



**EFFECT OF ISOMETRIC EXERCISES ON RECTIFYING UPPER BODY
MUSCLE IMBALANCE AMONG YOUNG ELITE BADMINTON PLAYERS**

By

GASIBAT QAIS MUSTAFA MOHAMED

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of
Philosophy**

April 2024

FPP 2024 6

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of the material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Doctor of Philosophy

EFFECT OF ISOMETRIC EXERCISES ON RECTIFYING UPPER BODY MUSCLE IMBALANCE AMONG YOUNG ELITE BADMINTON PLAYERS

By

GASIBAT QAIS MUSTAFA MOHAMED

April 2024

Chairman : Borhannudin bin Abdullah, PhD
Faculty : Educational Studies

This study examined the effect of isometric exercise on muscle imbalance in young elite badminton players. The experimental research design was performed using pre-test-post-test methodologies. Approximately 80 participants in this study were Malaysian male ($N = 42$) and female ($N = 38$) elite badminton players. These participants demonstrated an average age and maturity level of 14.74 years and 2.05 Peak Height Velocity, respectively. Initially, the participants were assigned using random sampling into two groups. These groups then proceeded with their respective physical training routines. The experimental group followed a 12-week internal and external rotation isometric exercise regimen. Each exercise consisted of 5 repetitions, 5 s of hold, and 5 s of relaxation. This exercise was repeated for three sets (with a 1 min rest between sets) and was performed 3 times per week. Meanwhile, the physical training routines from the intervention conducted by the experimental group were ensured to be distinct in this study. The researcher then closely monitored and regulated both groups during the

experimental duration. The non-dominant shoulder's internal and external rotation isometric exercises were only demonstrated for the experimental group. This study encompassed three key measurements: pre-test data collected before any intervention, post-test1 data after 4 weeks of isometric exercises (12 sessions), and post-test2 data after 12 weeks of isometric exercises (36 sessions). A MicroFET®2 digital handheld dynamometer was then employed to conduct the muscle imbalance assessment concerning the internal and external rotations of the dominant and non-dominant shoulders. The data were collected at a specialised facility in the Kuala Lumpur Badminton Association, Bukit Kiara, Kuala Lumpur, Malaysia, which was tailored explicitly for elite badminton players. Consequently, the muscle imbalance variables demonstrated a significant effect (p -value = 0.000) while possessing the most substantial influence within the model (η^2 = 0.903). Subsequent analysis indicated that both post-test 1 and post-test 2 positively influenced muscle imbalance (p -value = 0.000; η^2 = 0.791). Furthermore, the players exhibited a significant decrease in muscle imbalance ratios (p -value = 0.000; η^2 = 0.807) during this study. These ratios were also improved by the participation of the players in the experimental group. Meanwhile, the within-subject effect tests (assuming sphericity) revealed a significant impact of isometric exercise variables on muscle imbalance (p -value = 0.000; η^2 = 0.762). Both groups involving the between-subject effect tests also significantly impacted the intervention, accounting for 43.4% of the variance (p -value = 0.000; η^2 = 0.434). Therefore, the isometric exercises substantially affected muscle imbalance (p -value = 0.000; η^2 = 0.769). The pairwise comparisons test also revealed a substantial influence of isometric exercises in post-test 1 and

post-test 2 on muscle imbalance (p -value = 0.000). Compared with the control group (p -value = 0.000), this study established a positive and significant interaction between isometric exercise repetitions and muscle imbalance within the experimental group. Overall, the findings concluded that isometric exercises could significantly decrease muscle imbalance. Even after just 4 weeks of the intervention, the isometric exercises positively and significantly influenced the treatment group.

Keyword: Athletic Training, Exercise Physiology, Injury Prevention, Isometric Exercises, Muscle imbalance

SDG: GOAL 3: Good Health and Well-Being

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**KESAN LATIHAN ISOMETRIK PADA MEMPERBAIKI
KETIDAKSEIMBANGAN OTOT BADAN ATAS DI KALANGAN PEMAIN
BADMINTON REMAJA ELIT**

Oleh

GASIBAT QAIS MUSTAFA MOHAMED

April 2024

Pengerusi : Borhannudin bin Abdullah, PhD
Fakulti : Pengajian Pendidikan

Kajian ini mengkaji kesan senaman isometrik terhadap ketidakseimbangan otot dalam kalangan pemain badminton remaja elit. Reka bentuk kajian eksperimen dilakukan menggunakan metodologi ujian pra-ujian-pasca-ujian. Seramai 80 peserta dalam kajian ini adalah pemain badminton remaja elit lelaki Malaysia ($N = 42$) dan wanita ($N = 38$). Peserta ini menunjukkan purata umur dan tahap kematangan masing-masing 14.74 tahun dan 2.05 (*peak height velocity*). Pada mulanya, peserta telah diasingkan menggunakan pensampelan rawak kepada dua kumpulan. Kumpulan ini kemudiannya meneruskan rutin latihan fizikal masing-masing. Kumpulan eksperimen ini mengikuti program latihan isometrik *internal and external rotation* selama 12 minggu. Setiap latihan terdiri daripada 5 kali ulangan, 5 saat tahan, dan 5 s saat rehat. Latihan ini diulang selama tiga set (dengan rehat 1 minit antara set) dan dilakukan tiga kali seminggu. Sementara itu, rutin latihan fizikal daripada intervensi yang dijalankan oleh kumpulan eksperimen dipastikan berbeza

dalam kajian ini. Penyelidik kemudian memantau dan mengawal selia kedua-dua kumpulan dengan teliti semasa tempoh kajian. Latihan isometrik *internal and external rotation* bahu bukan dominan hanya ditunjukkan untuk kumpulan eksperimen sahaja. Kajian ini merangkumi tiga ukuran utama: data ujian pra yang dikumpul sebelum sebarang intervensi, data pasca ujian 1 selepas empat minggu latihan isometrik (12 sesi) dan data ujian pasca 2 selepas 12 minggu latihan isometrik (36 sesi). Dinamometer digital pegangan tangan MicroFET®2 kemudiannya digunakan untuk menjalankan penilaian ketidakseimbangan otot berkenaan *internal and external rotation* bahu dominan dan bukan dominan. Data dikumpul di Persatuan Badminton Kuala Lumpur, Bukit Kiara, Kuala Lumpur, Malaysia, iaitu kemudahan khusus yang disesuaikan secara eksplisit untuk pemain badminton elit. Akhirnya, pembolehubah ketidakseimbangan otot menunjukkan kesan yang signifikan (nilai $p = 0.000$) manakala mempunyai pengaruh yang paling besar dalam model ($\eta^2 = 0.903$). Analisis seterusnya menunjukkan bahawa kedua-dua ujian pasca 1 dan ujian pasca 2 mempengaruhi ketidakseimbangan otot secara positif (nilai $p = 0.000$; $\eta^2 = 0.791$). Tambahan pula, pemain menunjukkan penurunan ketara dalam nisbah ketidakseimbangan otot (nilai $p = 0.000$; $\eta^2 = 0.807$) sepanjang kajian ini berlangsung. Nisbah ini juga telah diperbaiki dengan penglibatan pemain melalui kumpulan eksperimen. Sementara itu, ujian kesan dalam subjek (dengan andaian *sphericity*) mendedahkan kesan signifikan pembolehubah senaman isometrik terhadap ketidakseimbangan otot (nilai $p = 0.000$; $\eta^2 = 0.762$). Kedua-dua kumpulan yang terlibat ujian kesan antara subjek juga memberi impak yang signifikan terhadap intervensi, menyumbang sebanyak 43.4% daripada varians (nilai $p = 0.000$; $\eta^2 = 0.434$).

Oleh itu, latihan isometrik memberi kesan ketidakseimbangan otot dengan signifikan (nilai $p = 0.000$; $\eta = 0.769$). Ujian perbandingan berpasangan juga mendedahkan pengaruh besar latihan isometrik dalam ujian pasca 1 dan ujian pasca 2 terhadap ketidakseimbangan otot (nilai $p = 0.000$). Berbanding dengan kumpulan kawalan ($p\text{-value} = 0.000$), kajian ini mewujudkan interaksi yang positif dan signifikan antara ulangan senaman isometrik dan ketidakseimbangan otot dalam kumpulan eksperimen. Secara keseluruhan, penemuan menyimpulkan bahawa latihan isometrik boleh mengurangkan ketidakseimbangan otot dengan signifikan. Walaupun selepas hanya empat minggu intervensi, latihan isometrik secara positif dan signifikan mempengaruhi kumpulan rawatan.

Kata kunci: Fisiologi Senaman, Ketidakseimbangan Otot, Latihan Atletik, Pencegahan Kecederaan, Senaman Isometric

SDG: *MATLAMAT 3: Kesihatan dan Kesejahteraan Yang Baik*

ACKNOWLEDGEMENTS

My sincere gratitude and appreciation go to my dear supervisor and mentor, Dr. Borhannudin bin Abdullah, for his professional guidance, insightful help, academic support, and comments that made this outcome achievable. Without his help, encouragement, and patience, I could not finish this research. Dr. Borhannudin bin Abdullah has encouraged me to go further than only research during my PHD lifetime. He has encouraged me to publish articles and participate in conferences where I could meet many featured experts in the fields of my academic interests. Furthermore, I want to express gratitude to my committee member, Dr. Shamsulariffin bin Samsudin, for his guidance, passion, and extensive contributions to my dissertation. He offered me precious intellectual input. Without his comments and assistance, I would not have been successful. In addition, I express my appreciation to Dr. Nasnoor Juzail bin Mohd for his help, intellectual support, and comments, which helped me in writing my proposal and submitting it to the faculty. Without his help, I would not have been able to register for my PhD and complete this dissertation. My sincere appreciation also goes to all the badminton players involved in this experimental study as well as the Kuala Lumpur badminton association that helped me train and collect data from their athletes.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Borhannudin bin Abdullah, PhD

Senior Lecturer
Faculty of Educational Studies
Universiti Putra Malaysia
(Chairman)

Shamsulariffin bin Samsudin, PhD

Senior Lecturer
Faculty of Educational Studies
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD

Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 August 2024

TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	iv
ACKNOWLEDGMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xv
LIST OF FIGURES	xvii
LIST OF ILLUSTRATIONS	xviii
LIST OF APPENDICES	xix
LIST OF ABBREVIATIONS	xx
 CHAPTER	
 1 INTRODUCTION	 1
1.1 Introduction	1
1.2 Background of the Study	1
1.3 Significance of the Study	4
1.4 Statement of the Problems	5
1.5 Scope of the Study	8
1.6 Objectives	11
1.7 Research Questions	11
1.8 Limitations	11
1.9 Delimitation	13
1.10 Operational Definition of Terms	14
1.10.1 Anatomical Shoulder Movement	14
1.10.2 Shoulder Strength Imbalance	15
1.10.3 Dominant and Non-dominant Hands	17
1.10.4 Isometric Exercises	18
1.10.5 Maturity	19
1.11 Conclusion	21
 2 LITERATURE REVIEW	 22
2.1 Introduction	22
2.2 Badminton Injuries	22
2.3 Muscle Imbalance	25
2.4 Biomechanics of the Shoulder Joint	28
2.5 Imbalanced Muscle Physiology	31
2.6 Effects of Gender and Maturity on Muscle Imbalance	35
2.7 Influence of Gender and Maturation on Exercise	38
2.8 Previous Studies	45
2.9 The Effectiveness of Isometric Exercise Programme	53
2.10 Theoretical Framework	57
2.11 Conceptual Framework	60
2.12 Conclusion	64

3	METHODOLOGY	65
3.1	General Overview	65
3.2	Research Design	65
3.3	Participants	66
3.4	Instruments Used in the Study	70
3.4.1	Hand-held Dynamometer	71
3.4.2	Portable Massage Table	72
3.4.3	Anthropometric Measurements	73
3.5	Experiment Procedure	74
3.5.1	Pre-test	78
3.5.2	Internal and External Rotation Strength Test	78
3.5.3	Intervention Programme (Experimental Group)	80
3.5.4	Post-Test	82
3.6	Data Analysis	83
3.6.1	Independent Samples t-test	84
3.6.2	ANOVA	86
3.6.3	Two-way ANOVA with Repeated Measures	89
3.6.4	MANOVA	91
3.7	Conclusion	95
4	DATA ANALYSIS	97
4.1	Introduction	97
4.2	Normality and the Assumption Test	97
4.2.1	Normality	98
4.2.2	Homogeneity Test	99
4.2.3	Demographic Characteristic of the Respondents	100
4.2.4	Comparison of Pre-data	101
4.3	Research Question 1	103
4.4	Research Question 2	115
4.5	Research Question 3	119
4.6	Research Objective 4	123
4.7	Conclusion	128
5	DISCUSSION	130
5.1	Introduction	130
5.2	Critical Discussion of Findings Based on the Research Objectives	130
5.2.1	Objective 1: To Identify the Level of Muscle Imbalance of Shoulder Movement in Young Elite Badminton Players	131
5.2.2	Objective 2: To Determine the Effects of Isometric Exercises on the Non-dominant Shoulder Ratio between Gender and Maturation Levels	134
5.2.3	Objective 3: To Determine the Effect of the Fourth and Twelfth Weeks of Isometric Exercises on Muscle Imbalance between the Experimental and Control Groups	141
5.2.4	Objective 4: To Determine the Effect of Gender and Maturation Factors on Isometric Exercises	146
5.3	Conclusion	153

6	SUMMARY, RECOMMENDATIONS, IMPLICATION OF STUDY AND CONCLUSION	154
6.1	Introduction	154
6.2	Research Summary	154
6.3	Recommendations	156
6.3.1	Implementation and Progressive Shoulder Strengthening Programme	157
6.3.2	Individualise Training Based on Gender and Maturity Status	157
6.3.3	Emphasis on Proper form and Technique	159
6.3.4	Following a Multidisciplinary Approach in Collaboration with Trainers, Physiotherapists, and Sport Medicine Professionals	159
6.3.5	Gradual Progression of Exercises	161
6.3.6	Management Training and Gap Identification	161
6.3.7	Training Progression	163
6.3.8	Gender-Based Training Needs	164
6.3.9	Modification of the Training Policies and Compliance System	164
6.4	Implications and Strengths of the Study	165
6.4.1	Implications of the Study	165
6.4.2	Strengths of the Study	166
6.5	Conclusion	167
	REFERENCES	170
	APPENDICES	198
	BIODATA OF STUDENT	209
	LIST OF PUBLICATIONS	210

