0.646	2.59	0.241	1.23	0.522
IR | ecc | 60º/s	4.27	**0.037***	0.97	0.959	2.71	0.275
IR | con | 120º/s	1.21	0.494	2.60	0.284	0.55	0.745
IR | ecc | 120º/s	3.38	0.074	2.11	0.878	4.79	0.074
IR | con | 180º/s	-0.30	0.818	0.84	0.640	0.60	0.723
IR | ecc | 180º/s	2.89	0.241	0.56	0.878	6.50	0.112
ER | con | 60º/s	1.20	0.220	1.51	0.352	1.68	**0.009***
ER | ecc | 60º/s	2.89	**0.012***	3.39	0.266	0.09	0.960
ER | con | 120º/s	1.31	0.173	2.73	**0.035***	1.21	0.181
ER | ecc | 120º/s	3.05	**0.045***	2.22	0.285	1.24	0.247
ER | con | 180º/s	0.98	0.386	1.47	0.362	0.79	0.167
ER | ecc | 180º/s	3.40	**0.032***	3.63	0.098	4.13	0.122

*Statistically significant difference

DS – Dominant shoulder; NDS – Non-dominant shoulder; IR – Internal rotation; ER – External rotation; con – concentric; ecc – eccentric

Table 2. Differences in the rotators' peak torque between the dominant and non-dominant shoulders at T1.

T0	Weights group			Elastic band group			Control group		
	DS (Nm)	NDS (Nm)	p	DS (Nm)	NDS (Nm)	p	DS (Nm)	NDS (Nm)	p
CR | 60º/s	71.41 ± 18.15	100.89 ± 22.18	**0.001***	84.47 ± 17.20	106.23 ± 16.95	0.034*	66.88 ± 12.99	83.48 ± 15.28	**0.009***
FR | 60º/s	91.64 ± 24.17	104.86 ± 17.82	0.133	110.16 ± 23.91	118.27 ± 21.31	0.440	91.59 ± 19.17	88.95 ± 27.55	0.682
CR | 120º/s	83.12 ± 33.09	96.56 ± 22.81	**0.047***	85.18 ± 12.59	105.57 ± 17.40	**0.018***	65.82 ± 11.56	82.65 ± 22.95	**0.013***
FR | 120º/s	105.30 ± 43.31	103.32 ± 16.63	0.856	112.55 ± 21.38	127.23 ± 29.73	0.105	89.48 ± 16.10	92.18 ± 24.43	0.701
CR | 180º/s	81.92 ± 35.77	99.01 ± 23.92	**0.028***	86.71 ± 18.28	112.30 ± 19.02	**0.015***	68.20 ± 10.36	85.25 ± 26.14	**0.022***
FR | 180º/s	120.12 ± 49.48	126.17 ± 25.30	0.386	137.25 ± 32.71	150.01 ± 36.04	0.333	96.54 ± 10.49	103.66 ± 23.69	0.275

*Statistically significant difference

DS – Dominant shoulder; NDS – Non-dominant shoulder; CR – Conventional ratio; FR – Functional ratio

Table 3. Differences in the shoulder rotators' ratios between the dominant and non-dominant sides at T0.

T1	Weights group			Elastic band group			Control group		
	DS (Nm)	NDS (Nm)	p	DS (Nm)	NDS (Nm)	p	DS (Nm)	NDS (Nm)	p
CR | 60º/s	87.69 ±16.77	79.92 ± 10.02	0.087	91.05 ± 15.93	90.46 ± 8.50	0.923	93.82 ± 18.41	90.98 ± 14.82	0.705
FR | 60º/s	102.36 ± 18.98	87.60 ± 20.08	0.112	112.03 ± 22.30	108.90 ± 8.63	0.700	110.31 ± 25.47	113.70 ± 26.59	0.752
CR | 120º/s	85.12 ± 14.96	80.65 ± 8.38	0.381	91.45 ± 13.40	85.88 ± 6.92	0.307	93.46 ± 19.98	88.73 ± 16.36	0.542
FR | 120º/s	101.52 ± 15.91	90.45 ± 16.92	0.131	115.24 ± 30.65	111.90 ± 13.76	0.732	117.07 ± 25.94	112.67 ± 20.37	0.668
CR | 180º/s	88.99 ± 10.74	82.59 ± 9.21	0.083	95.93 ± 23.99	86.67 ± 10.70	0.336	91.97 ± 22.55	91.56 ± 16.58	0.966
FR | 180º/s	120.63 ± 33.92	101.78 ± 19.12	0.093	143.35 ± 55.79	122.40 ± 16.64	0.285	131.56 ± 28.94	122.73 ± 36.19	0.606

