«Effect of concentric and eccentric exercise-induced fatigue on proprioception, motor control and performance of the upper limb in handball players»

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Abstract

Purpose: To investigate the impact of concentric exercise-induced fatigue on proprioception, motor control, and performance of the upper-limb in handball athletes and non-athletes (healthy young adults). The second aim was to evaluate the impact of eccentric exercise-induced fatigue on proprioception, motor control, and upper-limb performance in handball athletes and compare its effects with concentric fatigue.

Methods: Forty-six and thirty-three handball players were included to study the effects of concentric and eccentric exercise-induced fatigue respectively, on the outcome measures. In addition, twenty healthy active males were recruited as non-athlete control subjects. Proprioception was evaluated using joint reposition sense (JRS), the threshold to detection of passive movement (TTDPM), motor control using the Y balance test upper quarter (YBT-UQ), and performance using the Athletic Shoulder test (ASH) before and immediately after fatigue intervention. Muscle onset latency (MOL) was assessed only after concentric exercise –induced fatigue. Fatigue protocol consisted of concentric or eccentric, maximal effort, and isokinetic contractions at 90˚/sec with sets of 30 repetitions (concentric) or 15 repetitions (eccentric) of the shoulder external and internal rotator muscles in the right arm. Fatigue was determined by a 60% 40% decline in the peak torque over three consecutive contractions despite reinforcing feedback and encouragement.

Results: After concentrically induced fatigue in handball players, a notable increase in absolute angular error (AAE) during joint repositioning, was found in all target angles in both external rotation (ER) and internal rotation (IR) directions ($p < 0.01$). In addition, a similar increase in TTDPM was found in internal rotation ($p=0.020$). Variable changes were found in YBT-UQ and ASH tests. Specifically, statistically significant differences were found in anteromedial (AM) ($p=0.041$), superolateral (SL) reach directions ($p=0.005$), composite score ($p=0.009$) in the right exercised hand and inferolateral (IL) reach direction in the left non-exercised hand ($p=0.020$) in the YBT-UQ. In addition, there was a significant reduction in isometric strength (ASH test) in the I position of the right hand ($p=0.010$) and all positions of the left hand ($p<0.05$). Furthermore, there was an increase of 47.37% in MOL scores after fatigue, but the increase was not significant ($p > 0.05$). Concentric fatigue in healthy non-handball players, induced a significant impairment in AAE at all target angles ($p < 0.05$). Moreover, there were no significant differences in kinesthesia (TTDPM), motor control (YBT-UQ), and performance (ASH test) before and after fatigue intervention ($p > 0.05$). After eccentric fatigue in handball players, a notable rise ($p < 0.05$) in AAE was detected in five of the six target angles (ER15˚, ER30˚, ER45˚, IR15˚, and IR30˚). No statistically significant change in the target angle of IR45˚ ($p = 0.967$). Furthermore, there was a significant increase in TTDPM ($p = 0.011$). The YBT-UQ test revealed statistically significant differences in all reach directions of the right hand. No statistically significant differences were found in the left hand ($p > 0.05$). The composite score (CS) shows a statistically significant difference only for the right hand ($p < 0.001$). Furthermore, after the eccentric fatigue, there was a decrease in the isometric strength in the ASH test for all hand positions on the right side and for two out of three test positions on the left side ($p < 0.05$). No significant change ($p = 0.063$) was found in the "T" Left-hand position.

Conclusions: Concentric exercise-induced fatigue of the rotator cuff muscles induces notable deficits in joint position awareness, kinesthesia, and motor control of the upper extremity in elite, male, handball players. Although fatigue reduces reflex reaction time, the effect is only marginal. In addition, concentric exercise-induced fatigue impaired proprioception but not motor control or performance in healthy non-athlete males. Furthermore, eccentric exercise-induced fatigue of the rotator cuff muscles can cause significant impairments in joint position awareness, kinesthesia, and motor control of the upper extremities in elite male handball players.

Keywords: Concentric exercise-induced fatigue, eccentric exercise-induced fatigue, shoulder, proprioception, motor control, performance, overhead athletes, handball, muscle onset latency, reflex reaction time, risk factors, shoulder injuries, joint position sense, kinesthesia.

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Declaration

"I declare that the regulations of the University of Nicosia carried out the manuscript in this thesis. Unless otherwise stated by reference or some other acknowledgment, the present thesis is written solely by me. It has not previously been submitted, in whole or in part, to this or any other organization for a degree, diploma, or other qualification".

Date: …………22/08/24………… **Signature: ………………**

Publications towards this Doctoral Thesis

List of Presentations

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2. Hadjisavvas S, Efstathiou MA, Themistocleous IC, Daskalaki K, Malliou P, Lewis J, Stefanakis M. Can resistance training improve throwing performance in handball players? A Systematic review and meta-analysis. BMC Sports Sci Med Rehabil. 2024 Apr 16;16(1):85. doi: 10.1186/s13102-024-00872-y.

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2. Hadjisavvas S, Efstathiou MA, Themistocleous IC, Malliou P, Giannaki CD, Stefanakis M. Concentric exercise-induced fatigue of the shoulder impairs proprioception but not motor control or performance in healthy young adults. Hum Mov Sci. 2024 Oct 25;98:103299.

Table of Contents

List of Tables

List of Figures

List of Abreviations

AAE	Absolute angular error
ACL	Anterior cruciate ligament
AJR	Active joint repositiong
AM	Anteromedial
ANS	Autonomic nervous system
ASH	Athletic Shoulder test
BES	Best evidence synthesis
BMI	Body mass index
BW	Body weight
CE	Constant error
CFFT	Critical flicker fusion threshold
CI	Confidence interval
CNS	Central nervous system
CS	Composite score
DA	Dopamine
EMG	Electromyography
ER	External roration
F	Female
GABA	Gamma-aminobutyric acid
GIRD	Glenohumeral internal rotation deficit
$H_{1}0 – H_{9}0$	Null hypothesis
$H_{1 –} H_{9}$	Alternative hypothesis
HIIT	High-intensity interval training
HR	Hazard rate ratios
I, Y, T	Initial assessment hand position in ASH
IL	Inferolateral
INF	Infraspinatus
IR	Internal rotation
JPS	Joint position sense
JRS	Joint repositiong sense
L-DOPA	4-dihydroxyphenylalanine
LFF	Low-frequency fatigue
M	Male
MeSH	Medical subject heading
MOL	Muscle onset latency
MU	Motor unit
MVC	Maximal voluntary contraction
N	Number of participants
NR	Not reported
OBLA	Onset blood lactate accumulation
OR	Odds ratios

OSTRC	Oslo Sports Trauma Research Center
P	Probability value
PD	Posterior deltoid
PJR	Passive joint repositioning
PNS	Peripheral nervous system
PR	Prevalence risk ratios
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
RAE	Relative angular error
ROM	Range of motion
ROS	Peactive oxygen species
RR	Relative risk ratios
SL	Superolateral
SPEx	Sports Injury Surveillance
TROM	Total range of motion
TTDPM	Threshold to detection of passive movement
VE	Variable error
VPL	Ventral posterior lateral
WOSI	Western Ontario Shoulder Index
YBT-UQ	Y balance test upper quarter
±	Standard deviation

Chapter 1 INTRODUCTION

1.0 Introduction

1.1 Epidemiology of shoulder pain

Disorders of the shoulder are a usual source of pain and impairment (Lucas et al., 2022). Following low back pain and cervical pain, shoulder discomfort ranks as the third most prevalent musculoskeletal condition (Urwini et al., 2004). The prognosis for persons experiencing musculoskeletal shoulder discomfort exhibits significant variation among individuals. On average, over 50% of individuals with shoulder pain continue to report symptoms six months after seeking primary care (Kuijpers et al., 2004). Overhead athletes, such as handball players, due to the nature of their sport, commonly experience shoulder injuries, which can be either acute or chronic (Gomoll et al., 2006).