LIST OF TABLES

Table	Page
2.1 Occurrence of Muscle Imbalance in Overhead Sports in Previous Studies	50
3.1 Isometric Shoulder External and Internal Rotation Exercises	81
4.1 Normality Test for Shoulder Movement Data	99
4.2 Test of Homogeneity of Variance	100
4.3 Descriptive Demographic Characteristics of the Respondent	101
4.4 Descriptive Analysis of Muscle Imbalance Level on Shoulder Movement (Gender)	107
4.5 Descriptive Analysis of Muscle Imbalance Level on Shoulder Movement (Maturity Status)	113
4.6 Descriptive Analysis of Non-Dominant Shoulder on Gender towards Pre-test, Post-test 1, and Post-test 2	115
4.7 Analysis of Non-Dominant Shoulder Comparison between Genders across Pre-test, Post-test 1, and Post-test 2	116
4.8 Descriptive Analysis of Non-Dominant Shoulder on Maturity Status towards Pre-test, Post-test 1, and Post-test 2	117
4.9 Comparison of Non-Dominant Shoulder between Maturity Status towards Pre-test, Post-test 1, and Post-test 2	118
4.10 Comparison between Maturity Status towards Pre-test, Post-test 1, and Post-test 2 using Tukey HSD	118
4.11 Descriptive Analysis of Isometric Exercises on Muscle Imbalance between Experimental and Control Group	120
4.12 Analysis of Two-Way ANOVA Repeated Measurement Effect of 4 th and 12 th Weeks on Isometric Exercises towards Muscle Imbalance	121
4.13 Test of Within-Subject Effects Test	122
4.14 Test of Between-Subjects Effects (Experimental group vs Control Group)	123
4.15 Multiple Pairwise Comparisons of Muscle Imbalance and Post-test 1 vs Post-test 2	123

4.16	Analysis of MANOVA for Gender and Maturity Status at 12 Weeks of the Intervention	125
4.17	Analysis of MANOVA to Determine Changes in 4 th and 12 th Week Intervention Influenced Gender and Maturity Status between Subjects	126



LIST OF FIGURES

Figure	Page
2.1 Theoretical Framework of Muscle Imbalance by the Janda Approach	59
2.2 Conceptual Framework of Muscle Imbalance	61
3.1 Experimental Procedure	75
4.1 Mean Difference in Non-dominant Shoulder between Gender towards Pre-test, Post-test 1, and Post-test 2	116
4.2 Mean Difference between Maturity Status towards Pre-test, Post-test 1, and Post-test 2	119
4.3 Marginal Mean Different for Non-dominant Shoulder	123
4.4 Analysis of MANOVA for Gender on Both Groups	127
4.5 Analysis of MANOVA to Determine Changes in 4 th and 12 th Week Intervention Influenced by Maturity Status	128

LIST OF ILLUSTRATIONS

Illustration	Page
3.1 Shoulder External Rotation Measurement	80
3.2 Shoulder Internal Rotation Measurement	80
3.3 Isometric Shoulder External Rotation	81
3.4 Isometric Shoulder Internal Rotation	82



LIST OF APPENDICES

Appendix	Page
A G-POWER	198
B Approval Letter	199
C 2022 PAR-Q+	201
D Physical Training Routines for Badminton	205
E Assessment Form	207



LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
BMI	Body Mass Index
EMG	Electromyography
FET	Force Evaluation and Testing
HHD	Hand-Held Dynamometry
HSD	Tukey's Honestly Significant Difference
ICC	Intraclass Correlation Coefficient
LBP	Low Back Pain
MRI	Magnetic Resonance Imaging
NMQ	Nordic Musculoskeletal Questionnaire
PAR-Q	Physical Activity Readiness Questionnaire
PHV	Peak Height Velocity
POST1DER	Post-Test 1 Dominant External Rotation
POST1DER/IR	Post-Test 1 Dominant Ratio
POST1DIR	Post-Test 1 Dominant Internal Rotation
POST1NDER	Post-Test 1 Non-Dominant External Rotation
POST1NDER/IR	Post-Test 1 Non-Dominant Ratio
POST1NDIR	Post-Test 1 Non-Dominant Internal Rotation
POST2DER	Post-Test 2 Dominant External Rotation
POST2DER/IR	Post-Test 2 Dominant Ratio
POST2DIR	Post-Test 2 Dominant Internal Rotation
POST2NDER	Post-Test 2 Non-Dominant External Rotation
POST2NDER/IR	Post-Test 2 Non-Dominant Ratio

POST2NDIR	Post-Test 2 Non-Dominant Internal Rotation
PREDER	Pre-Test Dominant External Rotation
PREDER\IR	Pre-Test Dominant Ratio
PREDIR	Pre-Test Dominant Internal Rotation
PRENDER	Pre-Test Non-Dominant External Rotation
PRENDER\IR	Pre-Test Non-Dominant Ratio
PRENDIR	Pre-Test Non-Dominant Internal Rotation
ROM	Range of Motion
SRD	Smallest Real Difference
SSC	Stretch-Shortening Cycle
USTA	United States Tennis Association

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, the researcher details the study's concentration on imbalance in shoulder muscles among young elite badminton players. This study explores the importance of athletic performance and injury avoidance, laying the groundwork for a thorough investigation of the causes, treatments, and physiological aspects of muscle imbalance.

1.2 Background of the Study

The weaker side of the body may overcompensate and engage incorrect muscles if the stronger or larger side of the body and trigger malregulation by the central nervous system, which has been hypothetically proven by the Janda approach (Kim et al., 2019; Fernández-Martínez et al., 2021).

The probability of encountering muscle imbalance significantly increases among athletes who exclusively engage in one-sided sports such as squash, badminton, and water polo (Virgile & Bishop, 2021; Arora et al., 2015; Tülin et al., 2019). In the context of badminton, similar to other racket sports, players frequently undergo cycles of intense, short-term bursts of maximal or

submaximal effort, interspersed with brief resting intervals, as outlined by Olivier and Daussin (2019).

Current research fails to adequately address fundamental movements essential to overhead sports, particularly focusing on the internal and external rotation of the shoulder (Edouard et al., 2013; Avrahami & Potvin, 2014; Sung et al., 2016). Weakness in these movements has been consistently linked to an increased risk of shoulder injuries, given their crucial role in strengthening the rotator cuff muscles (Kim, 2015; Paterno et al., 2013; Dodds et al., 2020; Freitas et al., 2021).

Hadzic et al. (2014) emphasised that overhead athletes face a heightened injury risk if their dominant shoulder exhibits a 9% greater internal rotation strength and a 14% greater external rotation strength than their non-dominant shoulder. Despite the literature recognising a 15% bilateral strength differential as indicative of an imbalance, there has been limited investigation into addressing strength disparities within specific muscle groups (Tatlici et al., 2021; Freitas et al., 2021).

Stausholm et al. (2021) found that adolescent badminton players display greater shoulder external rotation strength than adults, indicating a decline in this strength with age among elite players. However, studies on gender-specific training methods and their impact on intervention programme design are lacking (Kim & Deshpande, 2017; Rahrovan et al., 2018). Both male and female players exhibited reduced overall Range of Motion (ROM) in their

dominant shoulder compared with their non-dominant shoulder (Couppé et al., 2014). Interestingly, female athletes showed increased strength in the internal rotation of their dominant side compared with their non-dominant side. Conversely, male athletes presented an unexpected finding, there was no discernible difference in rotational strength between their dominant and non-dominant sides (Couppé et al., 2014; Kamalden & Gasibat, 2021; Guney et al., 2016; Kamalden et al., 2021; Edouard et al., 2013).

Isometric exercises have gained recognition as safe and effective methods for strengthening muscles and alleviating pain (Anastasio, 2020; Pearson et al., 2020). Balasch-Bernat et al. (2021) found that isometric exercises had no discernible impact on pain sensitivity. This suggests that individuals can engage in isometric exercises without worsening pain. This indicated that isometric exercises can be tailored to target specific shoulder issues, offering a more targeted approach to pain management (Alsouhibani et al., 2019; Lum & Barbosa, 2019).

Despite the popularity of isometric exercises among coaches, a lack of comprehensive research hampers a full understanding of their implications for muscle imbalance, biomechanical changes, and injury prevention (Kaldau et al., 2021; Mussa et al., 2021; Giuliano et al., 2017; Yoon et al., 2015). The present study aims to fill this gap by addressing the necessity for proper training of sports professionals to optimise training regimes and cater to the specific requirements of elite athletes. The conventional recommendation involves performing 1–3 sets of 5–10 repetitions of isometric contractions lasting at least 5 s with a moderate to high level of force (Izraelski, 2012). This

regimen is typically conducted 3 times per week and serves to activate tonic muscle function, enhance strength, and prepare the patient for more dynamic exercises, as described by Izraelski in 2012.

1.3 Significance of the Study

The benefit of unilateral exercises is the ability to train both sides of the body equally. It prevents overusing, overtraining, or compensating with the dominant side, which helps to isolate and correct muscle imbalance and can aid in injury prevention and rehabilitation. Furthermore, focussing on shoulder health and strengthening may help reduce the occurrence of injuries in this specific muscle imbalance group.

Furthermore, this study holds promise for injury prevention. By focussing on shoulder health and strengthening, it may help reduce the occurrence of injuries in this specific athlete group. This is especially crucial for elite athletes whose livelihoods depend on their physical condition and performance consistency.

Another noteworthy aspect of this research is its exploration of how different factors, including gender and maturation levels, impact the effectiveness of exercise protocols. This approach promotes the development of personalised training plans, ensuring that each athlete's unique needs are met. This level of customisation not only benefits badminton players but also serves as a model for tailored training across various sports and activities.

In addition to its immediate applications in the sporting arena, this study contributes to a broader understanding of shoulder health. The insights gained may have far-reaching effects, benefiting individuals engaged in various exercises, from recreational sports fans to those seeking to maintain shoulder health in their daily lives.

In summary, the significance of this study lies in its potential to elevate athletic performance, reduce injuries, offer customised training, and contribute to the broader knowledge of shoulder health. This aims to enhance the well-being and performance not only of elite badminton players but also of individuals seeking to maintain healthy and pain-free shoulders, ultimately impacting the quality of life for a diverse range of people.

1.4 Statement of the Problems

The present study investigates the hypothesis that tendinopathies in youth sports may result from unequal adaptation of muscle and tendon, potentially influenced by increased sex hormone levels in developing athletes (Ishikawa et al., 2023). The rise in tendon overuse injuries among underdeveloped athletes further underscores the importance of understanding imbalance in muscular strength and tendon mechanics. Guermont et al. (2023) suggested that temporal dynamics and responsiveness to mechanical stimuli contribute to imbalanced musculotendinous development, creating a need for a more comprehensive investigation.

Stausholm et al. (2021) revealed that adolescent badminton players exhibit greater shoulder external rotation strength than adults, suggesting an age-related decline in this strength among elite players. However, gender-specific training methods and their influence on the intervention programme design remain understudied. This study aims to fill this gap by focussing on muscle imbalance in one-sided sports such as badminton, squash, and water polo (Tülin et al., 2019), particularly delving into gender-specific training methods and their impact on muscle imbalance.

While acknowledging the role of age-related factors in muscle imbalance (Malina et al., 2021; Yaprak, 2020), there is a lack of comprehensive studies exploring how growth phases, hormonal changes, and neurological adaptations influence imbalance in muscles and biomechanics. This study aims to provide a deeper understanding of how these factors interact in the context of players' overall performance and maturation levels.

Addressing strength imbalance within specific muscle groups has received limited scrutiny despite the literature recognising 15% bilateral strength differential as constituting an imbalance (Tatlici et al., 2021). This study explored effective exercises for rotator cuff muscle imbalance, following the prevailing notion that the intervention should exclusively target the non-dominant side (Kamalden & Gasibat, 2021; Tülin et al., 2019).

Existing research lacks consideration for fundamental movements crucial to overhead sports, particularly the internal and external rotation of the shoulder,

as their weakness has been empirically linked to a heightened risk of shoulder injuries, and they play a pivotal role in bolstering the rotator cuff muscles (Pennock et al., 2018; Hams et al., 2019; Hadzic et al., 2014; Wdowski & Gittoes, 2020; Clarsen et al., 2014). Hadzic et al. (2014) highlighted that an overhead athlete is at greater risk of having an injury if their internal rotation in the dominant shoulder is 9% stronger than that in the non-dominant shoulder and 14 % of external rotation in the dominant shoulder is stronger than that in the non-dominant shoulder. This research seeks to fill this void by investigating particular exercises that address these rotations, aiming to diminish the risk of injuries in a range of overhead sports. This expands beyond the golf-centered perspective presented by Sung et al. (2016) and water polo considerations by Nekooei et al. (2021).

Isometric exercises have been established as secure and efficient techniques for fortifying muscles and mitigating discomfort (Anastasio, 2020; Pearson et al., 2020; Izraelski, 2012). Based on this notion, the current study emphasises isometric internal and external shoulder exercises as a novel strategy to address muscle imbalance in overhead sports such as badminton, where there is a notable absence of prior studies.

Despite the popularity of isometric exercises among coaches, a lack of comprehensive research obstructs a full understanding of their implications for muscle imbalance, biomechanical changes, and injury prevention (Kaldau et al., 2021; Mussa et al., 2021; Giuliano et al., 2017; Yoon et al., 2015). The current study also addresses the need for proper training of sports

professionals to optimise training regimes and cater to the specific requirements of elite athletes.

1.5 Scope of the Study

This study evaluates shoulder muscle imbalance among young elite badminton players. It involves measuring shoulder strength differences and exploring the effectiveness of the internal and external rotation isometric exercises specifically targeted at the non-dominant shoulder after 4 and 12 weeks. This investigation explores how exercise outcomes are influenced by gender and maturation levels. Furthermore, the study assesses the impact of exercise durations, specifically 4 and 12 weeks, on muscle imbalance, providing valuable insights into the optimal exercise duration for addressing this concern.

Gender plays a substantial role in neuromuscular control, and females typically demonstrate superior control and proprioception compared with males (Khowailed & Lee, 2021; Zemková & Zapletalová, 2022). This phenomenon has the potential to mitigate strength imbalances to a certain extent. Nevertheless, the interplay among gender, neuromuscular control, and muscle imbalance is intricate and susceptible to various factors such as individual training backgrounds and the unique demands imposed by different sporting activities.

Muscle imbalances manifest prominently among adolescent athletes owing to the swift growth and developmental changes characteristic of this phase. Such growth dynamics intricately influence muscle physiology and coordination, particularly given the individual variances in skeletal maturation, thereby presenting hurdles in muscular adaptation (Geng et al., 2023; Boyce & Schoenfeld, 2022). This concern assumes heightened significance within sports characterised by repetitive and strenuous movements.

Studies focusing on overhead athletes, particularly female participants, elucidated distinctions in shoulder strength between competitive athletes and non-competitive counterparts. Notably, despite comparable agonist and antagonist ratios, female athletes exhibited heightened shoulder torque, underscoring the critical role of shoulder strength and equilibrium in optimising athletic performance (Lin et al., 2015; Alarab et al., 2019).