*Statistically significant difference

DS – Dominant shoulder; NDS – Non-dominant shoulder; CR – Conventional ratio; FR – Functional ratio

Table 4. Differences in the shoulder rotators' ratios between the dominant and non-dominant sides at T1.

CONCLUSIONS

- A preventive exercise program has a limited impact on enhancing shoulder rotators' strength symmetry between the dominant and non-dominant sides.
- The volume of water training combined with the cyclical and symmetrical nature of swimming are two factors that possibly explain the increase in strength symmetry and rotational ratios during the first 12 weeks of the swimming season.
- However, its implementation plays a significant role in improving muscle balance in swimmers' rotator cuff.
- Further studies are needed to explore how an athlete's body symmetry changes during the sports season and to determine the impact of specific interventions on this symmetry.

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U.PORTO FACULDADE DE DESPORTO UNIVERSIDADE DO PORTO

Impact of two dry-land exercise programs on the symmetry of shoulder rotator cuff strength and rotational muscle balance between dominant and non-dominant shoulders in swimmers

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[5] Centre of Mechanical Engineering, Materials and Processes (CEMMPRE), University of Coimbra, Coimbra, Portugal

Introduction

Applying similar force between the right and left sides can positively affect the swimmer's performance, particularly by promoting better body alignment, reducing drag, and lowering intracycle velocity variations [1,2]. Due to the competitive swimmers' high training volume, the presence of body imbalances is an important risk factor that increase the risk of overuse injuries, particularly in swimmers' shoulders [1,3,4]. Dry-land exercise programs improve some swimmers' shoulders musculoskeletal risk factors [5]. However, no information has been found about the effects of these preventive programs on strength symmetry between the dominant and non-dominant sides.

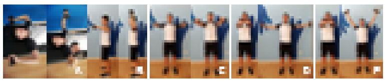
Purpose

To analyse the impact of two 12-week dry-land exercise programs on the symmetry of shoulder rotator cuff strength and rotational muscle balance between dominant and non-dominant shoulders in competitive swimmers.

Methods

- **Participants ►** The sample consisted of **30 competitive swimmers** with a mean age of 19.5 ± 3.1 years from 2 teams affiliated with the Portuguese Swimming Federation during the 2022/2023 season. The participants were randomly divided through stratified randomization according to the team, sex, and main swimming style into 3 groups: weights training program group (n = 10), elastic band training program group (n = 10), and control group (n = 10). The 3 groups exhibited homogeneity of variance (p > 0.05) concerning sample characterization and shoulder internal/external rotation peak torque at T0.

- **Experimental interventions ► Duration:** 2x a week for 12 weeks. **Characterization:** 2 sets of 10 reps of 5 exercises with 30s of rest time between sets. **Moment of realization:** Out of swimming training or before water training. **Material:** Domyos weights or Bodytone Power elastic bands. **Load:** 75% of 1RM. **Sessions:** Individual and monitored by a physiotherapist. **Progressions:** 6th week. Based on the quality of movement and RPE < 4.


Weights program group: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.


Elastic band program group: (A) IR at 90º, (B) ER at 90º, (C) Scapular punches, (D) T's, (E) Y's.

- **Control sham intervention ► Duration:** 2x a week for 12 weeks. **Characterization:** 2 sets of 10 reps of 5 exercises with 30s of rest time between sets. **Moment of realization:** Out of swimming training or before water training. **Sessions:** Coach-led group sessions. **Progressions:** No.