1.2 Handball and shoulder injuries

Handball is a sport that imposes significant physical demands on participants, primarily due to the substantial amount of throwing required and the regular occurrence of physical contact (Aasheim et al., 2018). Shoulder pain and related issues pose a considerable health burden in senior handball players (Asker et al., 2018). Between nineteen to thirty-six percent of handball athletes experience shoulder soreness (Clarsen et al., 2014). Furthermore, around twenty-eight percent of these athletes encountere shoulder difficulties on a weekly basis (Myklebust et al., 2013; Mohseni-Bandpei et al., 2012). Most injuries predominantly happen during the latter portion of matches or the final part of training sessions (Langevoort et al., 2007; Junge et al., 2006; Piry et al., 2011) and fatigue is believed to be a potential explanation for this fact (Povoas et al., 2014).

1.3 Fatigue and proprioception

A decrease in a muscle's force or power production as a result of exercise, impacted by both peripheral and central mechanisms, is known as fatigue (Philips, 2015). This decline is correlated with an elevation in perceived exertion during physical activity (Gandevia, 2001). Muscle fatigue can reduce the sensitivity of muscle receptors causing disturbances in proprioception. The reduced sensitivity is the result of the accumulation of metabolites and inflammatory substances due to exercise (Pedersen et al., 1997, 1999). There is extensive documentation indicating a correlation between a diminished sense of proprioception and shoulder problems, including shoulder instability (Smith and Brunoli, 1989; Lubiatowski et al., 2019), impingment (Jerosch and Wustner, 2002), dysfunctions of the rotator cuff (Sahin et al., 2017), and adhesive capsulitis (Anderson and Wee, 2017; Fabis et al., 2017).

Proprioception refers to the collective neural input received by the central nervous system from the sensory mechanoreceptors, in various anatomical structures (Voight et al., 1996; Carpenter et al., 1998). Proprioception is commonly categorized into three submodalities: the awarness of tension (resistance), the awarness of movement, and the awarness of joint position (Franco et al., 2015).

Chapter 2 LITERATURE REVIEW

2.0 Literature review

2.1 Handball

Handball is a sport that presents significant physical challenges. It encompasses various motions such as running, jumping, throwing, along with interactions, both direct and indirect, with opponents (Aasheim et al., 2018; Asker et al., 2018).

Originally an outdoor game with two teams of eleven players, handball has evolved into an indoor sport with a team of seven players. This transformation is a testament to the sport's adaptability and its ability to cater to different environments. Handball is a widely embraced activity, practiced at various levels from recreational to professional. Its roots can be traced back to Scandinavia in the early 19th century. Today, it boasts a participation of around 19 million individuals (International Handball Federation, 2022). It has been a part of the Olympic games for men since 1972 and for women since 1976, further solidifying its global recognition.

The repetitive act of throwing, coupled with the substantial stresses exerted on the shoulder, can induce adaptive alterations in the dominant extremity (Sabick et al., 2005; Whiteley et al., 2006). In elite handball players and other athletes who toss the ball overhead without any symptoms, the angle between the abducted arm's maximum internal and maximum external rotation is known as the dominant arm's arc of motion, and it is typically shifted posteriorly. The abducted shoulder's enhanced external rotation and decreased internal rotation are indicative of this shift (Reagan et al., 2002; Osbahr et al., 2002). The throwing arm's laxity and range of motion will likely undergo alterations. Previous studies have indicated that handball players exhibit a greater total arc of motion, encompassing internal and external rotation, than individuals who do not engage in throwing activities. This is typically accompanied by an increase in external rotation and a decrease in internal rotation in the throwing shoulder (Pieper, 1998). According to one hypothesis, the observed rise in external rotation can be attributed to an adaptive augmentation in humeral retroversion.

Consequently, any significant deficiency in internal rotation exceeding 20° is believed to be associated with soft-tissue adaptation and pathological conditions (Pieper, 1998). Furthermore, overhead athletes may experience an increase in bone mineral density in their throwing arms and the acquired retroversion of the humerus (Braun et al., 2009). The anteroinferior glenohumeral ligament is another significant component that limits external rotation. The occurrence of repetitive ligament strains has the potential to induce micro-tears in the collagen fascicles and subsequent capsule laxity, hence facilitating heightened external rotation (Chambers and Altchek, 2013; Kuhn et al., 2005). Studies have indicated a decline in the external rotational strength of the dominant shoulders of throwers, accompanied by concurrent enhancements in the power of the internal rotator and adductor muscles (Noffal, 2003). The observed disparity between the ER's and IR's strength has been associated with shoulder discomfort (Wilk et al., 2002).

2.2 Physical requirements in handball

The physical requirements for a team handball player can be categorized as following (Laver et al, 2018):

- The capacity to engage in extended (2 x 30 minutes) intermittent physical activity (endurance), while effectively recuperate from brief, high-intensity physical activities.
- The capacity to engage in high-intensity physical activity
- The capacity to engage in sprinting
- The capacity to cultivate substantial physical strength and generate high-intensity output, as well as to effectively coordinate actions during competitive scenarios, including passing, shooting, jumping, altering direction, tackling, and throwing.

2.3 Epidemiology of shoulder injuries in handball

According to biomechanical research, the loads induced on the peri-articular anatomical structures of the shoulder during ball throwing can reach up to one and half times the body weight (BW) of a handball athlete (Pieper & Muschol, 2014; Karcher & Buchheit, 2014; Fieseler et al., 2017). As a result of these enormous loads, the shoulder is frequently injured, with 30% of these injuries being acute and 45% being severe, resulting in long-lasting discomfort (Doyscher et al., 2014; Almeida et al., 2013; Pieper & Muschol, 2014). During the deceleration in throwing motion, the rotator cuff undergoes significant tensile pressures due to its eccentric motion, potentially resulting in injury (Wilk et al., 2009).

Asker et al. (2020) aimed to weekly document the occurrence of shoulder problems in 341 healthy handball athletes weekly throughout one or two seasons. The results showed that a total of 48 injuries had been caused to the shoulder and specifically to the dominant arm (26 injuries in women and 22 injuries in men). Additionally, 42 out of 48 injuries (88%) were overuse injuries. The incidence of shoulder injuries was 0.71 per 1000 hours of general game time in men and 0.92 injuries per 1000 hours of general game time in women.

Achenbach et al. (2020) employed online software to administer a specialized questionnaire to handball players on five separate occasions to document instances of shoulder overuse injuries. The findings indicated that 36 handball players, comprising of 17 boys and 19 girls, encountered shoulder pain or signs of overuse injury in their dominant hand during the game season, accounting for 26% of the total injuries. Fifteen players (11%) had previous shoulder injuries (dislocation, rotator cuff injury, labrum, and clavicle injury) before participating in the study.

In the study by Clarsen et al. (2014) involving 206 professional Norwegian league handball players in the 2011-2012 season, shoulder injuries were recorded. The results showed that 108 players (52%) had developed a problem with the dominant shoulder during the game season while fifteen of the 108 players had reported mild shoulder pain. In addition, 50 players reported moderate or severe limitations in their sports activities and athletic performance due to shoulder problems. Additionally, fifty-five players (27%) had reported a problem with the non-dominant shoulder, of which seven experienced mild pain and forteen more severe symptoms.

Aasheim et al. (2018) aimed to record overuse injuries in handball players aged 16-18 during the game season. A total of 145 male players participated in the study. The Oslo Sports Trauma Research Center overuse injury questionnaire was sent to all players sixteen times to record injuries. The results showed that the mean prevalence rate for all overuse injuries in all anatomical regions of the body was 39% and 15% for severe injuries. The anatomical region that showed the highest prevalence of injuries was the shoulder.