Physical therapists frequently employ isometric exercises in shoulder rehabilitation protocols due to their controlled nature, although caution is warranted regarding resistance levels, particularly during the initial stages of post-injury recovery. Isometric exercises have garnered attention for their efficacy in managing tendon pain, with several studies demonstrating significant pain alleviation compared to isotonic exercises, thus advocating their inclusion in early-stage recovery regimens (Holden et al., 2020; O'Neill et al., 2019). Overall, isometric exercises have exhibited superior effectiveness over isotonic exercises in pain reduction, intensity augmentation, and facilitation of swifter functional improvements, rendering them invaluable tools

in the rehabilitation and conditioning of athletes and individuals grappling with musculoskeletal issues.

The research also considers varied factors, including gender and maturation levels, as potential influences on the effectiveness of the internal and external rotation isometric exercises in reducing muscle imbalance. In summary, this comprehensive study aims to clarify muscle imbalance in young elite badminton players and the effectiveness of tailored isometric exercise protocols while considering the potential impact of gender and maturation factors. Ultimately, the findings will inform the development of a customised intervention to enhance shoulder health and performance within this specific athlete population.

The pre-test–post-test design involves measuring variables before and after the intervention, allowing for an understanding of cause-and-effect relationships (Wang et al., 2020). This approach is discussed in comparison to classical experimental designs, highlighting its relevance in human services and education evaluation, while also addressing potential threats to internal validity, concerns about external validity, and strategies to enhance the design (Siregar, 2021).

In this specific study, the researcher examined the effects of 12 weeks of internal and external rotation isometric exercises on the non-dominant shoulder (with post-tests conducted in the 4th and 12th weeks) among elite badminton players. The experimental group underwent 36 sessions, 3 times

per week, to assess the impact on shoulder strength imbalances (Siregar, 2021).

1.6 Objectives

- To identify muscle imbalance levels in shoulder movements among young elite badminton players.
- To determine the differences of isometric exercises on the non-dominant shoulder ratio between gender and maturation levels.
- To determine the effect of the fourth and twelfth weeks of isometric exercises on muscle imbalance between the experimental and control groups.
- To determine the effect of gender and maturation factors on isometric exercises.

1.7 Research Questions

- What is the level of muscle imbalance in shoulder movement among young elite badminton players?
- What are the differences in isometric exercises on the non-dominant shoulder ratio between gender and maturation levels?
- What are the effects of the fourth and twelfth weeks of isometric exercises on muscle imbalance between the experimental and control groups?
- What are the effects of gender and maturation factors on isometric exercises?

1.8 Limitations

Research limitations are weaknesses or gaps in the study that may not necessarily facilitate enriched data outcomes. In this context, despite the major

benefits that the research has generated, it has a few limitations that need to be addressed by future researchers. First, the present study exclusively included junior elite badminton players, identified as competitive-elite athletes by Swann et al. (2015). Therefore, the study's findings may be extrapolated to encompass other levels of badminton players.

Second, during the intensive intervention procedure, there might be scenarios where the participants might produce inconsistent delivery of performances due to psychophysiological elements associated with human performance, which is beyond the control of the researcher. However, players are highly encouraged to perform their best throughout the data collection process. These limitations are obvious because the human intervention is always subject to changes based on preferences and the likelihood of putting their maximum effort into the study process. The limitations identify conditions and circumstances that may influence or restrict the research data methods and analysis. In this study, the limits were uncontrollable.

In accordance with prior scholarly investigations, the measurement or inclusion of physical activity or physical fitness in the non-dominant body side has been infrequent due to its perceived limited impact on interventions. This neglect is evident in the studies conducted by Sung et al. (2016) and Malliou et al. (2004), in which such variables were seldom measured or tested. The predominant focus in past research has been on assessing the efficacy of isometric exercise interventions with regard to factors such as body part movement, maturation level, gender, and similar considerations. Consequently, in alignment with the

precedent set by Sung et al. (2016) and Malliou et al. (2004), the present study similarly refrains from designating physical activity as a variable of interest.

1.9 Delimitation

In each piece of research, delimitations are considered to be the boundaries that are set by researchers, which include what is to be included and what should be excluded (Gossel, 2022). In this study, the following delimitation considerations were set and stringently followed throughout the research process. Participants enrolled in the intervention process have not been allowed to take any kind of supplements during the timeframe. The participants have also not been allowed to undergo any forms of strength-based training other than the specific intervention used in the research.

Despite the expanding number of studies in this field, the question of what constitutes an acceptable control for physical activity remains unanswered. Participants in studies on the impact of physical activity are aware of the physiological challenges to which they are subjected. As a result, participants could fully commit to the process considering the potential benefit they may drive from it (Boot et al., 2013; Green et al., 2014). Similarly, it is critical to recognise the possibility of bias imposed because of physical demand characteristics. If participants establish an opinion about the experiment's hypothesised outcome, they may subconsciously change their behaviour to meet the hypothesis (Devine & Ash, 2022). Thus, in the current study, all participants were allowed to continue with their regular training routine or

physical activity, and the researcher was prohibited from altering the training programme in any manner that could compromise its synergy.

For this research, the corresponding set of delimitations enabled the researcher to focus on the specific problem that the research sought to investigate, thereby narrowing down the pre-defined objectives. The specific purpose of the current study was to evaluate whether isometric exercises helped to address issues related to muscle imbalance among the selected group of sports athletes. These delimitations have most certainly helped in accomplishing the desired results or outcomes necessary to meet the predefined study objectives.

1.10 Operational Definition of Terms

1.10.1 Anatomical Shoulder Movement

Anatomical shoulder movement refers to the natural and essential motions of the shoulder joint as it operates within its intended ROM. These movements encompass a variety of actions, including but not limited to flexion, extension, abduction, adduction, internal rotation, and external rotation (Zhang et al., 2016). Each of these actions occurs as the humerus (upper arm bone) interacts with the scapula (shoulder blade) and clavicle (collarbone), allowing versatile mobility of the shoulder (Funk, 2023).

The concept of anatomical shoulder movement is firmly rooted in anatomy and biomechanics. It draws on the well-established principles of human musculoskeletal structure and function. Extensive research and clinical practice have extensively documented and classified these movements, making them a fundamental component of shoulder assessment and rehabilitation (Funk, 2023).

Anatomical shoulder movements serve as the foundational framework for assessing shoulder mobility and function. By operationally defining these movements, we provide a clear and standardised basis for evaluating ROM and muscle balance within the shoulder. The identification and measurement of specific anatomical movements, such as the internal and external shoulder rotation, are vital for assessing the effectiveness of isometric exercises and shoulder muscle imbalance. Understanding these movements is essential for characterising how the shoulder functions and responds to the intervention, ultimately contributing to a comprehensive understanding of shoulder health and performance in young elite badminton players.

1.10.2 Shoulder Strength Imbalance

Shoulder strength imbalance is characterised as an inequity or asymmetry in the muscular strength and power between the shoulder muscles of an individual. It specifically relates to the disparity in strength among the muscles responsible for shoulder movements and stability (Page, 2011). Shoulder strength imbalance can manifest as one shoulder exhibiting greater or lesser

strength than the other, potentially resulting in an irregular distribution of muscular forces around the shoulder (Phomsoupha & Laffaye, 2015).

The concept of shoulder strength imbalance is well supported in the fields of sports science, physical therapy, orthopaedics research, and clinical assessments routinely investigate and diagnose muscle imbalance within the shoulder, often using objective measures such as muscle testing and Electromyography (EMG) (Stastny et al., 2018). Shoulder strength imbalance is recognised as a common issue, particularly in athletes, and are linked to an increased risk of injuries (Page, 2011). External/Internal Ratios (ER/IR X100%) were used to assess muscle balance (Stausholm et al., 2021).

Shoulder strength imbalance serves as a central focus and a key dependent variable in this study. It provides a clear and quantifiable indicator of the problem that we address among young elite badminton players. By operationally defining this term, we established a foundation for measuring and evaluating the extent of muscle imbalance within the study population. Moreover, recognising shoulder strength imbalance is essential for assessing the effectiveness of isometric exercises as an intervention. This study will contribute to the understanding of how these exercises can mitigate muscle imbalance, enhance shoulder health, and potentially reduce the risk of injuries, thereby offering valuable insights for both athletes and sports professionals.

1.10.3 Dominant and Non-dominant Hands

The dominant hand is defined as the hand that an individual instinctively and predominantly uses to perform precise and skilled tasks, such as writing, eating, and manipulating objects. The hand exhibits a higher degree of dexterity, control, and familiarity with these activities. Conversely, the non-dominant hand refers to the hand that an individual typically uses less frequently for precision tasks and is often considered less skilled (Dieu et al., 2017).

The concept of the dominant and non-dominant hands is a well-established construct in neuropsychology and motor skills research. This is supported by extensive literature on the hand preference and lateralisation of brain function, which explains why most individuals exhibit a strong preference for one hand over the other in everyday tasks (Dieu et al., 2017).

Distinguishing between the dominant and non-dominant hands is essential in the study context because it provides valuable insights into the participants' motor skills and muscle use patterns during isometric exercises. It helps in characterising individual variations and potential imbalance in strength and coordination between the two hands. This differentiation is particularly relevant when assessing the effectiveness of isometric exercises on shoulder muscle imbalance because the non-dominant shoulder is often more susceptible to muscle imbalance in athletes. By considering the non-dominant hand, the study can tailor intervention and analyse outcomes with greater precision,

ultimately contributing to a more comprehensive understanding of the role of the non-dominant hand in shoulder health and performance among young elite badminton players.

1.10.4 Isometric Exercises

Isometric exercises refer to a category of muscle-strengthening activities in which the muscles contract without any significant change in the length of the muscle or joint angle (White et al., 2012). These exercises involve static contractions in which force is generated against an immovable object or opposing force, and the muscle remains in a fixed position (Bonitch Góngora et al., 2013). In the context of this study, isometric exercises primarily target the muscles of the shoulder, focussing on specific movements such as internal and external shoulder rotation. The exercises enhance muscle strength, endurance, and stability without involving dynamic joint movements.

The concept of isometric exercises is well established in the exercise physiology and sports science literature (White et al., 2012). These exercises have been widely studied and applied in various contexts, including rehabilitation, strength training, and sports performance enhancement (Bonitch Góngora et al., 2013). The research supports their effectiveness in isolated muscle strengthening and stability improvement, making them a relevant intervention in addressing shoulder muscles (Pearson et al., 2020). Isometric exercises played a pivotal role in the study as they serve as the primary intervention for addressing shoulder muscle imbalance among young

elite badminton players. By precisely defining isometric exercises, this study can establish a clear framework for intervention protocols. The research will evaluate the effectiveness of these exercises in reducing muscle imbalance and improving shoulder health. In addition, isometric exercises offer a safe and targeted approach to address the specific muscle groups involved in shoulder rotation. This study aims to provide evidence-based insights into the utility of isometric exercises for athletes in this context, contributing to the development of tailored training strategies for shoulder health and sports performance optimisation.

In the context of badminton, the current study defines isometric exercises as movements that involve internal and external rotation of the shoulder. Prior research suggested that these movements are highly effective in enhancing muscle strength, reducing reliance on weaker muscles activated by the central nervous system, and consequently lowering the risk of injury to non-dominant muscles (Gómez et al., 2020).

1.10.5 Maturity

In the context of this study, maturity pertains to the stage of an individual's physical, biological, and psychosocial development in relation to their chronological age (Malina et al., 2021). It encompasses a multifaceted spectrum of changes, including skeletal growth, hormonal fluctuations, and psychosocial development, which collectively define the state of maturity (Moore et al., 2015). Maturity is often categorised into distinct developmental

stages or phases, including prepubescence, puberty, adolescence, and adulthood (Cossio-Bolaños et al., 2021; Gomez-Campos et al., 2019).

Maturity is a well-established concept in developmental psychology and sports science. It draws from extensive research on human growth and development, including studies on skeletal age assessment, pubertal development, and the influence of chronological age on physical performance (Malina et al., 2021). Sawyer et al. (2018) defined adolescence as the period between 10 and 19 years of age, aligning with the common understanding of the transitional phase from childhood to adulthood. The equations proposed by Moore et al. (2015) use age and standing height for both sexes:

Females: Maturity stage (years) = $-7.709133 + (0.0042232 \times [\text{age} \times \text{height}])$.

Males: Maturity stage (years) = $-7.999994 + (0.0036124 \times [\text{age} \times \text{height}])$.

To classify maturity status, the method suggested by Kozieł and Malina (2018) was used, with young people within -1 to $+1$ years of Peak Height Velocity (PHV) classified as average, those under -1 years of PHV classified as early, and those over $+1$ years of PHV classified as late (Kozieł & Malina, 2018).

The concept of maturity is instrumental in understanding age-related variations within the study population of young elite badminton players. By categorising participants based on their maturity levels, the study can consider how different stages of development influence factors such as shoulder muscle imbalance and the response to isometric exercises. This categorisation facilitates the tailoring of the intervention to match the specific developmental needs of each

group. In addition, it helps contextualise the study's findings, making them more applicable to different age groups of athletes, and contributes to a broader understanding of the role of age-related factors in sports performance and injury prevention. Thus, accounting for potential variations in physiological response, muscle distribution, and exercise outcomes. Acknowledging diverse gender experiences in the study contributes to inclusivity and recognises the importance of considering individual identities within research. Additionally, this approach aligns with contemporary understandings of gender and ensures that the study's findings are relevant and respectful of the diversity of gender experiences among young elite badminton players.

1.11 Conclusion

The conclusion of chapter one states that the comprehensive study clarifies muscle imbalance in young elite badminton players and the effectiveness of tailored isometric exercise protocols. It also considers the potential impact of gender and maturation factors. The findings will ultimately inform the development of a customised intervention to enhance shoulder health and performance within this specific athlete population.