Control sham intervention: (A) Flexion-extension, (B) Horizontal abduction-adduction, (C) Internal-external rotation, (D) Clockwise circumductions, (E) Counterclockwise circumductions.

- **Data collection ► Instrument:** Isokinetic dynamometer Biodex System 3 (Biodex Medical Systems, NY, USA). **Evaluation moments:** Before (T0) and after (T1) 12 weeks of interventions and control procedures. **Start position:** Lying, 90º shoulder abduction, 90º elbow flexion, and with the hand palm facing the ceiling. **Analyzed movement:** 145º shoulder internal rotation followed by 145º shoulder external rotation (5 reps). **Analyzed actions:** Concentric and eccentric. **Angular velocity tests:** 60º/s, 120º/s, and 180º/s. **Main outcomes:** Peak torque (Nm) and conventional/functional ratios (%).

- **Data analysis ►** The collected data was filtered, windowed, and processed using **Acqknowledge 4.1 software**. All statistical analyses were conducted using **IBM SPSS Statistics 27 software**.

Results

T0	Weights group DS-NDS	p	Elastic band group DS-NDS	p	Control group DS-NDS	p
IR | con | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | ecc | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | con | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | ecc | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | con | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | ecc | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | con | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | ecc | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | con | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | ecc | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | con | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | ecc | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Differences in the rotators' peak torque between the dominant and non-dominant shoulders at T0.

T1	Weights group DS-NDS	p	Elastic band group DS-NDS	p	Control group DS-NDS	p
IR | con | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | ecc | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | con | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | ecc | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | con | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IR | ecc | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | con | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | ecc | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | con | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | ecc | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | con | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ER | ecc | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Differences in the rotators' peak torque between the dominant and non-dominant shoulders at T1.

T0	Weights group DS	NDS	p	Elastic band group DS	NDS	p	Control group DS	NDS	p
CR | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FR | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CR | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FR | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CR | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FR | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Differences in the shoulder rotators' ratios between the dominant and non-dominant sides at T0.

T1	Weights group DS	NDS	p	Elastic band group DS	NDS	p	Control group DS	NDS	p
CR | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FR | 60%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CR | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FR | 120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CR | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FR | 180%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Differences in the shoulder rotators' ratios between the dominant and non-dominant sides at T1.

Conclusions

- **A preventive exercise program has a limited impact on enhancing shoulder rotators' strength symmetry between the dominant and non-dominant sides.**
- **The volume of water training combined with the cyclical and symmetrical nature of swimming are two factors that possibly explain the increase in strength symmetry and rotational ratios during the first 12 weeks of the swimming season.**
- **However, its implementation plays a significant role in improving muscle balance in swimmers' rotator cuff.**
- **Further studies are needed to explore how an athlete's body symmetry changes during the sports season and to determine the impact of specific interventions on this symmetry.**

References

[1] Carvalho, D. D.; Soares, S.; Zacca, R.; Marinho, D. A.; Silva, A. J.; Pyne, D. B.; Vilas-Boas, J. P.; Fernandes, R. J. [illegible] *Int J Environ Res Public Health* 2020, 17(20).

[2] [illegible] *Sports Biomech* [illegible]

[3] [illegible] *Br J Sports Med* [illegible]

[4] [illegible] *Eur J Sport Sci* [illegible]

[5] [illegible] *J Sport Rehabil* [illegible]

APPENDIX E – Informed Consent

APRESENTAÇÃO DO ESTUDO DE INVESTIGAÇÃO PARA OBTENÇÃO DO CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO

Por favor, leia com atenção a seguinte informação. Se achar que algo está incorreto ou que não está claro, não hesite em solicitar mais informações. Se concorda com a proposta que lhe foi feita, queira assinar o documento de Consentimento informado livre e esclarecido.

Título do Estudo: **Efetividade de um programa de exercício terapêutico monitorizado à distância no torque dos músculos rotadores do ombro em nadadores federados.**

Este projeto está a ser desenvolvido por uma equipa de investigação do Laboratório RoboCorp I2a do Instituto Politécnico de Coimbra e da Faculdade de Desporto da Universidade do Porto.