Myklebust et al. (2013) aimed to record shoulder injuries in female professional athletes from the Norwegian league during the 2007-2008 season. Of the one hundred seventy-nine athletes who participated, sixty-five (36%) reported current shoulder pain and forty (22%) reported that they never had experienced shoulder pain in the past. Female athletes who reported experiencing pain in the past were significantly older compared to female athletes who did not report shoulder pain. Ten players experienced bilateral pain, whereas five only reported pain in their non-dominant shoulder. Of the players experiencing shoulder pain, almost all felt pain in their dominant arm. Of the players (n = 65) who reported experiencing shoulder pain at the time of being asked, eleven had complained of the pain within the four weeks prior to the test; six players had complained of the pain for five to 26 weeks; seven players (19.4%) for twenty-seven to fifty-two weeks; and twelve players (33.3%) for more than a year. Of the players who reported experiencing pain at the time of being asked, , 34 individuals (52.3%) reported experiencing shoulder pain during handball. Additionally, ten players (15.4%) experienced pain after engaging in handball activities. Furthermore, sixteen players (24.6%) reported experiencing intermittent pain irrespective of their handball exposure, while one player (1.5%) reported experiencing persistent pain.

The study by Moller et al. (2017) included 679 (49% female) handball players (14-18 years), and their shoulder injuries were recorded every week. The results showed that by the 679 players, 709 new injuries were reported of which 85 shoulder injuries occurred during 73546 hours of handball activity.

Another study (Andersson et al., 2018), reported that eighty-seven male players (52%) and sixty-eight female players (43%) who had participated in the previous handball season reported having shoulder pain at the follow-up. Furthermore, forty-seven male players (28%) and forty-nine female players (31%), reported having shoulder ache at the time of being asked. In the past seven days, eighty-two male players (49%) and seventy-four female players (46%) reported having a shoulder issue. Of these, substantial shoulder difficulties were reported by twenty-five female players (13%) and twenty-one male players (16%) of them.

Giroto et al. (2017), aimed to investigate the incidence for handball injuries in Brazilian elite handball players. Over the course of a season, 339 players from 21 handball teams who competed in the two major Brazilian championships were monitored. A total of 201 athletes reported 312 injuries. The injury incidence rate was 20.3/1000 matches and 3.7/1000 hours during training. Traumatic injury was most common in the knee (13.5%, n = 32) and ankle (19.4%, n = 46). Overuse injuries were most common in the knee (26.7%, n = 20) and shoulders (44.0%, n = 33).

According to the provided data, it appears that handball players are more prone to shoulder injuries. Moreover, the incidence of shoulder injuries is comparable between males and females. Given the gravity of shoulder injuries, it appears that if a handball player experiences a shoulder issue, there is a significant likelihood that it will impede the athlete's sports activities and performance. However, more studies are necessary to investigate the correlation between shoulder pain and/or injury on performance. Moreover, the majority of injuries were observed in the dominant hand, with a significant proportion of these injuries being attributed to overuse. This implies that the combination of recurrent overhead throwing actions over a period of time and fatigue in athletes can lead to an overuse injury.

2.4 Fatigue and handball injuries

Dirx et al. (1992) reported an elevated occurrence of injuries in the latter half of matches, ascribed to the escalating fatigue experienced by players and the heightened intensity of closely contested bouts. According to Asembo and Wekesa (1998), most injuries (57%) were also observed during the game's latter half. Luig et al. (2017) examined data from the initial two professional German leagues from 2010 to 2016 in their study. Their findings revealed a comparable distribution of injuries throughout the two halves, with a notable concentration of injuries observed during the latter ten minutes of each half (Bere et al., 2015). The disparity in time-loss injuries between the first and second halves was notably more significant, with 68.5 and 29.1 injuries per 1000 hours, respectively.

2.5 Definition of Fatigue

"Fatigue" is defined as the decline in physical performance that occurs when the actual or perceived difficulty of a task or exercise increases (Gandevia, 2001). Fatigue during muscle activity is characterized by the incapacity to sustain the necessary level of strength (Allman and Rice 2002). The definition above is linked to a "breakpoint," the abrupt onset of weariness and the incapacity to maintain physical activity (Boyas and Guevel, 2011). Nevertheless, numerous neurophysiological pathways are disrupted before the body experiences the impact of weariness, and these alterations might occasionally serve as a preliminary indication of fatigue (Place et al., 2010). In addition, exercise causes changes in the early conditions of the neuromuscular system, such as energy stores, ion concentrations, and contractile protein arrangement. Fatigue gradually intensifies until the muscle cannot carry out the specified task (Boyas and Guevel, 2010). Neuromuscular fatigue refers to the decrease in force or power due to exercise, irrespective of the ability to maintain the task (Bigland-Ritchie and Woods, 1984).

2.6 Classification of fatigue

Depending on the onset time, fatigue is divided into acute (normal/after physical activity) and chronic (pathological) fatigue. In acute fatigue, the onset or worsening of fatigue occurs within six weeks or less in contrast to chronic fatigue, where fatigue remains for long periods, for more than six weeks (Piper et al., 1989). Pathological chronic fatigue is commonly associated with diseases such as cancer, chronic obstructive pulmonary disease (Ream & Richardson, 1997), rheumatoid arthritis, major depressive disorder (Lavidor et al., 2002), and fibromyalgia (Drayer et al., 2005). Other data shows a possible association with diabetes mellitus (Fritschi & Quinn, 2010).

According to Phillips (2015), exercise-induced weariness is divided into central and peripheral. Peripheral fatigue is defined as a reduction in maximal muscle strength or motor capacity due to overexertion, from prolonged or intense physical activity and is the result of neuromuscular dysfunction in areas outside the central nervous system (O'Connell & Stokes, 2014). It is associated with impaired transmission of peripheral nerve impulses and impairments in muscle contraction (Aaronson et al., 1999). Central fatigue is caused by "central" factors such as the nerve signals responsible for muscle activation and transmission of the stimulus to the central nervous system (Gandevia, 2001).

Fatigue can arise from various factors, including the transmission of commands from the Central nervous system (CNS) to the motoneurons via the specific pathways, the main motor cortex being active, the propagation of neuromuscular signals, the connection between contraction and excitation, the blood flow, the intracellular medium condition, the metabolic substrate availability, the contractile apparatus performance, and the contraction of the motor units (Boyas and Guevel, 2011). The mechanisms and physiological areas that can be impacted by neuromuscular fatigue and, consequently, may be the cause of a reduction in force generation are covered below.

2.7 Etiology of fatigue

2.7.1 Central fatigue

Historically, authors believed that central weariness originated from any disruption in the neuromuscular transmission that impacts cross bridges. Central tiredness, however, appears to originate in the brain, according to current studies (Zajac et al., 2015). Central fatigue refers to a decrease in the motivational drive from the motor cortex, which leads to a reduction in performance or even cessation of activity. This occurs when inhibitory and excitatory processes are impaired (Ament and Verkerke, 2009). Exercise-induced extracellular serotonin accumulation, along with other substances such as dopamine, gamma-aminobutyric acid, is one of the important elements that leads to metabolic changes (Tornero-Aguilera et al., 2022). Dopamine's role in the exhaustion process is associated with its extracellular space build-up brought on by dopaminergic activity, which modifies the dopamine and serotonin balance. Furthermore, serotonergic projections connect with the hypothalamus and the thermoregulatory center regions. Observations have shown that when exercise intensity increases, there is an increase in serotonergic activity which leads to a sensation of lethargy, a decrease in neural drive, and, ultimately, a decrease in motor unit recruitment (Tornero-Aguilera et al., 2022).