REFERENCES

- Abdullaev, M. J. (2020). Methodology of application games in the training of young athletes. *American journal of social and humanitarian research*, 1(4), 118-127. <https://doi.org/10.31150>
- Abdullah, B., Samsudin, S., Gasibat, Q., & Mohd Nasirudddin, N. J. (2023). A reliability study of isometric shoulder internal and external rotation strength in young badminton players using a hand-held dynamometry. *Journal of physical education & sport*, 23(7), 1642-1649. <https://doi.org/10.7752/jpes.2023.07201>
- Abian-Vicen, J., Castanedo, A., Abian, P., & Sampedro, J. (2013). Temporal and notational comparison of badminton matches between men's singles and women's singles. *International journal of performance analysis in sport*, 13(2), 310-320. <https://doi.org/10.1080/24748668.2013.11868650>
- Adam, R., & Cogan, N. (2019). The personal meanings and experiences of resilience amongst elite badminton athletes in the build up to competition. *Journal of qualitative research in sports studies*, 13(1), 61-84.
- Ahmadi, S., Gutierrez, G. L., & Uchida, M. C. (2019). Asymmetry in glenohumeral muscle strength of sitting volleyball players: an isokinetic profile of shoulder rotations strength. *The journal of sports medicine and physical fitness*, 60(3), 395-401. <https://doi.org/10.23736/s0022-4707.19.10144-2>
- Alarab, A., Shamsiyeh, B. A., Abdo, A., Seder, A., Shameh, R. A., & Amro, A. (2019). Isometric exercises and mobilization technique for patellofemoral syndrome: case report 2019. *Acta scientific orthopaedics*, 2(7), 74-80. <https://doi.org/10.31080/ASOR.2019.02.0070>
- Aljandali, A. (2017). *Multivariate methods and forecasting with IBM® SPSS® statistics* (pp. 80-95). Berlin/Heidelberg, Germany: Springer. https://doi.org/10.1007/978-3-662-55366-1_10
- Almousawi, A. M. (2002). *Audit of sports injuries and services*. Doctoral Dissertation. University of Glasgow.
- Alsouhibani, A., Vaegter, H. B., & Hoeger Bement, M. (2019). Systemic exercise induced hypoalgesia following isometric exercise reduces conditioned pain modulation. *Pain medicine*, 20(1), 180-190. <https://doi.org/10.1093/pm/pny057>
- Alvarez, J. T., Gerez, L. F., Araromi, O. A., Hunter, J. G., Choe, D. K., Payne, C. J., & Walsh, C. J. (2022). Towards soft wearable strain sensors for muscle activity monitoring. *IEEE Transactions on neural systems and rehabilitation engineering*, 30, 2198-2206. <https://doi.org/10.1109/TNSRE.2022.3196501>

- Anastasio, A. T. (2020). Discrete isometric exercise for the individual with time and facility constraints. *ACSM's health & fitness journal*, 24(2), 22-30. <https://doi.org/10.1249/FIT.0000000000000556>
- Andrade, D. S., Fachina, R. J., Cruz, W., Benedito-Silva, A. A., Da Silva, A. C., & De Lira, C. A. (2014). Strength field tests performance are correlated with isokinetic strength of shoulder rotator muscles in female handball players. *journal of sports medicine and physical fitness*, 54(4), 403-409.
- Andrew, R., Tiggemann, M., & Clark, L. (2015). The protective role of body appreciation against media-induced body dissatisfaction. *Body image*, 15, 98-104. <https://doi.org/10.1016/j.bodyim.2015.07.005>
- Ansdell, P., Thomas, K., Hicks, K. M., Hunter, S. K., Howatson, G., & Goodall, S. (2020). Physiological sex differences affect the integrative response to exercise: acute and chronic implications. *Experimental physiology*, 105(12), 2007-2021. <https://doi.org/10.1113/EP088548>
- Arora, M., Shetty, S. H., Khedekar, R. G., & Kale, S. (2015). Over half of badminton players suffer from shoulder pain: is impingement to blame?. *Journal of arthroscopy and joint surgery*, 2(1), 33-36. <https://doi.org/10.1016/j.jajs.2014.12.006>
- Asker, M., Brooke, H. L., Waldén, M., Tranaeus, U., Johansson, F., Skillgate, E., & Holm, L. W. (2018). Risk factors for, and prevention of, shoulder injuries in overhead sports: a systematic review with best-evidence synthesis. *British journal of sports medicine*, 52(20), 1312-1319. <http://dx.doi.org/10.1136/bjsports-2017-098254>
- Atkins, S. J., Bentley, I., Hurst, H. T., Sinclair, J. K., & Hesketh, C. (2016). The presence of bilateral imbalance of the lower limbs in elite youth soccer players of different ages. *The journal of strength & conditioning research*, 30(4), 1007-1013. <https://doi.org/10.1519/JSC.0b013e3182987044>
- Avci, M., & Akliman, C. K. (2018). Gender differences in perception of body, expressions of body image and body image coping strategies among turkish adolescents. *International journal of curriculum and instruction*, 10(2), 30-44.
- Avrahami, D., & Potvin, J. R. (2014). The clinical and biomechanical effects of fascial muscular lengthening therapy on tight hip flexor patients with and without low back pain. *The journal of the Canadian chiropractic association*, 58(4), 444-455. <https://www.ncbi.nlm.nih.gov/pubmed/25550670>
- Badenhorst, J., Pienaar, A. E., & Gerber, B. P. (2021). Effect of the growth spurt on training of strength and power during mid-adolescence in boys. *The journal of strength & conditioning research*, 35(8), 2193-2204. <https://doi.org/10.1519/JSC.00000000000003916>

- Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International journal of production economics*, 229(2020), 2-15. <https://doi.org/10.1016/j.ijpe.2020.107776>
- Balasch-Bernat, M., Lluch, E., Vaegter, H. B., & Dueñas, L. (2021). Should exercises be painful or not? effects on clinical and experimental pain in individuals with shoulder pain. *The journal of pain*, 22(10), 1246-1255. <https://doi.org/10.1016/j.jpain.2021.03.153>
- Bastug, G., & Sitki, M. (2018). Investigation of attention, concentration and mental toughness properties in tennis, table tennis, and badminton athletes. *The sport journal*, 21, 1-8.
- Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied physiology, nutrition, and metabolism*, 41(1), 1-11. <https://doi.org/10.3389/fphys.2016.00164>
- Birrer, D., & Morgan, G. (2010). Psychological skills training as a way to enhance an athlete's performance in high-intensity sports. *Scandinavian journal of medicine & science in sports*, 20, 78-87. <https://doi.org/10.1111/j.16000838.2010.01188.x>
- Blomstrand, E. L. I. A. S., & Demant, M. (2017). *Simulation of a badminton racket. A parametric study of racket design parameters using finite element analysis*. Master Dissertation, University of Technology.
- Blue, M. N., Smith-Ryan, A. E., Trexler, E. T., & Hirsch, K. R. (2018). The effects of high intensity interval training on muscle size and quality in overweight and obese adults. *Journal of science and medicine in sport*, 21(2), 207-212. <https://doi.org/10.1016/j.jsams.2017.06.001>
- Bolotin, A., & Bakayev, V. (2016). Efficacy of using isometric exercises to prevent basketball injuries. *Journal of physical education and sport*, 16(4), 1177-1185. <https://doi.org/10.7752/jpes.2016.04188>
- Bonitch Góngora, J. G., Almeida, F., Padial Puche, P., Bonitch-Domínguez, J. G., & Feriche Fernández-Castany, M. B. (2013). Maximal isometric handgrip strength and endurance differences between elite and non-elite young judo athletes. *Archives of budo science of martial arts and extreme sports*, 9(4), 239-248.
- Boot, W. R., Simons, D. J., Stothart, C., & Stutts, C. (2013). The pervasive problem with placebos in psychology: Why active control groups are not sufficient to rule out placebo effects. *Perspectives on psychological science*, 8(4), 446-454. <https://doi.org/10.1177/1745691613491271>

- Borghuis, J., Hof, A. L., & Lemmink, K. A. (2008). The importance of sensory motor control in providing core stability: implications for measurement and training. *Sports medicine*, 38, 893-916. <https://doi.org/10.2165/00007256200838110-00002>
- Boyce, L., & Schoenfeld, M. (2022). *Strength training for all body types: the science of lifting and levers*. Human kinetics.
- Bragazzi, N. L., Rouissi, M., Hermassi, S., & Chamari, K. (2020). Resistance training and handball Players' isokinetic, isometric and maximal strength, muscle power and throwing ball velocity: a systematic review and meta analysis. *International journal of environmental research and public health*, 17(8), 2-19. <https://doi.org/10.3390/ijerph17082663>
- Bressel, E., Yonker, J. C., Kras, J., & Heath, E. M. (2007). Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of athletic training*, 42(1), 42-46. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1896078/>
- Brumitt, J., & Dale, R. B. (2009). Integrating shoulder and core exercises when rehabilitating athletes performing overhead activities. *North American journal of sports physical therapy: NAJSPT*, 4(3), 132-138. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2953337/>
- Campbell, A., Straker, L., Whiteside, D., O'Sullivan, P., Elliott, B., & Reid, M. (2016). Lumbar mechanics in tennis groundstrokes: differences in elite adolescent players with and without low back pain. *Journal of applied biomechanics*, 32(1), 32-39. <https://doi.org/10.1123/jab.2015-0122>
- Cariati, I., Bonanni, R., Onorato, F., Mastrogregori, A., Rossi, D., Iundusi, R & Tarantino, U. (2021). Role of physical activity in bone–muscle crosstalk: Biological aspects and clinical implications. *Journal of functional morphology and kinesiology*, 6(2), 2-18. <https://doi.org/10.3390/jfmk6020055>
- Chang, L. R., Anand, P., & Varacallo, M. (2022). Anatomy, shoulder and upper limb, glenohumeral joint. In *StatPearls*. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK537018/>
- Chen, Y. L., Hsu, J. H., Tai, D. H. L., & Yao, Z. F. (2022). Training-associated superior visuomotor integration performance in elite badminton players after adjusting for cardiovascular fitness. *International journal of environmental research and public health*, 19(1), 2-12. <https://doi.org/10.3390/ijerph19010468>
- Chiminazzo, J. G. C., Barreira, J., Luz, L. S., Saraiva, W. C., & Cayres, J. T. (2018). Technical and timing characteristics of badminton men's single: comparison between groups and play-offs stages in 2016 Rio Olympic Games. *International journal of performance analysis in sport*, 18(2), 245-254. <https://doi.org/10.1080/24748668.2018.1463785>

- Chtara, M., Rouissi, M., Bragazzi, N. L., Owen, A. L., Haddad, M., & Chamari, K. (2018). Dynamic balance ability in young elite soccer players: implication of isometric strength. *The Journal of sports medicine and physical fitness*, 58(4), 414-420. <http://dx.doi.org/10.23736/S00224707.16.06724-4>
- Chua, Y. P. (2011). *Kaedah dan statistik penyelidikan: kaedah penyelidikan*. McGraw Hill Education. <http://eprints.um.edu.my/id/eprint/10246>
- Clark, N., Forshey, T., Mulligan, I., & Kindel, C. (2019). Knee mechanics during a change of direction movement in division I athletes following full return to sport from anterior cruciate ligament reconstruction. *Physical therapy in sport*, 35, 75-78. <https://doi.org/10.1016/j.ptsp.2018.11.008>
- Clarsen, B., Bahr, R., Andersson, S. H., Munk, R., & Myklebust, G. (2014). Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *British journal of sports medicine*, 48(17), 1327-1333. <http://dx.doi.org/10.1136/bjsports-2014-093702>
- Clemens, T., Richmond, S. A., Black, A., Babul, S., & Pike, I. (2018). Evidence summary: badminton. Active & safe central. *BC injury research and prevention unit*, Vancouver.
- Clifford, C., Challoumas, D., Paul, L., Syme, G., & Millar, N. L. (2020). Effectiveness of isometric exercise in the management of tendinopathy: a systematic review and meta-analysis of randomised trials. *BMJ open sport & exercise medicine*, 6(1), 1-19. <http://dx.doi.org/10.1136/bmjsem-2020-000760>
- Cohen, J. (1992). Statistical power analysis. *Current directions in psychological science*, 1(3), 98-101.
- Coinceicao, A., Parraca, J., Marinho, D., Costa, M., Louro, H., Silva, A., & Batalha, N. (2018). Assessment of isometric strength of the shoulder rotators in swimmers using a handheld dynamometer: a reliability study. *Acta of bioengineering and biomechanics*, 20(4), 114-119. <http://dx.doi.org/10.5277/ABB-01237-2018-02>
- Cole, S. R., Platt, R. W., Schisterman, E. F., Chu, H., Westreich, D., Richardson, D., & Poole, C. (2010). Illustrating bias due to conditioning on a collider. *International journal of epidemiology*, 39(2), 417-420. <https://doi.org/10.1093/ije/dyp334>
- Collin, P., Matsumura, N., Lädermann, A., Denard, P. J., & Walch, G. (2014). Relationship between massive chronic rotator cuff tear pattern and loss of active shoulder range of motion. *Journal of shoulder and elbow surgery*, 23(8), 1195-1202. <https://doi.org/10.1016/j.jse.2013.11.019>

- Cools, A. M., De Wilde, L., Van Tongel, A., Ceyssens, C., Ryckewaert, R., & Cambier, D. C. (2014). Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. *Journal of shoulder and elbow surgery*, 23(10), 1454-1461. <https://doi.org/10.1016/j.jse.2014.01.006>
- Cossio-Bolaños, M., Vidal-Espinoza, R., de Campos, L. F. C. C., Sulla-Torres, J., Cossio-Bolaños, W., Albornoz, C. U., & Gómez-Campos, R. (2021). Equations predicting maturity status: validation in a cross-sectional sample to assess physical growth and body adiposity in Chilean children and adolescents. *Endocrinología, diabetes y nutrición (English ed.)*, 68(10), 689-698. <https://doi.org/10.1016/j.endinu.2020.12.009>
- Couppé, C., Thorborg, K., Hansen, M., Fahlström, M., Bjordal, J. M., Nielsen, D., & Magnusson, S. P. (2014). Shoulder rotational profiles in young healthy elite female and male badminton players. *Scandinavian journal of medicine & science in sports*, 24(1), 122-128. <https://doi.org/10.1111/j.1600-0838.2012.01480.x>
- Dahlbo, H. (2021). *Hand-eye coordination in tennis: Exploration of manually influenced eye dominance and its association with the shoulder position in the tennis serve*. Doctoral Dissertation, University of Central Nicaragua.
- Damas, F., Phillips, S., Vechin, F. C., & Ugrinowitsch, C. (2015). A review of resistance training-induced changes in skeletal muscle protein synthesis and their contribution to hypertrophy. *Sports medicine*, 45(6), 801-807. <https://doi.org/10.1007/s40279-015-0320>
- De Lima Boarati, E., Hotta, G. H., McQuade, K. J., & de Oliveira, A. S. (2020). Acute effect of flexible bar exercise on scapulothoracic muscles activation, on isometric shoulder abduction force and proprioception of the shoulder of individuals with and without subacromial pain syndrome. *Clinical Biomechanics*, 72, 77-83. <https://doi.org/10.1016/j.clinbiomech.2019.12.001>
- De Melo, M. B., Daldegan-Bueno, D., Menezes Oliveira, M. G., & de Souza, A. L. (2022). Beyond ANOVA and MANOVA for repeated measures: Advantages of generalized estimated equations and generalized linear mixed models and its use in neuroscience research. *European journal of neuroscience*, 56(12), 6089-6098. <https://doi.org/10.1111/ejn.15858>
- Defoe, I. N., Dubas, J. S., Figner, B., & Van Aken, M. A. (2015). A meta-analysis on age differences in risky decision making: adolescents versus children and adults. *Psychological bulletin*, 141(1), 48-84. <https://psycnet.apa.org/doi/10.1037/a0038088>