O seu objetivo fundamental é verificar a efetividade de um programa de exercício terapêutico na redução das lesões no ombro em nadadores federados.

O procedimento experimental será feito durante 10 minutos, 2 vezes por semana, ao longo de 12 semanas. Ao longo destas 12 semanas existirão 3 momentos de avaliação da força dos músculos rotadores do ombro.

Todos os métodos utilizados são seguros, não existindo qualquer risco ou experiência dolorosa da sua utilização.

A confidencialidade e o anonimato dos dados serão garantidos. A identificação far-se-á por um código, não existindo em nenhum material de referência a dados de identificação.

Após análise de toda a informação recolhida, os dados serão guardados numa base de dados protegida por palavra-passe. Os dados recolhidos são para uso exclusivo do presente estudo, não existindo quaisquer interesses financeiros a motivar o estudo.

A sua participação é voluntária, não existindo nenhuma contrapartida financeira ou de outra natureza à sua participação. Em qualquer momento, poderá livremente recusar ou interromper a participação no estudo, sem qualquer tipo de penalização por este facto.

Este estudo não é financiado por qualquer bolsa ou fundo de investigação e mereceu a aprovação da Comissão de Ética do Politécnico de Coimbra.

Em nome da equipa de investigação do projeto, manifesto os nossos agradecimentos pela sua participação e manifesto a nossa disponibilidade para quaisquer esclarecimentos adicionais.

Investigador Principal do Projeto

Nome/ Categoria Profissional/Função e Unidade Orgânica do IPC e Contacto

Nuno Tavares / RoboCorp I2a | FADEUP / ftnunotavares@gmail.com ; 911170929

Assinatura do Investigador: Nuno André Santos Tavares **Data**: ___ / ___ / ______

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO PARA PARTICIPAÇÃO EM ESTUDO DE INVESTIGAÇÃO

De acordo com a Lei n.º 58/2019, de 8 de agosto, o RGPD e a Declaração de Helsínquia e a Convenção de Oviedo

Título do Estudo: **Efetividade de um programa de exercício terapêutico monitorizado à distância no torque dos músculos rotadores do ombro em nadadores federados**

Na qualidade de participante/representante legal do participante (riscar o que não interessa) no estudo acima referido, declaro que compreendi todos os objetivos da minha participação no mesmo, pelas informações verbais e escritas que me foram fornecidas pela equipa de investigação. Foi garantida a confidencialidade e anonimização dos dados, e a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências. Tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas. Desta forma, aceito de livre vontade a participação / daquele que legalmente represento (riscar o que não interessa), neste estudo e permito a utilização dos dados que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação, aceitando também a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Nome Completo: ____

Assinatura: ____ … Data: ____ /____ / ______

SE NÃO FOR O PRÓPRIO A ASSINAR POR IDADE /INCAPACIDADE

(se o menor tiver discernimento deve <u>também</u> assinar em cima, se consentir)

NOME: ____

BI/CC Nº: _________________________ DATA OU VALIDADE _____ /____ /_____

GRAU DE PARENTESCO OU TIPO DE REPRESENTAÇÃO: ____________________

ASSINATURA ____

ESTE DOCUMENTO É FEITO EM DUPLICADO:

UMA VIA PARA O INVESTIGADOR, OUTRA PARA QUEM CONSENTE

Politécnico de Coimbra

COMISSÃO DE ÉTICA
PARECER N.º 6_CEIPC_2022

Apreciação da proposta de projeto/Project proposal appreciation: "Efetividade de um programa de exercício terapêutico monitorizado à distância no torque dos músculos rotadores do ombro em nadadores federados / Effectiveness of a distance-monitored therapeutic exercise program on shoulder rotator muscle torque in federated swimmers"

A – RELATÓRIO

A.1. DOCUMENTOS PARA APRECIAÇÃO/DOCUMENTS FOR APPRECIATION:

1. Mod.CEIPC_PARE
2. Mod.CEIPC_CILE
3. Mod. CEIPC_DCH
4. Mod. CEIPC_TRO
5. Mod. CEIPC_CRONOGRAMA
6. Mod. CEIPC_DCPDI
7. Check List de Auto Avaliação
8. Curriculum do Investigador Principal
9. Curriculum do Orientador: https://orcid.org/0000-0002-1500-355X

A.2. RESUMO DO PROJETO/ PROJECT SUMMARY

This study will be conducted by a team from RoboCorp I2a of the Polytechnic Institute of Coimbra as part of the PhD in Physiotherapy at the Faculty of Sport of the University of Porto. According to the author information. *"Swimmer's shoulder, the most prevalent injury in swimming, is defined as a painful syndrome, which occurs mainly in the anterior region of the shoulder and results from the repeated impact of the rotator cuff on the coracoacromial arch during the swimming technique.*

According to existing studies, musculoskeletal risk factors related to shoulder pain in swimmers are: shoulder rotators strength, proprioception, posture, shoulder range of motion, scapular dyskinesia and ligament laxity or instability. Recently, it was found that shoulder rotators strength is the musculoskeletal risk factor with the greatest value for predicting this injury.

The shoulder rotators strength is normally assessed using the isokinetic dynamometer and the handheld dynamometer. Most of the time, investigators collecting peak torque of internal and external rotators and try to study muscle balance through conventional or functional ratios and between the right and left shoulder.

Exercise is described as one of the main tools used by the physiotherapist to minimize risk factors and thus reduce the prevalence of sports injuries. When analyzing the specific context of swimming, there seems to be a tendency for strength programs with few exercises, performed out of water and in open kinematic chain to lead to more significant improvements in the balance of the shoulder rotators muscles. However, these

1 de 1
Modelo CEIPC_PAREL_02

studies are highly heterogeneous and have a poor methodological quality, leading to the need for further studies to clarify and give greater scientific robustness to these conclusions. Furthermore, to authors' knowledge, there are no studies that assess if the preventive intervention effectively produces any change in the incidence and severity of swimmer's shoulder during a season.

Given the current pandemic context, remote exercise monitoring has had an exponential growth in the last year, being one of the main strategies to control the exercise performance. At the moment, little is known about the effectiveness of this type of monitoring compared to presential. Thus, it will be necessary to prepare new studies to have a concrete idea about the viability of this type of monitoring, which could be a resource with high use over the next few years."

The main objective of this research project is to verify, through a randomized controlled trial (RCT), the effectiveness of a remotely monitored preventive exercise program, during 12 weeks, on the torque of the external and internal shoulder rotator muscles in elite swimmers.

The secondary objectives are: 1) to identify, through a systematic review, the effectiveness of different therapeutic exercise programs reported in the scientific literature, in musculoskeletal risk factors related to swimmer's shoulder: muscle performance, proprioception, posture, shoulder range of motion, scapular dyskinesia and ligament laxity or instability. 2) To investigate, through a longitudinal observation study, the impact of a preventive therapeutic exercise program on the incidence of significant shoulder pain in swimmers during a season (± 9 months).

This investigation consists of 3 studies:
Study 1: Systematic review without metanalysis.
Study 2: RCT (principal study).
Study 3: Longitudinal observational study.

The sample consists of elite swimmers from four different clubs affiliates with the Portuguese Swimming Federation. To be included in the sample, participants must be federated swimmers aged between 18-35 years old and belong to a club affiliated in the Portuguese Swimming in 2021; have a minimum of 1 year of experience in national competitions; perform a minimum of 8 hours of weekly swim training and accept to participate in the study by filling out a Free and Informed Consent.

All individuals who have: a clinical history of significant shoulder pain in the last 6 months; a clinical history of traumatic shoulder injuries such as: fractures, subluxations or surgeries; a shoulder range of motion deficits, neurological injuries or simultaneously participate in another shoulder therapeutic program, will be excluded.