Dopamine (DO) is a neurotransmitter that plays a role in central fatigue mechanisms (Tornero-Aguilera et al., 2022). The process of delaying the development of fatigue is linked to the release of DO. The role of DO neurotransmission in causing weariness during exercise is a possible explanation (Cordeiro et al., 2017).

Glutamate (GL) is produced from structures obtained from carbohydrate substrates, provided that an amino group is present (Maddock et al., 2011). The execution of GL in exercise-induced weariness has been suggested, however, the specific mechanism remains unclear. Animal studies (Yeh et al., 2005; Wang and Wang, 2018) seek to ascertain the pivotal role of glutamate transporter-1 (GL-1) in regulating weariness generated by exercise. The release of GL-1 can be reduced after exhaustion produced by exercise. Suppressing the supply of GL-1 led to a reduction in exercise endurance, accompanied with a decline in lactate and elevation in GL levels in GL. In addition, the presence of GL-1 in the motor region seemed to diminish following an intense exercise regimen, followed with an elevation in glutamate concentration outside the cells. The decrease in extracellular lactate levels may be linked to the development of weariness (Tornero-Aguilera et al., 2022).

GABA, a neurotransmitter crucial for maintaining the balance of neuronal activity in the CNS, is produced by the action of glutamic acid decarboxylase. Studies have indicated that following an intense exercise, there is a substantial rise in GABA levels inside the sensorimotor cortex. This fact is associated with the elevation of blood lactate levels (Maddock et al., 2011; Coxon et al., 2018).

One additional reason for central tiredness is the alterations that take place at the level of the vertebral column regarding the sensory input from the muscular and tendon receptors (Gandevia, 2001).

CNS exhaustion affects physical performance and leads to cognitive weariness, which is linked to behavioral and mood issues. Continuing a severe condition of the central nervous system, tiredness can result in sleep disruptions, depression, pain, fatigue, challenges in sustaining cognitive alertness, and difficulties in retaining mental focus (Leavitt and DeLuca, 2010; Chaudhuri and Behan, 2000).

2.7.2 Peripheral fatigue

Peripheral fatigue refers to the decrease in the effectiveness of the connection between the nerves and muscles due to the expansion of metabolites (Myburgh, 2004). This weariness is particularly severe during intense exercise, as the expansion of metabolites may influence the interaction between myosin and actin cross-bridges. Consequently, the enzyme of ATP is decreased, maintaining a proportional correlation with the contraction rate. Fatigue occurs in a metabolic environment characterized by decreased PH amounts and acidosis. The buildup of PO4 (phosphate) marks this environment. Both components diminish the muscle fiber's capacity to produce force (Woodward et al., 2018).

Peripheral weariness is highly correlated with alterations in the internal environment, specifically in maintaining homeostasis (Tornero-Aguilera et al., 2022). The fundamental changes during exercise occur when the onset of blood lactate accumulation (OBLA) level is surpassed. The buildup of phosphates and hydrogens in the sarcoplasm can decrease muscle contraction strength by inhibiting the cross-bridge interaction. Calcium intake from the sarcoplasmic reticulum may also be influenced by changes in energy reserves, a decrease in glycogen stores, and, in severe situations, a reduction in blood glucose levels. Even a brief decline in blood glucose levels can significantly disrupt CNS activities (Tornero-Aguilera et al., 2022). In addition, exercise-induced tiredness can impact the velocity of the action potential across the sarcolemma, likely due to biochemical alterations occurring in the muscle fiber's surroundings. Another crucial element is the increased outflow of potassium ions (K+) from muscle fibers. An elevation in potassium levels within the T-tubules can obstruct the tubular action potential, leading to a decrease in force caused by a decline in excitation-contraction coupling (Tornero-Aguilera et al., 2022; Whitten et al., 2021). Moreover, research has demonstrated that the replenishment of electrolytes occurs more rapidly than the restoration of pH levels during periods of tiredness, hence adversely impacting on muscular contractions (Kelly et al., 2008; Deglado-Moreno et al., 2018; Chycki et al., 2018; Whitten et al., 2021).

Additionally, there is evidence indicating the occurrence of an inflammatory response to physical activity and the presence of peripheral weariness. Neuroinflammatory pathways are the primary processes of fatigue (Proschinger and Freese, 2019). Muscles' local production of IL6 during exercise is linked to managing glucose homeostasis as an energy source. This production is directly related to the duration of the activity (Steenberg et al., 2000). Moreover, after exercising, the highest level of IL6 and IL1Ra production in the local muscles is directly related to the intensity of the activity. However, the synthesis of IL6 is not linked to muscle injury (Trinh et al., 2021). Another consequence of fatigue-induced muscle injury during exercise is the release of IL6, as shown from the beginning of the activity (Trinh et al., 2021).

Fatigue is an intricate and multifaceted phenomenon that involves multiple organic systems. Tornero-Aguilera et al. (2022) proposed the “governor’s fatigue theory” according to which fatigue has repercussions at various psychological and physiological levels (Tornero-Aguilera et al., 2022).

2.8 Other factors that contribute to fatigue

2.8.1 Rest and sleep

Sleep deprivation can alter the psychological reactions associated with weariness. Research has shown that sleeping 7 to 8 hours is enough to support mental well-being and achieve optimal cognitive functioning. Lock et al., (2018) in their review paper have summarized the psychological responses linked linked to weariness as a contributor to inadequate sleep:

- Diminished alertness.
- Worse cognitive function.
- Slower cognitive processing.
- Inflexible thinking.
- Challenges in absorbing new knowledge.
- Increased difficulties in completing brief tasks.

2.8.2 Gender

Females would experience a higher subjective impression of weariness (LaSorda et al., 2020). Furthermore, the physiological aspects specific to females (e.g menstrual cycle) significantly influence performance, perception, and the manifestation of weariness (Shimo et al., 2021). In addition, women exhibit lower fatigue levels than men, which can be attributed to variances in neuromuscular, physiological, and anatomical characteristics (Bensing et al., 1999). For example, males are more muscular in general and specific muscles exhibit a greater relative size and possess a higher metabolic and functional speed (Porter et al., 2002; Roepstorff et al., 2002). Furthermore, sex-specific hormones such as androgens and estrogens lead to greater strength and power in males than in females. This results in a higher capacity for force and energy generation (Maher et al., 2009; Wan et al., 2017).

2.9 Assessment methods of fatigue

The two main methods used to quantify tiredness include measuring voluntary and electrically stimulated muscular force generation, as well as evaluating low frequency fatigue. Both approaches are conducted in a laboratory setting and necessitate meticulous processes to ensure precise outcomes. The evaluation of force generation is unable to identify restrictions originating from the central or peripheral regions, so it cannot ascertain the underlying mechanisms responsible for the development of fatigue. The measurement of low frequency fatigue is conducted on a limited amount of muscle mass, which restricts its relevance to real-world sport and exercise scenarios (Vollestad, 1997). The torque responses to various electrical stimulation frequencies are usually recorded in order to quantify low-frequency fatigue (large surface electrodes are used to stimulate the muscle over the motor point of a muscle or placed near the motor nerve) (Skurvydas et al., 2000; Keeton et al., 2006). The change in the ratio of force output with 20 Hz stimulation to that with 50 Hz or 80 Hz stimulation is a frequently used indicator of LFF (Jones, 1996; Keeton et al., 2006). LFF is typically defined as any decline in this ratio between before and after exposure to a fatiguing treatment (Martin et al., 2004).Indirect techniques for evaluating fatigue include tests measuring the time to exhaustion, electromyography, muscle biopsies, blood collection, perceptual assessments, and magnetic resonance imaging (Rondelli et al., 2009). Each of these measurements has both advantages and disadvantages in terms of their capacity to provide insights into the development of fatigue during exercise (Rondelli et al., 2009). Various factors, such as the particular research design, equipment availability, ethical and consent-related limitations, and the researcher's informed decision on which methods will yield information that can effectively quantify the potential causes of fatigue development during the exercise protocol or research scenario being used, will determine which method to use (Vollestad, 1997).