- Devine, P. G., & Ash, T. L. (2022). Diversity training goals, limitations, and promise: A review of the multidisciplinary literature. *Annual review of psychology*, 73, 403-429. <https://doi.org/10.1146/annurev-psych-060221122215>
- Dieu, O., Mikulovic, J., Fardy, P. S., Bui-Xuan, G., Béghin, L., & Vanhelst, J. (2017). Physical activity using wrist-worn accelerometers: comparison of dominant and non-dominant wrist. *Clinical physiology and functional imaging*, 37(5), 525-529. <https://doi.org/10.1111/cpf.12337>
- DiStefano, L. J., Padua, D. A., Blackburn, J. T., Garrett, W. E., Guskiewicz, K. M., & Marshall, S. W. (2010). Integrated injury prevention program improves balance and vertical jump height in children. *The journal of strength & conditioning research*, 24(2), 332-342. <https://doi.org/10.1519/JSC.0b013e3181cc2225>
- Dodds, F. T., Knotts, S. L. S., Penrod, M. I., Scoggins, W. A., & Conners, R. T. (2020). Shoulder strength and range of motion between collegiate pitchers and position players in baseball. *International journal of exercise science*, 13(6), 123.-130. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7039469/>
- 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. *Journal of human kinetics*, 75, 103-113. <https://doi.org/10.2478/hukin-2020-0041>
- Du, Y., & Fan, Y. (2023). The effect of fatigue on postural control and biomechanical characteristic of lunge in badminton players. *Bioengineering*, 10(3), 2-12. <https://doi.org/10.3390/bioengineering10030301>
- Edouard, P., Degache, F., Oullion, R., Plessis, J. Y., Gleizes-Cervera, S., & Calmels, P. (2013). Shoulder strength imbalances as injury risk in handball. *International journal of sports medicine*, 34(07), 654-660. <https://doi.org/10.1055/s-0032-1312587>
- Ellenbecker, T. S., & Cools, A. (2010). Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. *British journal of sports medicine*, 44(5), 319-327. <http://dx.doi.org/10.1136/bjsm.2009.058875>
- Eshghi, S., Zarei, M., Abbasi, H., & Alizadeh, S. (2022). The effect of shoulder injury prevention program on shoulder isokinetic strength in young male volleyball players. *Research in sports medicine*, 30(2), 203-214. <https://doi.org/10.1080/15438627.2020.1860050>
- Farpour-Lambert, N. (2020). Adolescent athletes. *Injury and health risk management in sports: a guide to decision making*, 7-15. <https://doi.org/10.1007/978366260752-72>

- Fawkner, S., Henretty, J., Knowles, A. M., Nevill, A., & Niven, A. (2014). The influence of maturation, body size and physical self-perceptions on longitudinal changes in physical activity in adolescent girls. *Journal of sports sciences*, 32(4), 392-401. <https://doi.org/10.1080/02640414.2013.825733>
- Feng, W. Z., Rasyid, H. N., & Juliati, J. (2017). Comparison of shoulder strength in routinely trained badminton players and non-badminton players. *Althea medical journal*, 4(2), 208-212. <https://doi.org/10.15850/amj.v4n2.1083>
- Fernández-Martínez, A. M., Alonso-Burgos, A., López, R., Marcos, M. T. C., & Baldi, S. (2021). Clinical outcomes of transcatheter arterial embolization for secondary stiff shoulder. *Journal of vascular and interventional radiology*, 32(4), 489-496. <https://doi.org/10.1016/j.jvir.2020.11.006>
- Fett, D., Trompeter, K., & Platen, P. (2017). Back pain in elite sports: a cross-sectional study on 1114 athletes. *PloS one*, 12(6), 1-17. <https://doi.org/10.1371/journal.pone.0180130>
- Fiebert, I., Kistner, F., Gissendanner, C., & DaSilva, C. (2021). Text neck: an adverse postural phenomenon. *Work*, 69(4), 1261-1270. <https://doi.org/10.3233/WOR-213547>
- Finch, C. F., & Twomey, D. (2013). 10 The biomechanical basis of injury during childhood. *Paediatric biomechanics and motor control: theory and application*, 1-9.
- Ford, C. A., Nowlan, N. C., Thomopoulos, S., & Killian, M. L. (2017). Effects of imbalanced muscle loading on hip joint development and maturation. *Journal of orthopaedic research*, 35(5), 1128-1136. <https://doi.org/10.1002/jor.23361>
- Ford, P., De Ste Croix, M., Lloyd, R., Meyers, R., Moosavi, M., Oliver, J., & Williams, C. (2011). The long-term athlete development model: Physiological evidence and application. *Journal of sports sciences*, 29(4), 389-402. <https://doi.org/10.1080/02640414.2010.536849>
- Forthomme, B., Croisier, J. L., Delvaux, F., Kaux, J. F., Crielaard, J. M., & Gleizes Cervera, S. (2018). Preseason strength assessment of the rotator muscles and shoulder injury in handball players. *Journal of athletic training*, 53(2), 174-180. <https://doi.org/10.4085/1062-6050216-16>
- Fortin, C., Ehrmann Feldman, D., Cheriet, F., & Labelle, H. (2011). Clinical methods for quantifying body segment posture: a literature review. *Disability and rehabilitation*, 33(5), 367-383. <https://doi.org/10.3109/09638288.2010.492066>

- Freitas, P. S., Santana, T. S., Manoel, L. S., Serenza, F. D. S., & Riberto, M. (2021). A comparison of isokinetic rotator cuff performance in wheelchair basketball athletes vs. non-athletes with spinal cord injury. *The journal of spinal cord medicine*, 44(4), 557-562. <https://doi.org/10.1080/10790268.2019.1603489>
- Funk, L. (2023). Biomechanics of the shoulder: in *shoulder arthroscopy: principles and practice* (pp. 17-32). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-66868-9_2
- Ganguly, J., Kulshreshtha, D., Almotiri, M., & Jog, M. (2021). Muscle tone physiology and abnormalities. *Toxins*, 13(4), 2-20. <https://doi.org/10.3390/toxins13040282>
- Garcia-Hernandez, N., Garza-Martinez, K., Parra-Vega, V., Alvarez-Sanchez, A., & Conchas Arteaga, L. (2019). Development of an EMG-based exergaming system for isometric muscle training and its effectiveness to enhance motivation, performance and muscle strength. *International journal of human-computer studies*, 124, 44-55. <https://doi.org/10.1016/j.ijhcs.2018.11.010>
- Gasibat, Q., & Kamalden, T. F. T. (2021). Kinetic chain disruption contributes to shoulder and elbow injuries. *Sports medicine and health science*, 3(4), 252-253. <https://doi.org/10.1016%2Fj.smhs.2021.10.004>
- Gasibat, Q., Abdullah, B., Samsudin, S., Alexe, D. I., Alexe, C. I., & Tohănean, D. I. (2023). Gender-specific patterns of muscle imbalance in elite badminton players: a comprehensive exploration. *Sports*, 11(9), 2-12. <https://doi.org/10.3390/sports11090164>
- Gasibat, Q., Kamalden, T. F. T., Jones, T., Dev, R., Dev, O., & Wazir, M. R. W. N. (2018). Musculoskeletal disorders among elite junior Malaysian badminton players. *Sport science*, 3(5), 44-55.
- Gatz, M., Betsch, M., Dirrichs, T., Schradung, S., Tingart, M., Michalik, R., & Quack, V. (2020). Eccentric and isometric exercises in achilles tendinopathy evaluated by the VISA-A score and shear wave elastography. *Sports health*, 12(4), 373-381. <https://doi.org/10.1177/1941738119893996>
- Gautam, S., Kumar, U., & Dada, R. (2020). Yoga and its impact on chronic inflammatory autoimmune arthritis. *Frontiers in bioscience-elite*, 13(1), 77-116. <https://doi.org/10.2741/873>
- Geng, Y., Trachuk, S., Ma, X. M., Shi, Y. J., & Zeng, X. (2023). Physiological features of musculoskeletal system formation of adolescents under the influence of directed physical training. *Physical activity and health*, 7(1), 2-12. <https://doi.org/10.5334/paah.217>

- Gerstner, G. R., Mota, J. A., Giuliani, H. K., Weaver, M. A., Shea, N. W., & Ryan, E. D. (2022). The impact of repeated bouts of shiftwork on rapid strength and reaction time in career firefighters. *Ergonomics*, 65(8), 1086-1094. <https://doi.org/10.1080/00140139.2021.2016997>
- Gharahdaghi, N., Phillips, B. E., Szewczyk, N. J., Smith, K., Wilkinson, D. J., & Atherton, P. J. (2021). Links between testosterone, oestrogen, and the growth hormone/insulin-like growth factor axis and resistance exercise muscle adaptations. *Frontiers in physiology*, 11, 1-12. <https://doi.org/10.3389/fphys.2020.621226>
- Gimeno-Santos, E., Frei, A., Dobbels, F., Rüdell, K., Puhon, M. A., Garcia-Aymerich, J., & PROactive Consortium. (2011). Validity of instruments to measure physical activity may be questionable due to a lack of conceptual frameworks: a systematic review. *Health and quality of life outcomes*, 9, 1-13. <https://doi.org/10.1186/1477-7525-9-86>
- Giuliano, C., Karahalios, A., Neil, C., Allen, J., & Levinger, I. (2017). The effects of resistance training on muscle strength, quality of life and aerobic capacity in patients with chronic heart failure: a meta-analysis. *International journal of cardiology*, 227, 413-423. <https://doi.org/10.1016/j.ijcard.2016.11.023>
- Gomes, M. J., Martinez, P. F., Pagan, L. U., Damatto, R. L., Cezar, M. D. M., Lima, A. R. R & Okoshi, M. P. (2017). Skeletal muscle aging: influence of oxidative stress and physical exercise. *Oncotarget*, 8(12), 20428-20440. <https://doi.org/10.18632/oncotarget.14670>
- Gómez, M. Á., Rivas, F., Leicht, A. S., & Buldú, J. M. (2020). Using network science to unveil badminton performance patterns. *Chaos, solitons & fractals*, 135(2020), 2-10. <https://doi.org/10.1016/j.chaos.2020.109834>
- Gomez-Campos, R., Arruda, M., Andruske, C. L., Leite-Portella, D., Pacheco-Carrillo, J., Urral-Albornoz, C., Sulla-Torres, J., Luarte-Rocha, C., & Cossio-Bolaños, M. A. (2019). Physical growth and body adiposity curves in students of the maule region (chile). *Frontiers in pediatrics*, 7, 1-11. <https://doi.org/10.3389/fped.2019.00323>
- Gossel, B. M. (2022). Analogies in entrepreneurial communication and strategic communication: definition, delimitation of research programs and future research. *International journal of strategic communication*, 16(2), 134-156.
- Grabara, M. (2015). Comparison of posture among adolescent male volleyball players and non-athletes. *Biology of sport*, 32(1), 79-85. <https://doi.org/10.5604/20831862.1127286>
- Green, C. S., Strobach, T., & Schubert, T. (2014). On methodological standards in training and transfer experiments. *Psychological research*, 78, 756-772. <https://doi.org/10.1007/s00426-013-0535-3>

- Greenland, S., & Brumback, B. (2002). An overview of relations among causal modelling methods. *International journal of epidemiology*, 31(5), 1030-1037. <https://doi.org/10.1093/ije/31.5.1030>
- Guermont, H., Mittelheisser, G., Reboursière, E., Gauthier, A., & Drigny, J. (2023). Shoulder muscle imbalance as a risk factor for shoulder injury in elite badminton players: a prospective study. *Physical therapy in sport*, 61, 149-155. <https://doi.org/10.1016/j.ptsp.2023.04.002>
- Guney, H., Harput, G., Colakoglu, F., & Baltaci, G. (2016). The effect of glenohumeral internal-rotation deficit on functional rotator-strength ratio in adolescent overhead athletes. *Journal of sport rehabilitation*, 25(1), 52-57. <https://doi.org/10.1123/jsr.20140260>
- Gungor, O., Ulu, S., Hasbal, N. B., Anker, S. D., & Kalantar-Zadeh, K. (2021). Effects of hormonal changes on sarcopenia in chronic kidney disease: where are we now and what can we do?. *Journal of cachexia, sarcopenia and muscle*, 12(6), 1380-1392. <https://doi.org/10.1002/jcsm.12839>
- Hadzic, V., Sattler, T., Veselko, M., Markovic, G., & Dervisevic, E. (2014). Strength asymmetry of the shoulders in elite volleyball players. *Journal of athletic training*, 49(3), 338-344. <https://doi.org/10.4085/1062-6050-49.2.05>
- Hair, J. F., LDS Gabriel, M., Silva, D. D., & Braga, S. (2019). Development and validation of attitudes measurement scales: fundamental and practical aspects. *RAUSP Management journal*, 54, 490-507. <https://doi.org/10.1108/RAUSP-05-2019-0098>
- Häkkinen, K., Pakarinen, A., Kraemer, W. J., Häkkinen, A., Valkeinen, H., & Alen, M. (2001). Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *Journal of applied physiology*, 91(2), 569-580. <https://doi.org/10.1152/jappl.2001.91.2.569>
- Hams, A., Evans, K., Adams, R., Waddington, G., & Witchalls, J. (2019). Reduced shoulder strength and change in range of motion are risk factors for shoulder injury in water polo players. *Physical therapy in sport*, 40, 231-237. <https://doi.org/10.1016/j.ptsp.2019.10.003>
- Hao, L., Zhi, J., Zhu, W., & Zhou, L. (2022). Research on badminton player's step training model based on big data and IOT networks. *Security and communication networks*, 2022, 2-9. <https://doi.org/10.1155/2022/1972389>
- Hernán, M. A., Hernández-Díaz, S., & Robins, J. M. (2004). A structural approach to selection bias. *Epidemiology*, 615-625. <https://doi.org/10.1097/01.ede.0000135174.63482.43>
- Higgins, A. W. (2019). *Correlations between shoulder rotational motion, strength measures and throwing biomechanics in collegiate baseball pitchers*. Master Dissertation, Marquette University.