The sample with a minimum of 16 participants will be required. However, it is intended to integrate in this study 64 elite swimmers (divided into 2 groups of 32 athletes) from 4 different clubs affiliated with the Portuguese Swimming Federation. The experimental group will carry out a therapeutic exercise program before normal swimming training, while the control group will only do the normal swimming training. The intervention will consist of 5 strength exercises and should be performed 3 times a week for 12 weeks. Before water training, 3 sets of 10 repetitions of each exercise will be performed, with a rest time of 30 seconds between sets. Monitoring will be performed by a physiotherapist and carried out remotely through the Zoom platform. Each athlete will receive 3 theraband Domyos with 3 levels of difficulty: soft (blue), medium (brown) and hard (black). Over 12 weeks, the physiotherapist will be responsible for evaluating the quality of exercise and making the necessary progressions.

The principal investigator of the project will execute the evaluation of the torque of the external and internal shoulders rotators muscles at moments T0 (week 0), T1 (week 6) and T2 (week 12). Each athlete will be assessed in the sitting position and will be stabilized using velcro straps to avoid compensatory trunk movements. In the start position, each individual will be positioned at 90° shoulder abduction, 90° flexion elbow and with the hand palm facing the ground. From this position, we will evaluate 90° shoulder external rotation followed by 90° shoulder internal rotation. Before this assessment, the dynamometer axis will be aligned with the humerus longitudinal axis and the gravity action will be corrected with the upper limb relaxed. Each swimmer will perform 3 repetitions to 60/s and 180/s. Concentric and eccentric actions of the external and internal shoulder rotator muscles of both sides will be tested in a random order. Prior to this, 2 familiarization series will be carried out. During the assessment, verbal stimulation will be given to encourage the achievement of maximum strength. A 2 minutes rest will be preserved between different tests, velocities and sides. Interest outcomes will be collected in all tests performed.

After the principal study, the sample will be controlled during a season (± 9 months) through telephone calls, in order to record monthly episodes of clinically significant shoulder pain resulting from swimming which have led to an alteration or cessation of that sport activity. The severity of the occurrences will also be evaluated, as well as whether it happened in training or competition.

B – IDENTIFICAÇÃO DAS QUESTÕES COM EVENTUAIS IMPLICAÇÕES ÉTICAS/IDENTIFICATION OF ISSUES WITH POTENTIAL ETHICAL IMPLICATIONS

B.1. The Investigator will carry out this non-invasive research. All methods used are safe, with no risk or painful experience of their use.

B.2. The subjects' participation is voluntary, with no financial interests or conflicts of interest to declare.

B.3. The authors guarantee the confidentiality and anonymity of the data collected. The data collected are for the exclusive use of this study.

B.4. The investigators ensure that all responses will be coded, sensitive data not being collected and allowing for the identification of the individual. The data will be included in a password-protected database, with access restricted to researchers involved in this research work.

B.5. The proposed text contained in the Informed Consent Term (CILE), safeguards the principles of autonomy, confidentiality, anonymity and data security.

B.6. No request was made to another Ethics Committee, nor are there any declared conflicts of interest.

B.7. The author was asked to send the Models CEIPC_TRO and CEIPC_DCPD duly dated and signed, as well as to send a new schedule or guarantee that any work procedure, including data collection, will only start after the issuance of a favorable opinion by part of this Ethics Committee.

B.8. Additional clarifications were also requested on some points of the Mod. CEIPC_CHLAVET.

All additional information regarding points B.7 and B.8 was received by email on 19th December and can be consulted in attachment.

The study has scientific rigor and social merit.

C – CONCLUSÕES/CONCLUSIONS

Since the ethical assumptions related to research are safeguarded, under the terms of paragraph 2 of article 7 of the Regulation of the Ethics Committee of the IPC, I have nothing to oppose the development of the aforementioned project.

DECISION: UNANIMOUSLY DEFERRED, at a meeting on 4th January 2022.

O/A Relator/a: Carla Matos Silva

Carla Matos Silva

O/A Presidente da CEIPC:

Assinado por: **Adelino Manuel Moreira dos Santos**
Num. de Identificação: BI03327047
Data: 2022.01.07 11:04:56+00'00'

CHAVE MÓVEL