2.10 Fatigue and proprioception

Muscle fatigue has been postulated to potentially hinder proprioceptive acuity through the elevation of discharge of muscle receptors threshold and the disruption of afferent information. The observed decline in proprioception following fatigue-induced exercise may be attributed to increased inflammatory substances and metabolites into the muscle. These substances directly influence the release pattern of muscle spindles and the activation of alpha-gamma receptors

(Pedersen et al., 1997, 1999). The presence of metabolites and/or inflammatory chemicals in the muscle during fatigue-inducing exercise modifies proprioceptive input by increasing the threshold for muscle spindle release (Pedersen et al., 1997; Djupsjobacka et al., 1995)

On the other hand, changes in alpha/gamma co-activation or activation of alpha motoneuron resulting from exhaustion might impact the excitability of the muscle spindle via stretching (Marks & Quinney, 1993). Changes in the central processing of proprioceptive signals brought on by fatigue processes in the Central Nervous System are primarily responsible for the reduction in proprioceptive acuity during tasking activities. According to Miura et al. (2004), central tiredness can decrease the precision of motor control and disrupt voluntary muscle-stabilizing activity to counteract applied joint stresses. Certain writers have attributed the proprioceptive impairments observed in their exercise programs, which incorporated eccentric contractions, to the muscular damage generated by exercise (Torres et al., 2010; Fortier et al., 2010; Holy et al., 2019). However, it is improbable that the observed changes were primarily caused by damage to muscle mechanoreceptors. This is supported by research on animal models, which demonstrated that, unlike extrafusal fibers, a sequence of eccentric contractions does not impact internal fibers of muscle spindles (Gregory et al., 2004) or tendon organs (Gregory et al., 2002).

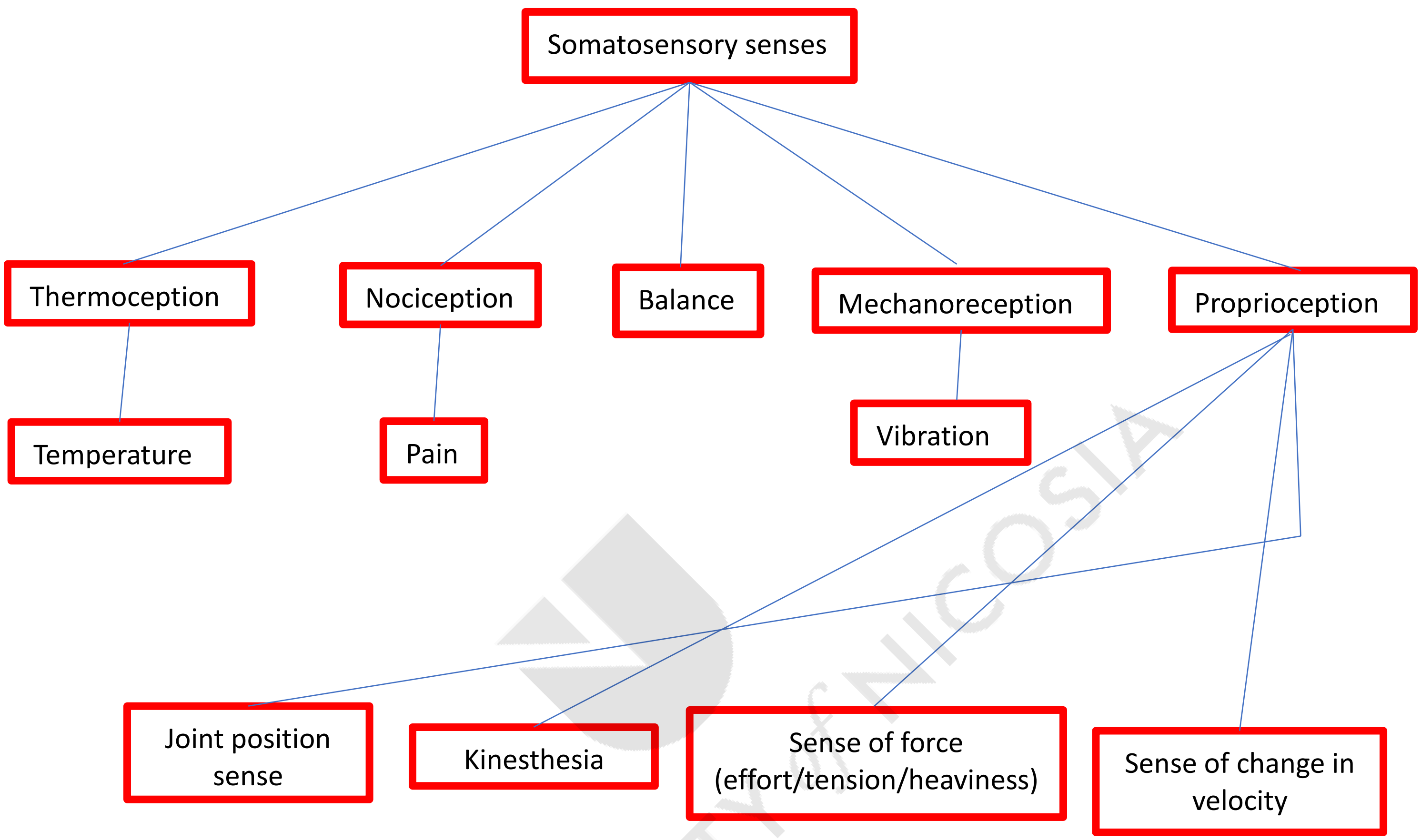
2.11 Definition of proprioception and categorization

The human body depends on many sensory inputs to regulate performance of daily activities. The necessity for intagrating significant senses, which encompass our visual, vestibular, auditory, olfaction, and tactile sensations, to prevent potentially hazardous circumstances is well acknowledged (Ager et al., 2020). However, it is frequently overlooked that body’s "sixth sense," known as somatosensation, encompasses other sensory modalities such as thermoception, nociception, equilibrioception, mechanoreception, and proprioception. Sherrington (1906) was the first researcher to define proprioception as the capacity to perceive the spatial relationship between the body's extremities and joints, even without visual cues (Han et al., 2016). Furthermore, proprioception has been defined by other researchers as the conscious and unconscious evaluation of the position and motion of a joint (Myers et al., 1999; Lephart et al., 1997). In contrast, kinesthesia refers to the perception of joint movement and its attributes, such as whether the movement is accelerated or decelerated (i.e., the variation in the speed of joint movement) (Swanik et al., 2002; Swanik et al., 2004).

Proprioception is attained by aggregating peripheral sensory data documenting the extent and alterations in muscle length, tension, joint angle, and skin elongation (Proske & Gandevia, 2012). Proprioception controls and regulates muscle stiffness during movements, ensuring sufficient joint stability, coordination, and balance (Riemann & Lephart, 2002; Roijeson et al., 2015). The perception of force exerted during joint motions results from the sensory receptors receiving information regarding their locations, movements, and loads. Subsequently, the receptors convey the centripetal signal to the CNS through the spinal cord. Conscious awareness of the position, movement, and force generated at a joint is acquired through this process. This information is essential since it is derived from the central nervous system's response via the central pathways, enabling accurate and contextually suitable joint functionality. Conversely, the concept of unconscious proprioception exists, which serves as the regulator of muscular action, facilitating the attainment of reflexive stabilization simultaneously (Riemann & Lephart, 2002).