- Holden, S., Lyng, K., Graven-Nielsen, T., Riel, H., Olesen, J. L., Larsen, L. H., & Rathleff, M.S. (2020). Isometric exercise and pain in patellar tendinopathy: a randomized crossover trial. *Journal of science and medicine in sport*, 23(3), 208-214. <https://doi.org/10.1016/j.jsams.2019.09.015>
- Hoogenboom, B. J., & Voight, M. L. (2015). Rolling revisited: using rolling to assess and treat neuromuscular control and coordination of the core and extremities of athletes. *International journal of sports physical therapy*, 10(6), 787-802. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4637914/>
- Horbacz, A., Majherová, M., & Perečinská, K. (2013). Posture and muscle imbalance in young tennis players. *Scientific review of physical culture*, 3(4), 33-38.
- Hosseinimehr, S. H., Anbarian, M., Norasteh, A. A., Fardmal, J., & Khosravi, M. T. (2015). The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes. *Manual therapy*, 20(6), 758-762. <https://doi.org/10.1016/j.math.2015.02.010>
- Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports medicine*, 41, 221-232. <https://doi.org/10.2165/11538560-000000000-00000>
- Huegel, J., Williams, A. A., & Soslowsky, L. J. (2015). Rotator cuff biology and biomechanics: a review of normal and pathological conditions. *Current rheumatology reports*, 17, 1-9. <https://doi.org/10.1007/s11926-014-0476-x>
- Hughes, W., Healy, R., Lyons, M., Nevill, A., Higginbotham, C., Lane, A., & Beattie, K. (2023). The effect of different strength training modalities on sprint performance in female team-sport athletes: a systematic review and meta-analysis. *Sports medicine*, 53(5), 993-1015. <https://doi.org/10.1007/s40279023-01820-5>
- Hunter, S. K. (2014). Sex differences in human fatigability: mechanisms and insight to physiological responses. *Acta physiologica*, 210(4), 768-789. <https://doi.org/10.1111/apha.12234>
- Hunter, S. K. (2016). The relevance of sex differences in performance fatigability. *Medicine and science in sports and exercise*, 48(11), 2-20. <https://doi.org/10.1249%2FMSS.0000000000000928>
- Hurst, C., Robinson, S. M., Witham, M. D., Dodds, R. M., Granic, A., Buckland, C., & Sayer, A. A. (2022). Resistance exercise as a treatment for sarcopenia: prescription and delivery. *Age and ageing*, 51(2), 1-10. <https://doi.org/10.1093/ageing/afac003>

- Impellizzeri, F. M., & Marcora, S. M. (2009). Test validation in sport physiology: lessons learned from clinimetrics. *International journal of sports physiology and performance*, 4(2), 269-277. <https://doi.org/10.1123/ijsp.4.2.269>
- Ishikawa, H., Smith, K. M., Wheelwright, J. C., Christensen, G. V., Henninger, H. B., Tashjian, R. Z., & Chalmers, P. N. (2023). Rotator cuff muscle imbalance associates with shoulder instability direction. *Journal of Shoulder and Elbow Surgery*, 32(1), 33-40. <https://doi.org/10.1016/j.jse.2022.06.022>
- Izraelski, J. (2012). Assessment and treatment of muscle imbalance: The Janda approach. *The journal of the canadian chiropractic association*, 56(2), 156-159. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3364069/>
- Jambassi Filho, J. C., Gurjão, A. L., Prado, A. K., Gallo, L. H., & Gobbi, S. (2020). Acute effects of different rest intervals between sets of resistance exercise on neuromuscular fatigue in trained older women. *The journal of strength & conditioning research*, 34(8), 2235-2240. <https://doi.org/10.1519/JSC.0000000000002409>
- Jayanthi, N. A., LaBella, C. R., Fischer, D., Pasulka, J., & Dugas, L. R. (2015). Sports specialized intensive training and the risk of injury in young athletes: a clinical case control study. *The American journal of sports medicine*, 43(4), 794-801. <https://doi.org/10.1177/0363546514567298>
- Jimenez-Olmedo, J. M., Pueo, B., Penichet-Tomas, A. (2016). Defensive systems during the men's European University beach volleyball championship. *Journal of physical education and sport*, 16(3), 945- 950. <http://dx.doi.org/10.7752/jpes.2016.03149>
- Johansson, F. R., Skillgate, E., Lapauw, M. L., Clijmans, D., Deneulin, V. P., Palmans, T., & Cools, A. M. (2015). Measuring eccentric strength of the shoulder external rotators using a handheld dynamometer: reliability and validity. *Journal of athletic training*, 50(7), 719-725. <https://doi.org/10.4085/1062-6050-49.3.72>
- Julian, R., Hecksteden, A., Fullagar, H. H., & Meyer, T. (2017). The effects of menstrual cycle phase on physical performance in female soccer players. *PloS one*, 12(3), 1-13. <https://doi.org/10.1371/journal.pone.0173951>
- Kaldau, N. C., Kerr, S., McCaig, S., & Hölmich, P. (2021). Training and injuries among world elite junior badminton players—Identifying the problems. *Asia Pacific journal of sports medicine, arthroscopy, rehabilitation and technology*, 26, 21-26. <https://doi.org/10.1016/j.asmart.2021.07.003>

- Kalkhoven, J. T., Watsford, M. L., & Impellizzeri, F. M. (2020). A conceptual model and detailed framework for stress-related, strain-related, and overuse athletic injury. *Journal of science and medicine in sport*, 23(8), 726-734. <https://doi.org/10.1016/j.jsams.2020.02.002>
- Kamalden, T. F. T., & Gasibat, Q. (2021). Muscle imbalance in badminton athletes: Preventive training programmes need to be designed. *Sport Sciences for health*, 17(1), 263-264. <https://doi.org/10.1007/s11332-020-00700-z>
- Kamalden, T. F. T., Gasibat, Q., Samsudin, S., & Joseph, J. A. (2021). Occurrence of muscle imbalance and risk of injuries in athletes using overhead movements: a systematic review. *Sport mont*, 19(3), 115-122. <https://doi.org/10.26773/smj.211012>
- Kaplan, S. L., Coulter, C., & Fethers, L. (2013). Physical therapy management of congenital muscular torticollis: an evidence-based clinical practice guideline: from the Section on pediatrics of the American physical therapy association. *Pediatric physical therapy*, 25(4), 348-394. <https://doi.org/10.1097/PEP.0b013e3182a778d2>
- Karahan, A. Y., Yesilyurt, S., Kaydok, E., Olcucu, B., & Bagcaci, S. (2013). Kienbock's disease that manifested in a badminton player: case report. *International journal of sports science*, 3(4), 132-134. <https://doi.org/10.5923/j.sports.20130304.06>
- Khawailed, I. A., & Lee, H. (2021). Neuromuscular control of ankle-stabilizing muscles specific effects of sex and menstrual cycle. *International journal of sports medicine*, 42(03), 270-276. <https://doi.org/10.1055/a-1236-3654>
- Kibler, W. B., Ludewig, P. M., McClure, P. W., Michener, L. A., Bak, K., & Sciascia, A. D. (2013). Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. *British journal of sports medicine*, 47(14), 877-885. <http://dx.doi.org/10.1136/bjsports2013092425>
- Kim, B., & Deshpande, A. D. (2017). An upper-body rehabilitation exoskeleton Harmony with an anatomical shoulder mechanism: design, modeling, control, and performance evaluation. *The international journal of robotics research*, 36(4), 414-435. <https://doi.org/10.1177/0278364917706743>
- Kim, J. E., Seo, T. B., & Kim, Y. P. (2019). The effect of a Janda-based stretching program range of motion, muscular strength, and pain in middle-aged women with self-reported muscular skeletal symptoms. *Journal of exercise rehabilitation*, 15(1), 123-128. <https://doi.org/10.12965%2Fjer.1836606.303>
- Kim, M. S. (2015). Influence of neck pain on cervical movement in the sagittal plane during smartphone use. *Journal of physical therapy science*, 27(1), 15-17. <https://doi.org/10.1589/jpts.27.15>

- Kim, Y., Lee, K., Moon, J., Koo, D., Park, J., Kim, K., ... & Shin, I. (2014). Effect of resistance training maintaining the joint angle-torque profile using a haptic-based machine on shoulder internal and external rotation. *Journal of physical therapy science*, 26(4), 525-528. <https://doi.org/10.1589/jpts.26.525>
- Kimura, Y., Tsuda, E., Hiraga, Y., Maeda, S., Sasaki, S., Sasaki, E., & Makino, M. (2014). Trunk motion and muscular strength affect knee valgus moment during single-leg landing after overhead stroke in badminton. *British journal of sports medicine*, 48(7), 620-620. <http://dx.doi.org/10.1136/bjsports-2014-093494.163>
- Kinder, J. M. (2018). *The relationship of hip muscle activation and the incidence of shoulder injury in collegiate women's volleyball athletes: a pilot study*. Doctoral Dissertation, North Dakota State University.
- Kinsella, R., Cowan, S. M., Watson, L., & Pizzari, T. (2017). A comparison of isometric, isotonic concentric and isotonic eccentric exercises in the physiotherapy management of subacromial pain syndrome/rotator cuff tendinopathy: study protocol for a pilot randomised controlled trial. *Pilot and feasibility studies*, 3(1), 2-12. <https://doi.org/10.1186/s40814017-0190-3>
- Kozieł, S. M., & Malina, R. M. (2018). Modified maturity offset prediction equations: validation in independent longitudinal samples of boys and girls. *Sports medicine*, 48(1), 221–236. <https://doi.org/10.1007/s40279-017-0750-y>
- Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports medicine*, 35, 339-361. <https://doi.org/10.2165/00007256-200535040-00004>
- Kuo, K. P., Liao, C. C., & Kao, C. C. (2022). Improving special ability performance of badminton players through a visual reaction training system. *Healthcare*, 10(8), 2-11. <https://doi.org/10.3390/healthcare10081454>
- Laffaye, G., Phomsoupha, M., & Dor, F. (2015). Changes in the game characteristics of a badminton match: a longitudinal study through the olympic game finals analysis in men's singles. *Journal of sports science & medicine*, 14(3), 584-590. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4541123/>
- Langenberg, B., Helm, J. L., & Mayer, A. (2022). Repeated measures ANOVA with latent variables to analyze interindividual differences in contrasts. *Multivariate behavioral research*, 57(1), 2-19. <https://doi.org/10.1080/00273171.2020.1803038>

- Lee, J. H., Park, S. J., & Na, S. S (2013). The effect of proprioceptive neuromuscular facilitation therapy on pain and function. *Journal of physical therapy science*, 26, 713-718. <https://doi.org/10.1589/jpts.25.713>
- Li, D. (2022). Psychological skills training of adolescent badminton players. *Advances in educational technology and psychology*, 6(5), 96-102. <https://dx.doi.org/10.23977/aetp.2022.060515>
- Li, X., Ma, R., Zhou, H., Thompson, M., Dawson, C., Nguyen, J., & Coleman, S. (2015). Evaluation of hip internal and external rotation range of motion as an injury risk factor for hip, abdominal and groin injuries in professional baseball players. *Orthopedic reviews*, 7(4), 111-115. <https://doi.org/10.4081%2For.2015.6142>
- Lim, H. Y., & Wong, S. H. (2018). Effects of isometric, eccentric, or heavy slow resistance exercises on pain and function in individuals with patellar tendinopathy: A systematic review. *Physiotherapy research international*, 23(4), 1-15. <https://doi.org/10.1002/pri.1721>
- Lin, H. T., Ko, H. T., Lee, K. C., Chen, Y. C., & Wang, D. C. (2015). The changes in shoulder rotation strength ratio for various shoulder positions and speeds in the scapular plane between baseball players and non-players. *Journal of physical therapy science*, 27(5), 1559-1563. <https://doi.org/10.1589/jpts.27.1559>
- Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Howard, R., Croix, M. B. D. S., Williams, C. A., & Myer, G. D. (2015). Long-term athletic development part 1: a pathway for all youth. *The journal of strength & conditioning research*, 29(5), 1439-1450. <https://doi.org/10.1519/JSC.0000000000000756>
- Lohrasbipeydeh, E., Geok, S. K., Dev, R. D. O., Ahrari, S., Leong, O. S., & Sunardi, J. (2021). Balance comparison between Iranian elderly with and without knee range of motion limitations. *Pertanika journal of social sciences & humanities*, 29(S1), 375 - 393. <https://doi.org/10.47836/pjssh.29.S1.20>
- Luk, H. Y., Winter, C., O'Neill, E., & Thompson, B. A. (2014). Comparison of muscle strength imbalance in powerlifters and jumpers. *The journal of strength & conditioning research*, 28(1), 23-27. <https://doi.org/10.1519/JSC.0b013e318295d311>
- Lum, D., & Barbosa, T. M. (2019). Brief review: effects of isometric strength training on strength and dynamic performance. *International journal of sports medicine*, 40(06), 363-375. <https://doi.org/10.1055/a-0863-4539>
- Lv, S., Wang, Q., Ni, Q., Qi, C., Ma, Y., Li, S., & Xu, Y. (2022). Progress of muscle chain theory in shoulder pain rehabilitation: potential ideas for pulmonary rehabilitation. *Evidence-based complementary and alternative medicine*, 2022, 2-10. <https://doi.org/10.1155/2022/2537957>

- Macías-Hernández, S. I., Morones-Alba, J. D., Miranda-Duarte, A., Coronado-Zarco, R., Soria-Bastida, M. D. L. A., Nava-Bringas, T & Palencia, C. (2017). Glenohumeral osteoarthritis: overview, therapy, and rehabilitation. *Disability and rehabilitation*, 39(16), 1674-1682. <https://doi.org/10.1080/09638288.2016.1207206>
- Madden, A. M., & Smith, S. (2016). Body composition and morphological assessment of nutritional status in adults: a review of anthropometric variables. *Journal of human nutrition and dietetics*, 29(1), 7-25. <https://doi.org/10.1111/jhn.12278>
- Magalhães, E., Silva, A. P. M., Sacramento, S. N., Martin, R. L., & Fukuda, T. Y. (2013). Isometric strength ratios of the hip musculature in females with patellofemoral pain: a comparison to pain-free controls. *The journal of strength & conditioning research*, 27(8), 2165-2170. <https://doi.org/10.1519/JSC.0b013e318279793d>
- Magnusson, S. P., & Kjaer, M. (2019). The impact of loading, unloading, ageing and injury on the human tendon. *The journal of physiology*, 597(5), 1283-1298. <https://doi.org/10.1113/JP275450>
- Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity. Human kinetics.*
- Malina, R. M., Koziół, S. M., Králik, M., Chrzanowska, M., & Suder, A. (2021). Prediction of maturity offset and age at peak height velocity in a longitudinal series of boys and girls. *American journal of human biology*, 33(6), 1-15. <https://doi.org/10.1002/ajhb.23551>
- Malliaras, P., Cook, J., Purdam, C., & Rio, E. (2015). Patellar tendinopathy: clinical diagnosis, load management, and advice for challenging case presentations. *journal of orthopaedic & sports physical therapy*, 45(11), 887-898. <https://www.jospt.org/doi/10.2519/jospt.2015.5987>
- Malliou, P. C., Giannakopoulos, K., Beneka, A. G., Gioftsidou, A., & Godolias, G. (2004). Effective ways of restoring muscular imbalances of the rotator cuff muscle group: a comparative study of various training methods. *British journal of sports medicine*, 38(6), 766-772. <https://dx.doi.org/10.1136/bjsm.2003.009548>
- Maly, T., Ford, K. R., Sugimoto, D., Izovska, J., Bujnovsky, D., Hank, M & Zahalka, F. (2021). Isokinetic strength, bilateral and unilateral strength differences: variation by age and laterality in elite youth football players. *International journal of morphology*, 39(1), 260-267
- Manske, R. C., & Reiman, M. P. (2007). Muscle weakness. in *physical rehabilitation: evidence-based examination, evaluation, and intervention*. Saunders Elsevier. <https://doi.org/10.1016/B978072160361-2.50008-9>
- Markovic, G., & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports medicine*, 40, 859-895. <https://doi.org/10.2165/11318370-000000000-00000>