The concept of proprioception encompasses several subcategories (figure 2.1), including joint position awarness, kinesthesia, awarness of force, sense of velocity, and the sense of vibration (Kerr & Worringham, 2002; Arzi et al., 2014; Franco et al., 2015). For joint position sense to be satisfactory, the human body must have the ability to sense the position of any joint at all times during voluntary active movements and involuntary passive movements (Riemann & Lephart, 2002; Dover & Powers, 2003). To achieve a good level of kinaesthesia, it is essential to possess the capacity to perceive both active and passive movements (Riemann & Lephart, 2002; Dover & Powers, 2003). Force sense is the ability to estimate and recognize the force applied to a joint and the human's ability to reproduce a force at the desired level (Myers & Lephart, 2000). The sense of change in velocity refers to the ability to perceive and measure the speed at which a limb moves around a joint (Soltys & Wilson, 2008).

Figure 2.1. The multimodal sensory system. Adapted from (Ager et al, 2020).



2.12 Mechanoreceptors

Mechanoreceptors are the primary sensory structures that provide information about mechanical changes in the internal and external environment (French & Torkkeli, 2009). All sensory information of proprioception is initially recognized and received by the mechanoreceptors. Mechanoreceptors are found in muscles, intramuscular tissues, bursa, ligaments, periosteum, and skin. They are responsible for detecting mechanical alterations in tissues and transmitting the corresponding sensory data to the Central Nervous System for cerebral analysis (Gilman, 2002). There are several types of mechanoreceptors, including Golgi tendon organs, muscle spindles, Pacinian corpuscles, Ruffini end organs, and free nerve endings (Jha et al., 2017).

In joints, there are three different morphological forms of mechanoreceptors: free nerve terminals, Meissner corpuscles, and Paccini corpuscles. These mechanoreceptors fall into one of two categories: slow adapting, which discharges continuously as long as the stimulus is there, or quick adapting, which stops discharging soon after the stimulus begins. Fast-adapting mechanoreceptors in healthy joints are hypothesized to give motor sensations, both conscious and unconscious, in response to joint movement or acceleration. Slow-adapting mechanoreceptors, on the other hand, provide constant feedback and proprioceptive information regarding joint position sense (Roijeson et al., 2015).

Proprioception, kinesthesia, and force perception are all influenced by the pressure and stretch mechanoreceptors in the skin (Proske and Gandevia, 2012). The intuitive nature of their contribution to the perception of force is evident since the compression of the skin by the fingers and hand during object grabbing indicates the force is applied to the object. Similarly, joint movement causes the skin at a joint to stretch and compress, thereby stimulating cutaneous receptors and contributing to the sense of joint position and movement (Proske and Gandevia, 2012).

The muscle spindles and the organs of the Golgi tendon are the mechanoreceptors found in the musculo-tendinous complex. In all skeletal muscles, the muscle spindles that run parallel to the extrafusal muscle fibers are commonly thought to be the main source of proprioception (Proske and Gandevia, 2012). These receptors are specialized fibers located inside the muscle that are responsible for detecting alterations in muscle length, as well as the velocity of contraction. When a muscle undergoes passive lengthening, it generates spindle afferent signals that are subsequently interpreted as a perception of movement (Banks et al., 2021). As the velocities of the muscle increase, there is a corresponding increase in the response. The spindle system can predict changes in length due to its ability to detect velocity and size, with the latter exhibiting a higher rate of change. During contractions, the muscle spindle is subject to fusimotor control, specifically the gamma system. This control can modify the calibration or sensitivity of the receptor by adjusting its internal length. The modulation process enables the receptors to adapt during action and facilitates simulation without actual action (Banks et al., 2021). The role of thixotrophy, which illustrates the connection between a muscle's characteristics and its recent history of contracting/lengthening, is closely linked to the sensitivity of the spindle. The property of muscle, including muscle spindles, impacts proprioception. Specifically, proprioception, which refers to the sensitivity of the spindle, can be modified based on whether the muscle has had recent contractions (Macefield and Knellwolf, 2018).

The Golgi tendon organ encircles the ends of the muscle's intrafusal fibers and is situated at the musculotendinous junction. It is responsive to the tension that is created in the muscle by either active contraction or passive stretching (Moore, 1984). When excessive tension develops in the muscle, the Golgi tendon organ fires, inhibiting alpha motor neuron activity and reducing muscle tension. Details for the mechanoreceptors of the human body are presented in Table 2.1

Table 2.1 Mechanoreceptors of the human body. Adapted from (Roijeson et al, 2015).

Body Region	Mechanoreceptor	Stimulation
Musculo-tendinous junction	Muscle spindle Golgi tendon	Change in muscle length The rate at which muscle length changes. Muscular contraction
Joint	Mazzoni Paccinian Ruffini Golgi	Tension and compression loads at both low and high levels across the whole range of motion.
Fascia	Pacinian Ruffini	Tensile loads experienced at both low and high levels during joint movement.
Skin	Trichoreceptor Pacinian Ruffini Meissner Merkel	Joint movement can result in superficial tissue deformation, stretching, or compression.

2.13 Mechanoreceptors of the shoulder

Capsulo-ligamentous shoulder mechanoreceptors are most stimulated at extreme angles of shoulder external rotation (Janwantanakul et al., 2001). The scapular muscles play a crucial role in proprioceptive information via muscle spindles, and any injury to these muscles will result in impaired proprioception in the middle angles of the glenohumeral range of motion. However, at the extreme angles of the range of motion, the capsule-ligamentous mechanoreceptors can compensate for this incorrect sensory information (Yang et al., 2010). According to Blasier et al. (1994), the sensitivity of external shoulder rotation surpasses that of internal rotation, aphenomenon which can be related to the increased transmission of nerve signals to the CNS during external rotation, that occurs due to stretching the anterior shoulder capsule.

Furthermore, it has been suggested that shoulder joint position sense increases with increasing torque angle, at shoulder elevation angles (Suprak et al., 2006), and with external mechanical load (Suprak et al., 2007). This may be related to increased muscle activation and stimulation of the muscle spindles. Additionally, previous studies have demonstrated a positive correlation between the intensity of isometric shoulder contraction and the proprioceptive information transmitted by mechanoreceptors (Zuckerman et al., 2003; Walsh et al., 2009). Most researchers agree that with increasing shoulder elevation angle, the periarticular soft tissues are subjected to more tension, resulting in greater proprioceptive information (Janwantanakul et al., 2001; Suprak et al., 2007). This mechanism is fundamental in counteracting the forces that cause humeral head displacement (Anderson et al., 2011). So the shoulder joint capsule, glenohumeral ligaments, and labrum present mechanoreceptors that provide proprioceptive information for the sensorimotor system, promoting stability and neuromuscular control in the glenohumeral joint. It has been proven that capsulo-ligamentous structures and muscles cooperate through reflexes to prevent injury (Myers et al., 2002). Specifically, when the capsule-ligamentous structures within the glenohumeral joint experience tension, the mechanoreceptors relay this information to the spinal cord. Subsequently, the rotator cuff muscles contract reflexively to mitigate the excessive tension exerted on the capsule-ligamentous structures. This reflex is also known as the “ligamentous-muscular reflex” (Myers et al., 2002; Myers and Oyama, 2008).

2.14 The role of proprioception in motor control

Accurate sensory information about the body's external and internal environmental conditions is crucial for achieving adequate motor control (Mathews, 1989; Riemann and Lephart, 2002). During goal-directed activities (e.g picking up a box while walking), the motor program for walking must be modified to account for changes in the internal environment (such as shifts in center of gravity brought on by an additional weight) and the external environment (such as uneven ground).These provisions are triggered by sensory stimuli that occur in both feedback loops (mechanoreceptor detection of changes in the support surface) and feedforward loops (anticipating changes in the center of gravity based on prior experiences) (Sainburg et al., 1995; Bard et al., 1995).

Proprioceptive information, a key player in motor control, can be classified into two distinct types, with the first involving proprioception in relation to the surrounding external environment, and the second the planning and modulation of internally generated motor orders (Hasan and Stuart, 1988). In addition, the first type, motor plans often need to be adjusted to accommodate unforeseen disturbances or changes in the external environment. While visual input is commonly seen as the primary source of this information, there are many instances where proprioceptive input proves to be the most efficient, accurate, or both (Prentice, 2020). In the example mentioned in the previous paragraph, adjustments to the motor program for walking were necessary due to the presence of an uneven support surface. In addition, the motor control system must take into consideration the present and varying positions of the joints involved both before and during a motor command, in order to accommodate the intricate mechanical interactions within the musculoskeletal system (Prentice, 2020). Proprioception is often regarded as the most efficient means of supplying the motor control system with the essential information on segmental movement and position (Sainburg et al., 1995; Bard et al., 1995).

2.15 Assessment of proprioception

Proprioception evaluation entails conducting targeted tests to assess an individual's joint proprioception, kinesthesia, or force perception levels (Riemann et al., 2002; Proske and Gandevia, 2012). The assessments can be carried out using either passive or active conditions (Riemann et al., 2002; Clark, 2015). Joint position sense (JPS) tests assess the degree of precision and accuracy in readjusting a joint to a predetermined goal angle (Benjaminse et al., 2009). Kinesthesia assessments measure an individual's ability to perceive joint movement. These assessments include tests such as the threshold for detection of passive movement, movement discrimination tests, and acuity of a tracking task (Carpenter et al., 1998). The force awareness tests assess an individual's ability to perceive and produce a predetermined and controlled level of force that is lower than the maximum limit (Dover and Powers, 2003; O'Leary et al., 2005; Benjaminse et al., 2009)

The awareness of joint position, the sensation of force and kinesthesia tests frequently calculate many variables. According to Schmidt and Lee (2011), variables encompass constant error, variable error, and absolute error. The constant error is calculated as the mean positive or negative discrepancy between the observed and real values along a certain dimension of interest, while variable error is determined by calculating the standard deviation. Absolute error refers to the discrepancy between the measured or inferred value and the true value of a quantity. The purpose of these variables is to provide descriptions of various components of JPS and force sense. The representation of acuity in a chase or tracking task is frequently depicted as the departure from the target or the duration of time spent on the target (Schmidt et al., 2018).

2.16 Factors that influence proprioception

2.16.1 Age

Numerous alterations in the neuromuscular system have been linked to aging (Hunter et al. 2016; Shaffer and Harrison 2007). These changes have been accompanied by a decline in maximal force production (Frontera et al. 1991), a reduction in control precision (Baudry et al. 2010; Tracy and Enoka 2002), and impairments in motor control (Seidler at el., 2010). Furthermore, aging has been associated with a decline in postural control, increasing the risk of falls (Horak 2006; Maki et al. 1994). Changes in muscle spindles and the transmission of sensory information at the supraspinal level have also been observed in elderly individuals, causing disturbances in proprioception and postural control (Goble et al., 2011, 2012). Regarding the muscle spindles, it has been found that with increasing age, the diameter of them decreases (Goble et al., 2009). Additionally, Liu et al. (2005) found a decrease in the number of intrafusal muscle fibers, which has been associated with increasing age. Other studies (Miwa et al., 1995; Kim et al., 2007) have found that increasing age associates with decreased muscle spindle sensitization (difficulty in activating after a sensory stimulus). A decrease in nerve conduction velocity of Ia nerve fibers has been observed with increasing age (Kim et al., 2007), thus causing disturbances in the stretch reflex (Klass et al., 2011). Some studies have found that with increasing age, the activation of areas of the brain responsible for motor function increases a mechanism that is attributed to the effortof the brain, through compensation, to increase the motor capacity in elderly individuals (Zwergal et al., 2012; Mouthon et al., 2018).

Barrack et al. (1984) concluded that young professional ballet dancers had a significantly better joint movement perception threshold compared to healthy, active elderly subjects. Skinner et al. (1984) investigated the effect of age on knee proprioception during passive motion (passive motion detection threshold and ability to perceive joint position during passive motion). The results showed that the older participants had significantly less proprioception in both tests than the younger participants. Similar results were found in the study by Kaplan et al. (1985), who concluded that the elderly had significantly poorer proprioception during active movements than the young participants. The age effect seems to be similar across different body areas. Vuillerme et al. (2008), who aimed to investigate the effect of age on neck joint position sense, concluded that older subjects had significantly less accuracy and perception of neck position. In addition, Tonak et al. (2020) aimed to investigate the effect of age on hand proprioception. The results showed that elderly subjects showed reduced hand position sense perception, increased dynamic hand grip errors, and decreased vibration sense.

2.16.2 Osteoarthritis

There have been several studies that had concluded that osteoarthritis of the knee is associated with a reduced ability to perceive joint position (Marks et al., 1993; Hurley et al., 1997; Garsden & Bullock-Saxton, 1999; Hassan et al., 2001; Hortobagyi et al., 2004) and kinesthesia (Sharma et al., 1997; Pai et al., 1997; Hewitt et al, 2002), when a total of 387 osteoarthritic knees were evaluated and compared with healthy elderly knees (Knoop et al., 2011). However, in one study (Lund et al., 2008), which evaluated 21 female osteoarthritic knees, a significant impairment was found in knee kinesthesia but not knee position sense. Furthermore, when the osteoarthritic knees of 134 people were assessed, no substantial impairment of knee joint position sense (Hall et al., 2006; Bayramoglu et al., 2007) and kinesthesia (Pap et al., 1998) was found. In an effort to resolve this disagreement a more recent systematic review (van Tuden et al., 2018), in which 9825 patients with knee osteoarthritis were evaluated, found that knee osteoarthritis was significantly associated with decreased muscle strength and proprioceptive disorders. Nevertheless, van Tuden et al., (2018) in their review concluded that most studies were of low to moderate methodological quality and the results should be interpreted with caution.

2.16.3 Trauma

According to the reputable research of Myers et al. (2008), following a shoulder injury, individuals experience pain and tissue damage, which subsequently lead to disturbances in the sensorimotor system, proprioception, and neuromuscular control. Their findings are further supported by studies that have shown that reduced shoulder kinesthesia has been associated with shoulder dislocations (Lephart et al, 1994) and shoulder instabilities (Barden et al, 2004). Additionally, patients with rotator cuff injury were found to have significantly less shoulder proprioception compared to non-injured subjects (Anderson & Wee, 2011). Similar results have been found in other areas and other types of injuries. A systematic review conducted in 2014 by Relph et al. examined seven studies on individuals with ACL tears andfound that they had a notable decrease in proprioception for the injured leg in comparison to the non-injured one.

Conversely, a separate systematic review conducted by Fyhr et al. (2015) examined the impact of shoulder injuries on shoulder proprioception. The review revealed limited to moderate evidence indicating that individuals with post-traumatic shoulder instability had a decreased ability to detect passive motion and sense the position of the shoulder joint during both active and passive shoulder motion.

2.16.4 Inflammation

Chemical mediators of inflammation can stimulate accessible nerve endings, thereby affecting proprioception (Lephart et al., 1998; Xu et al., 2000). A study by Cudejko et al. (2018) aimed to investigate whether inflammation in patients with knee osteoarthritis affects knee proprioception. The evaluation of inflammation was carried out with blood tests detecting the increased number of erythrocytes. The findings indicated a positive correlation between elevated erythrocyte counts, increased knee proprioception, and muscle weakness in patients, suggesting systemic inflammation.