- Maryam, S., Malhotra, D., Khan, S. A., Singla, D., & Zaidi, S. (2022). Shoulder rotator muscle imbalance in collegiate cricket bowlers: measurement by isokinetic dynamometer at different angular velocities. *Measurement: sensors*, 24(2022), 2-5. <https://doi.org/10.1016/j.measen.2022.100556>
- Matthews, M. J., Green, D., Matthews, H., & Swanwick, E. (2017). The effects of swimming fatigue on shoulder strength, range of motion, joint control, and performance in swimmers. *Physical therapy in sport*, 23, 118-122. <https://doi.org/10.1016/j.ptsp.2016.08.011>
- McLaine, S. J., Ginn, K. A., Kitic, C. M., Fell, J. W., & Bird, M. L. (2016). The reliability of strength tests performed in elevated shoulder positions using a handheld dynamometer. *Journal of sport rehabilitation*, 25(2), 1-11. <https://doi.org/10.1123/jsr.20150034>
- Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D & Urhausen, A. (2013). Prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of sport science (ECSS) and the American College of sports medicine (ACSM). *European journal of sport science*, 13(1), 1-24. <https://doi.org/10.1080/17461391.2012.730061>
- Mersmann, F., Charcharis, G., Bohm, S., & Arampatzis, A. (2017). Muscle and tendon adaptation in adolescence: elite volleyball athletes compared to untrained boys and girls. *Frontiers in physiology*, 8, 1-11. <https://doi.org/10.3389/fphys.2017.00417>
- Mignogna, C. A., Welsch, L. A., & Hoch, M. C. (2016). The effects of short-foot exercises on postural control: a critically appraised topic. *International Journal of athletic therapy and training*, 21(6), 8-12. <https://doi.org/10.1123/ijatt.20160049>
- Miller, A. H., Evans, K., Adams, R., Waddington, G., & Witchalls, J. (2018). Shoulder injury in water polo: a systematic review of incidence and intrinsic risk factors. *Journal of science and medicine in sport*, 21(4), 368-377. <https://doi.org/10.1016/j.jsams.2017.08.015>
- Moore, S. A., McKay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D., Cameron, N., & Brasher, P. M. (2015). Enhancing a somatic maturity prediction model. *Medicine & science in sports & exercise*, 47(8), 1755-1764. <https://doi.org/10.1249/MSS.0000000000000588>
- Mussa, B., Pinelli, F., Cortés Rey, N., Caguioa, J., Van Loon, F. H. J., Munoz Mozas, G., & Lepelletier, D. (2021). Qualitative interviews and supporting evidence to identify the positive impacts of multidisciplinary vascular access teams. *Hospital practice*, 49(3), 141-150. <https://doi.org/10.1080/21548331.2021.1909897>

- Myer, G. D., Ford, K. R., McLean, S. G., & Hewett, T. E. (2006). The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *The American journal of sports medicine*, 34(3), 445-455. <https://doi.org/10.1177/0363546505281241>
- Myer, G. D., Ford, K. R., Paterno, M. V., Nick, T. G., & Hewett, T. E. (2008). The effects of generalized joint laxity on risk of anterior cruciate ligament injury in young female athletes. *The American journal of sports medicine*, 36(6), 1073-1080. <https://doi.org/10.1177/0363546507313572>
- Myer, G. D., Quatman, C. E., Khoury, J., Wall, E. J., & Hewett, T. E. (2009). Youth versus adult "weightlifting" injuries presenting to United States emergency rooms: accidental versus nonaccidental injury mechanisms. *Journal of strength and conditioning research/national strength & conditioning association*, 23(7), 2054-260. <https://doi.org/10.1519%2FJSC.0b013e3181b86712>
- Nanda, A., Mohapatra, B. B., Mahapatra, A. P. K., Abiresh Prasad Kumar Mahapatra, A. P. K., & Mahapatra, A. P. K. (2021). Multiple comparison test by Tukey's honestly significant difference (HSD): do the confident level control type I error. *International journal of statistics and applied mathematics*, 6, 59-65.
- Nekooei, P., Tengku-Fadilah, T. K., Amri, S., Baki, R. B., Majlesi, S., & Nekouei, P. (2019). Anatomical shoulder movement strength imbalance among water polo overhead athletes. *International journal of kinesiology and sports science*, 7(2), 15-20. <http://dx.doi.org/10.7575/aiac.ijkss.v.7n.2p.15>
- Nekooei, P., Tengku-Fadilah, T. K., Amri, S., Baki, R. B., Majlesi, S., & Nekouei, P. (2021). *Effect of land and aquatic medicine ball training on shoulder imbalance among water polo players*. Doctoral Dissertation, UPM.
- Nitayarak, H., Charntaraviroj, P., & Nawarat, J. (2022). Investigation of muscle imbalance among asymptomatic and symptomatic neck pain male office workers. *Physiotherapy quarterly*, 30(2), 1-7. <https://doi.org/10.5114/pq.2021.108679>
- O'Neill, S., Radia, J., Bird, K., Rathleff, M. S., Bandholm, T., Jorgensen, M., & Thorborg, K. (2019). Acute sensory and motor response to 45-S heavy isometric holds for the plantar flexors in patients with Achilles tendinopathy. *Knee surgery, sports traumatology, arthroscopy*, 27(9), 2765-2773. <https://doi.org/10.1007/s00167-018-5050-z>
- Oleksy, L., Czarny, W., Bajorek, W., Krol, P., Mika, A., & Kielnar, R. (2018). The evaluation of shoulder muscle fatigue in volleyball players. *Journal of novel physiotherapies*, 8(2), 2-6 <https://doi.org/10.4172/2165-7025.1000388>

- Olivier, N., & Daussin, F. (2019). Isokinetic torque imbalances of shoulder of the french women's national water polo team. *Science & sports*, 34(2), 82-87. <https://doi.org/10.1016/j.scispo.2018.10.003>
- Ozmen, T., & Aydogmus, M. (2016). Effect of core strength training on dynamic balance and agility in adolescent badminton players. *Journal of bodywork and movement therapies*, 20(3), 565-570. <https://doi.org/10.1016/j.jbmt.2015.12.006>
- Page, P. (2011). Shoulder muscle imbalance and subacromial impingement syndrome in overhead athletes. *International journal of sports physical therapy*, 6(1), 51-58. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3105366/>
- Pallant, J. (2020). SPSS survival manual: a step by step guide to data analysis using IBM SPSS. McGraw-hill education (UK).
- Pardiwala, D. N., Subbiah, K., Rao, N., & Modi, R. (2020). Badminton injuries in elite athletes: a review of epidemiology and biomechanics. *Indian journal of orthopaedics*, 1-9. <https://doi.org/10.1007/s43465-020-00054-1>
- Parle, P. J., Riddiford-Harland, D. L., Howitt, C. D., & Lewis, J. S. (2017). Acute rotator cuff tendinopathy: does ice, low load isometric exercise, or a combination of the two produce an analgaesic effect?. *British journal of sports medicine*, 51(3), 208-209. <http://dx.doi.org/10.1136/bjsports-2016-096107>
- Patel, D. R., Yamasaki, A., & Brown, K. (2017). Epidemiology of sports-related musculoskeletal injuries in young athletes in United States. *Translational pediatrics*, 6(3), 160-166. <https://dx.doi.org/10.21037%2Ftp.2017.04.08>
- Paterno, M. V., Taylor-Haas, J. A., Myer, G. D., & Hewett, T. E. (2013). Prevention of overuse sports injuries in the young athlete. *Orthopedic clinics*, 44(4), 553-564. <https://doi.org/10.1016/j.ocl.2013.06.009>
- Pearson, S. J., & Hussain, S. R. (2015). A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. *Sports medicine*, 45, 187-200. <https://doi.org/10.1007/s40279-014-0264-9>
- Pearson, S. J., Stadler, S., Menz, H., Morrissey, D., Scott, I., Munteanu, S., & Malliaras, P. (2020). Immediate and short-term effects of short-and long-duration isometric contractions in patellar tendinopathy. *Clinical journal of sport medicine*, 30(4), 335-340. <https://doi.org/10.1097/JSM.0000000000000625>
- Pennock, A. T., Dwek, J., Levy, E., Stearns, P., Manning, J., Dennis, M. M., & Taylor, K. S. (2018). Shoulder MRI abnormalities in asymptomatic little league baseball players. *Orthopaedic journal of sports medicine*, 6(2), 2-6. <https://doi.org/10.1177%2F2325967118756825>

- Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports medicine*, 45(4), 473-495. <https://doi.org/10.1007/s40279-014-0287-2>
- Phomsoupha, M., & Laffaye, G. (2020). Injuries in badminton: a review. *Science & sports*. 35(4), 189-199. <https://doi.org/10.1016/j.scispo.2020.01.002>
- Plotkin, D. L., Roberts, M. D., Haun, C. T., & Schoenfeld, B. J. (2021). Muscle fiber type transitions with exercise training: Shifting perspectives. *Sports*, 9(9), 2-11. <https://doi.org/10.3390/sports9090127>
- Proske, U., & Gandevia, S. C. (2012). The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiological reviews*, 92(4), 1651-1686. <https://doi.org/10.1152/physrev.00048.2011>
- Rahrovan, S., Fanian, F., Mehryan, P., Humbert, P., & Firooz, A. (2018). Male versus female skin: what dermatologists and cosmeticians should know. *International journal of women's dermatology*, 4(3), 122-130. <https://doi.org/10.1016/j.ijwd.2018.03.002>
- Raman, D., & Nageswaran, A. (2013). Effect of game-specific strength training on selected physiological variables among badminton players. *International journal of scientific research*, 1(57.563), 57-563. <https://doi.org/10.1.1.683.6421&rep=rep1&type=pdf>
- Read, P. J., Oliver, J. L., De Ste Croix, M. B., Myer, G. D., & Lloyd, R. S. (2018). Landing kinematics in elite male youth soccer players of different chronologic ages and stages of maturation. *Journal of athletic training*, 53(4), 372-378. <https://dx.doi.org/10.4085%2F1062-6050-493-16>.
- Riemann, B. L., Davies, G. J., Ludwig, L., & Gardenhour, H. (2010). Hand-held dynamometer testing of the internal and external rotator musculature based on selected positions to establish normative data and unilateral ratios. *Journal of shoulder and elbow surgery*, 19(8), 1175-1183. <https://doi.org/10.1016/j.jse.2010.05.021>
- Rinaldo, N., Gualdi-Russo, E., & Zaccagni, L. (2021). Influence of size and maturity on injury in young elite soccer players. *International journal of environmental research and public health*, 18(6), 2-13. <https://doi.org/10.3390/ijerph18063120>
- Rio, E., Kidgell, D., Purdam, C., Gaida, J., Moseley, G. L., Pearce, A. J., & Cook, J. (2015). Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. *British journal of sports medicine*, 49(19), 1277-1283. <http://dx.doi.org/10.1136/bjsports-2014-094386>

- Rio, E., Van Ark, M., Docking, S., Moseley, G. L., Kidgell, D., Gaida, J. E & Cook, J. (2017). Isometric contractions are more analgesic than isotonic contractions for patellar tendon pain: an in-season randomized clinical trial. *Clinical journal of sport medicine*, 27(3), 253-259. <https://doi.org/10.1097/JSM.0000000000000364>
- Rojas-Valverde, D., Gómez-Carmona, C. D., Fernández-Fernández, J., García-López, J., García Tormo, V., Cabello-Manrique, D., & Pino-Ortega, J. (2020). Identification of games and sex-related activity profile in junior international badminton. *International journal of performance analysis in sport*, 20(3), 323-338. <https://doi.org/10.1080/24748668.2020.1745045>
- Rosa-Caldwell, M. E., & Greene, N. P. (2019). Muscle metabolism and atrophy: let's talk about sex. *Biology of sex differences*, 10(1), 1-14. <https://doi.org/10.1186/s13293-019-0257-3>
- Ruas, C. V., McManus, R. T., Bentes, C. M., & Costa, P. B. (2018). Acute effects of proprioceptive neuromuscular facilitation on peak torque and muscle imbalance. *Journal of functional morphology and kinesiology*, 3(4), 2-10. <https://doi.org/10.3390/jfmk3040063>
- Ruedl, G., Schobersberger, W., Pocecco, E., Blank, C., Engebretsen, L., Soligard, T., & Burtcher, M. (2012). Sport injuries and illnesses during the first winter youth olympic games 2012 in Innsbruck, Austria. *British journal of sports medicine*, 46(15), 1030-1037. <http://dx.doi.org/10.1136/bjsports-2012-091534>
- Sabzehparvar, E., Khaiyat, O. A., Ganji Namin, B., & Minoonejad, H. (2019). Electromyographic analysis in elite swimmers with shoulder pain during a functional task. *Sports biomechanics*, 1-11. <https://doi.org/10.1080/14763141.2019.1597153>
- Sadeghi, A., Rostami, M., Ameri, S., Karimi Moghaddam, A., Karimi Moghaddam, Z., & Zeraatchi, A. (2022). Effectiveness of isometric exercises on disability and pain of cervical spondylosis: a randomized controlled trial. *BMC sports science, medicine and rehabilitation*, 14(1), 2-17. <https://doi.org/10.1186/s13102-022-00500-7>
- Sasada, S., Endoh, T., Ishii, T., Kawashima, K., Sato, S., Hayashi, A., & Komiyama, T. (2020). Differential effects of transcranial direct current stimulation on sprint and endurance cycling. *Translational sports medicine*, 3(3), 204-212. <https://doi.org/10.1002/tsm2.129>
- Saunders, G. (2019). Tools of the trade: Massage tables, table accessories, linens, lubricants, essential oils, and the treatment room. *Massage therapy e-book: principles and practice*, 37.

- Savitzky, J. A., Abrams, L. R., Galluzzo, N. A., Ostrow, S. P., Protosow, T. J., Liu, S. A., & Friel, K. (2021). Effects of a novel rotator cuff rehabilitation device on shoulder strength and function. *Journal of strength and conditioning research*, 35(12), 3355-3363. <https://doi.org/10.1519/JSC.0000000000003347>
- Sawyer, S. M., Azzopardi, P. S., Wickremarathne, D., & Patton, G. C. (2018). The age of adolescence. *The lancet child & adolescent health*, 2(3), 223-228. [https://doi.org/10.1016/S2352-4642\(18\)30022-1](https://doi.org/10.1016/S2352-4642(18)30022-1)
- Schelling, X., & Torres-Ronda, L. (2016). An integrative approach to strength and neuromuscular power training for basketball. *Strength & conditioning journal*, 38(3), 72-80. <https://doi.org/10.1519/SSC.0000000000000219>
- Schlumberger, A., Laube, W., Bruhn, S., Herbeck, B., Dahlinger, M., Fenkart, G., & Mayer, F. (2006). Muscle imbalances—Fact or fiction?. *Isokinetics and exercise science*, 14(1), 3-11. <https://doi.org/10.3233/IES-2006-0229>
- Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *The journal of strength & conditioning research*, 24(10), 2857-2872. <https://doi.org/10.1519/JSC.0b013e3181e840f3>
- Schoenfeld, B. J., Ratamess, N. A., Peterson, M. D., Contreras, B., & Tiryaki Sonmez, G. (2015). Influence of resistance training frequency on muscular adaptations in well-trained men. *The journal of strength & conditioning research*, 29(7), 1821-1829. <https://doi.org/10.1519/JSC.0000000000000970>
- Schrama, P. P., Stenneberg, M. S., Lucas, C., & van Trijffel, E. (2014). Intraexaminer reliability of hand-held dynamometry in the upper extremity: a systematic review. *Archives of physical medicine and rehabilitation*, 95(12), 2444-2469. <https://doi.org/10.1016/j.apmr.2014.05.019>
- Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. John Wiley & sons.
- Seminati, E., & Minetti, A. E. (2013). Overuse in volleyball training/practice: A review on shoulder and spine-related injuries. *European journal of sport science*, 13(6), 732-743. <https://doi.org/10.1080/17461391.2013.773090>
- Seyed Hoseini, M. A., Barati, A. H., Shirzad Araghi, E., Akoochakian, M., & Naderifar, H. (2021). The comparison of lower extremity malalignment during hurdle preflight and traditional approach at forward diving straight. *Journal of rehabilitation sciences & research*, 8(3), 132-138. <https://doi.org/10.30476/jrsr.2021.89231.1128>
- Shah, P. K., & Koley, S. (2016). Swimmer's shoulder in athletes: comparison between efficacy of aquatic versus dry-land concentric-eccentric exercises. *Human biology review*, 5(2), 168-175.

- Sighamoney, R., Kad, R., & Yeole, U. L. (2018). Effect of core strengthening on dynamic balance and agility in badminton players. *International journal of physical education, sports and health*, 5(1), 86-88.
- Siregar, A. H. (2021). The Effectiveness of using the zondaag maandag traditional sports game model to improve learning outcomes of basic motion for children aged 10-12 years. *Budapest international research and critics institute-journal (BIRCI-journal)*, 4(1), 1226-1235. <https://doi.org/10.33258/birci.v4i1.1740>
- Slater, A., & Tiggemann, M. (2011). Gender differences in adolescent sport participation, teasing, self-objectification and body image concerns. *Journal of adolescence*, 34(3), 455-463. <https://doi.org/10.1016/j.adolescence.2010.06.007>
- Soldado, F., Fontecha, C. G., Marotta, M., Benito, D., Casaccia, M., Mascarenhas, V. V & Kozin, S. H. (2014). The role of muscle imbalance in the pathogenesis of shoulder contracture after neonatal brachial plexus palsy: a study in a rat model. *Journal of shoulder and elbow surgery*, 23(7), 1003-1009. <https://doi.org/10.1016/j.jse.2013.09.031>
- Soo Hoo, J. (2019). Shoulder pain and the weight-bearing shoulder in the wheelchair athlete. *Sports medicine and arthroscopy review*, 27(2), 42-47. <https://doi.org/10.1097/JSA.0000000000000241>
- Stastny, P., Lehnert, M., & Tufano, J. J. (2018). Muscle imbalances: testing and training functional eccentric hamstring strength in athletic populations. *Journal of visualized experiments*, 135, 1-7. <https://dx.doi.org/10.3791/57508>
- Stausholm, M. B., Baun, M., Bjordal, J. M., Nielsen, D., Aagaard, H., Magnusson, S. P., & Couppé, C. (2021). Shoulder rotational strength profiles of Danish national level badminton players. *International journal of sports physical therapy*, 16(2), 504-510. <https://doi.org/10.26603/001c.21531>
- Struyf, F., Tate, A., Kuppens, K., Feijen, S., & Michener, L. A. (2017). Musculoskeletal dysfunctions associated with swimmers' shoulder. *British journal of sports medicine*, 51(10), 775-780. <http://dx.doi.org/10.1136/bjsports-2016-096847>
- Suetta, C., Aagaard, P., Magnusson, S. P., Andersen, L. L., Sipila, S., Rosted, A., & Kjaer, M. (2007). Muscle size, neuromuscular activation, and rapid force characteristics in elderly men and women: effects of unilateral long-term disuse due to hip-osteoarthritis. *Journal of applied physiology*, 102(3), 942-948. <https://doi.org/10.1152/jappphysiol.00067.2006>
- Sumartiningsih, S. (2021). The Effect of Balance Training on Ankle Sprains in Badminton Players. *ACPES Journal of physical education, sport, and health (AJPESH)*, 1(1), 57-63. <https://orcid.org/0000-0002-3971-5092>

- Sung, D. J., Park, S. J., Kim, S., Kwon, M. S., & Lim, Y. T. (2016). Effects of core and non-dominant arm strength training on drive distance in elite golfers. *Journal of sport and health science*, 5(2), 219-225. <https://doi.org/10.1016/j.jshs.2014.12.006>
- Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: Issues in the study of expert performance in sport psychology. *Psychology of sport and exercise*, 16, 3-14. <https://doi.org/10.1016/j.psychsport.2014.07.004>
- Tabachnick, B. G., Fidell, L. S., & Ullman, J. B. (2013). *Using multivariate statistics* (Vol. 6, pp. 497-516). Boston, MA: pearson.
- Tank, S. N., & Shukla, Y. (2020). Effect of janda's approach on pain and function in patients with non-specific low back pain-an interventional study. *International journal of science and healthcare research*, 5, 216-221.
- Tarnopolsky, M. A. (2008). Sex differences in exercise metabolism and the role of 17 beta estradiol. *Medicine and science in sports and exercise*, 40(4), 648-654. <https://doi.org/10.1249/mss.0b013e31816212ff>
- Tatlici, A., Unlu, G., Cakmakci, E., & Cakmakci, O. (2021). Investigation of the relationship between strength and dynamic balance performance in elite wrestlers. *Ido movement for culture. journal of martial arts anthropology*, 21(3), 18-22. <http://dx.doi.org/10.14589/ido.21.3.3>
- Thakur, H. K., Pareek, P. A., & Sayyad, M. G. (2022). Comparison of bioelectrical impedance analysis and skinfold thickness to determine body fat percentage among young women. *Current research in nutrition and food science journal*, 10(1), 295-301. <http://dx.doi.org/10.12944/CRNFSJ.10.1.24>
- Thomas, G., Devine, K., & Molnár, G. (2022). Experiences and perceptions of women strength and conditioning coaches: a scoping review. *International sport coaching journal*, 10(1), 78-90. <https://doi.org/10.1123/iscj.2022-0026>
- Thompson, D., Karpe, F., Lafontan, M., & Frayn, K. (2012). Physical activity and exercise in the regulation of human adipose tissue physiology. *Physiological reviews*, 91(1), 157-191. <https://doi.org/10.1152/physrev.00012.2011>
- Tiwari, L. M., Rai, V., & Srinet, S. (2011). Relationship of selected motor fitness components with the performance of badminton player. *Asian journal physics education, computer science and sports*, 5(1), 88-91.
- Tonin, K., Stražar, K., Burger, H., & Vidmar, G. (2013). Adaptive changes in the dominant shoulders of female professional overhead athletes: mutual association and relation to shoulder injury. *International journal of rehabilitation research*, 36(3), 228-235. <https://doi.org/10.1097/MRR.0b013e32835d0b87>

- Tooth, C., Gofflot, A., Schwartz, C., Croisier, J. L., Beudart, C., Bruyère, O., & Forthomme, B. (2020). Risk factors of overuse shoulder injuries in overhead athletes: a systematic review. *Sports health*, 12(5), 478-487. <https://doi.org/10.1177%2F1941738120931764>
- Trinidad, A., González-Garcia, H., & López-Valenciano, A. (2021). An updated review of the epidemiology of swimming injuries. *The journal of injury, function and rehabilitation*, 13(9), 1005-1020. <https://doi.org/10.1002/pmrj.12503>
- Tülin, A. T. A. N., Keskin, D. Ö. Y., Çamlıdağ, İ., & Derebaşı, D. G. (2019). Analysis of dominant and non-dominant biceps and deltoid muscle volumes of badminton players. *Turkish journal of sport and exercise*, 21(2), 323-327. <https://doi.org/10.15314/tsed.496133>
- Victora, C. G., Huttly, S. R., Fuchs, S. C., & Olinto, M. T. (1997). The role of conceptual frameworks in epidemiological analysis: a hierarchical approach. *International journal of epidemiology*, 26(1), 224-227. <https://doi.org/10.1093/ije/26.1.224>
- Virgile, A., & Bishop, C. (2021). A narrative review of limb dominance: Task specificity and the importance of fitness testing. *The journal of strength & conditioning research*, 35(3), 846-858. <https://doi.org/10.1519/JSC.00000000000003851>
- Vithanage, S., Ratnadiwakara, M., Sandaruwan, D., Arunathileka, S. M. K. D., Weerasinghe, M., & Ranagsinghe, C. (2018). A novel approach to detect muscle strength imbalances via motion analysis using sensory inputs. *European journal of computer science and information technology*, 6(5), 37-50.
- Wang, I. L., Chen, Y. M., Jiang, Y. H., Wang, J., Chiu, W. C., & Chiu, Y. S. (2020). Immediate effect of acupuncture on performance in the drop jump task: a single-group pretest–posttest experimental study. *European journal of integrative medicine*, 36, 2-8. <https://doi.org/10.1016/j.eujim.2020.101120>
- Wasfy, M. M., & Lee, I. M. (2022). Examining the dose–response relationship between physical activity and health outcomes. *The New England journal of medicine evidence*, 1(12), 2-10. <https://doi.org/10.1056/EVIDra2200190>
- Wdowski, M., & Gittoes, M. J. (2020). Inter-limb step asymmetry in closed and open skill sprint accelerations in soccer players. *Human movement*, 22(1), 1-8. <https://doi.org/10.5114/hm.2021.98458>
- White, C. E., Dedrick, G. S., Apte, G. G., Sizer, P. S., & Brismée, J. M. (2012). The effect of isometric shoulder internal and external rotation on the acromiohumeral distance. *American journal of physical medicine & rehabilitation*, 91(3), 193-199. <https://doi.org/10.1097/PHM.0b013e31823c74ab>

- Whittaker, J. L., & Roos, E. M. (2019). A pragmatic approach to prevent post traumatic osteoarthritis after sport or exercise-related joint injury. *Best practice & research clinical rheumatology*, 33(1), 158-171. <https://doi.org/10.1016/j.berh.2019.02.008>
- Wiggins, A. J., Grandhi, R. K., Schneider, D. K., Stanfield, D., Webster, K. E., & Myer, G. D. (2016). Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *The American journal of sports medicine*, 44(7), 1861-1876. <https://doi.org/10.1177/0363546515621554>
- Wik, E. H., Martínez-Silván, D., Farooq, A., Cardinale, M., Johnson, A., & Bahr, R. (2020). Skeletal maturation and growth rates are related to bone and growth plate injuries in adolescent athletics. *Scandinavian journal of medicine & science in sports*, 30(5), 894-903. <https://doi.org/10.1111/sms.13635>
- Xu, K., ping Deng, W., & Du, Y. (2021). Experimental research on the influence of different group teaching on physical education course in colleges and universities: taking badminton course as an example. *International Journal of social sciences in universities*, 4(1), 15-20.
- Yadav, A., & Vaz, D. W. (2017). Comparative effect of isometric and isotonic training on speed of tennis players. *International journal of behavioral social and movement sciences*, 6(3), 53-59.
- Yaprak, Y. (2020). A comparison of the anaerobic power in sub-elite male racket and futsal players. *Journal of educational issues*, 6(1), 280-292. <https://doi.org/10.5296/jei.v6i1.17022>
- Yeom, S., Jeong, H., Lee, H., & Jeon, K. (2023). Effects of lumbar stabilization exercises on isokinetic strength and muscle tension in sedentary men. *Bioengineering*, 10(3), 2-12. <https://doi.org/10.3390/bioengineering1003042>
- Yıldırım, İ., Doğan, İ., Yıldırım, Y., & Karagöz, Ş. (2020). Investigation of the relationship between basal metabolic rate and body composition in young adults using CHAID analysis. *Progress in nutrition*, 22(1), 6-10. <https://doi.org/10.23751/pn.v22i1-S.9761>
- Yin, N. H., Fromme, P., McCarthy, I., & Birch, H. L. (2021). Individual variation in Achilles tendon morphology and geometry changes susceptibility to injury. *Elife*, 10, 1-15. <https://doi.org/10.7554/eLife.63204>
- Yoon, S. D., Sung, D. H., & Park, G. D. (2015). The effect of active core exercise on fitness and foot pressure in Taekwondo club students. *Journal of physical therapy science*, 27(2), 509-511. <https://doi.org/10.1589/jpts.27.509>

- Zemková, E., & Zapletalová, L. (2022). The role of neuromuscular control of postural and core stability in functional movement and athlete performance. *Frontiers in physiology*, 13, 1-12. <https://doi.org/10.3389/fphys.2022.796097>
- Zhang, Z., Li, S., Wan, B., Visentin, P., Jiang, Q., Dyck, M., & Shan, G. (2016). The influence of X-factor (trunk rotation) and experience on the quality of the badminton forehand smash. *Journal of human kinetics*, 53(1), 9-22. <https://dx.doi.org/10.1515%2Fhukin-2016-0006>
- Zuzgina, O., & Wdowski, M. M. (2019). Asymmetry of dominant and non-dominant shoulders in university level men and women volleyball players. *Human movement*, 20(2), 19-27. <https://dx.doi.org/10.5114/hm.2019.85095>