2.16.5 Pain

Proprioception is disrupted when there is acute or ongoing musculoskeletal pain in the neck (Sjolander et al., 2008; Kristjansson & Oddsdottir, 2010), lumbar spine (Lee et al., 2010; Williamson & Marshall, 2014), upper extremities (Andersson & Wee, 2011; Juul-Kristensen et al., 2008), and lower extremities (Sharma et al., 2003; Salahzadeh et al, 2013). Proprioception is disrupted by pain because it alters the sensitivity and reflex activity of the muscle spindle by activating type III and IV afferent nerve fibers (Johansson et al., 2003). Studies in animals have demonstrated that intramuscular and intracapsular injections of inflammatory chemicals cause significant effects on the muscle spindle (Thunberg et al., 2001; Djupsjobacka et al., 1995). Humans have also shown disruption of proprioception after experimentally generated pain (Malmstrom et al., 2013; Weerakkody et al., 2008).

Moreover, pain can have a deep impact on how the body is perceived, leading to somatosensory cortical disarray (Moseley & Flor, 2012). Therefore, proprioception in the peripheral and central nervous systems can be adversely affected by pain.

Sole et al. (2015) aimed to investigate whether experimentally induced pain, caused be a hypertonic saline injection, in the subacromial space can affect shoulder proprioception. The results showed that participants who were given hypertonic saline showed significantly less ability to detect the direction of the movement. However, no significant correlation was found between experimentally induced pain and shoulder joint repositioning during passive movement. Harvie et al. (2016) conducted a study examining neck's pain impact on neck proprioception. The findings revealed that individuals experiencing neck pain had a notably greater frequency of neck kinesthesia mistakes than those without pain. In a systematic review conducted by Ager et al. (2020), eleven studies examining individuals with shoulder pain revealed moderate evidence of impaired kinesthesia and sense of velocity of movement in these patients.

Significant skeletal muscle function suppression and a major impact on limb proprioception can result from intra-articular swelling, even in the absence of pain (Vaxendalle & Ferrell, 1987; Cho et al, 2011).

2.16.6 Warm-up and cryotherapy

Performing a 5 – 10 minute warm-up positively affects proprioception and balance (Subasi, 2008). Additionally, the Fifa 11+ and Harmo knee warm-up programs have been found to improve knee proprioception at forty-five and sixty degrees of knee flexion and balance in soccer athletes (Daneshjoo et al., 2012; Lopes et al., 2019). In a recent systematic review conducted by Sayyadi et al., (2024), concluded that both absolute and relative angle inaccuracy can be decreased by warm up.

Reduced evidence has been found that cryotherapy increases the number of repositioning errors in the ankle, knee, and shoulder joints (Costello et al., 2010). In a randomized, double-blind study (Torres et al., 2016), found that applying 15 minutes of ice therapy to the shoulder can significantly reduce muscle strength, shoulder joint position sense, and passive shoulder motion detection threshold. However, Furmanek et al. (2018) conducted a study that yielded contractive results. Their investigation revealed that the administration of cryotherapy to the knee did not disrupt knee proprioception among healthy volunteers.

2.16.7 Fatigue

Numerous peripheral and central alterations, such as modified metabolic state, altered muscular activation patterns, disruption of muscle spindle and spinal reflexes, and a heightened perception of exertion, are linked to muscle tiredness (Enoka & Stuart, 1992; Gandevia, 2002). Following high-intensity physical work or exercise, particularly eccentric training, it is frequently observed that individuals may experience clumsiness and encounter challenges when attempting to execute fine motor movements. This phenomenon has been substantiated by multiple studies that have demonstrated a decrease in proprioception (Weerakkondy et al., 2003; Iwasa et al., 2005; Johanson et al., 2011; Tsay et al., 2012).

2.17 Proprioceptive training and prevention of sport injuries

Postle et al. (2012) concluded that proprioceptive training was not associated with reducing ankle injuries. However, the addition of proprioceptive training caused a significant reduction in subjective instability and improved functionality. In addition, moderate evidence has been found that proprioceptive training can help prevent future ankle sprains (Schiftan et al., 2015; Žech et al., 2009) and ACL injuries (Žech et al., 2009). Also, Hubsher et al. (2010), evaluating seven high methodological quality studies, concluded that proprioceptive training can reduce the incidence of lower extremity injuries, especially ankle and knee injuries. The systematic review conducted by de Vasconcelos et al. (2018) yielded positive findings, indicating that the implementation of proprioceptive training combined with balance exercises effectively reduces the occurrence of ankle sprains by thirty-eight percent compared to the control group. The researchers concluded that the implementation of proprioceptive training, specifically focusing on balance exercises, can mitigate ankle injuries, enhance neuromuscular control, minimize swing movements required for balance maintenance, and augment joint position sensing among athletes.

There is a scarcity of evidence regarding the efficacy of shoulder injury prevention programs in overhead athletes, particularly in terms of reducing shoulder injuries (Wright et al., 2021). Out of all the research conducted, only three reported a positive outcome in terms of preventing injuries (Andersson et al., 2017; Shitara et al., 2017; Osteras et al., 2015). Currently, there is insufficient evidence to draw any definitive conclusions about the efficacy of shoulder injury prevention programs in overhead athletes.

2.18 Negative effects due to impairment of proprioception

Short-term sensorimotor control loss due to decreased proprioception is expected to affect feedforward and feedback mechanisms as well as the modulation of muscle rigidity (Treleaven, 2011). This could account for clinical signs of musculoskeletal diseases such as clumsiness and balance problems (Treleaven, 2011). Additionally, it may result in motor dysfunctions, such as an increase in errors in particular proprioceptive tests. Reduced alpha motor neuron activity (Konishi et al., 2002), poor joint reflex stabilization (Beard et al., 1994), increased sway in balancing movements (Radebold et al., 2001; Treleaven et al., 2005; Roijezon et al., 2011), and increased visual movement errors (Sandlund et al., 2008; Williamson & Marchall, 2014) are some of these dysfunctions. Neuromuscular adaptations typically observed in painful illnesses, likely entail altered proprioception among many other pathways (Falla & Farina, 2008; Hodges, 2011). Disrupted neck proprioception can also result in dizziness, visual abnormalities, and poor head and eye movement control and coordination (Treleaven, 2008; Treleaven & Takasaki, 2014). According to Segal et al. (2010), there is a potential pathophysiological association between impaired proprioception, reduced motor performance from the central nervous system, and inadequate muscle protection of joint tissues. A higher incidence of injury, recurrence, and chronic pain—including the onset and advancement of post-injury secondary osteoarthritis—may be attributed to these variables. Osteoarthritis has been linked to reduced muscular performance as a result of disrupted sensory input from mechanoreceptors in wounded tissues (Konishi et al., 2002).

2.19 The impact of exercise induced-muscle fatigue on shoulder proprioception, motor control and performance.

The study conducted by Voight et al. (1996) was one of the initial investigations on the impact of rotator cuff muscle fatigue on shoulder proprioception. Eighty individuals, 30 males and 43 females, participated in this study. The assessment encompassed the evaluation of shoulder active joint repositioning (AJR) and passive joint repositioning (PJR) as outcome measures. The measurement of proprioception was performed on the isokinetic dynamometer. The participants' shoulder was initially positioned at a 90° angle of abduction, with a 90° angle of elbow flexion, and with a neutral elbow posture (midway between supination and pronation). From this position, the examiner passively moved the patient's shoulder to 75° of external rotation (target angle), remained in that position for 10 sec, and then returned to the starting position. The participant then had to identify this specific target angle unthinkingly by performing active movement for three trials. Subsequently, the subject would be required to ascertain the identical shoulder position using passive movement, as imposed by the isokinetic dynamometer. Upon perceiving that the shoulder had attained the appropriate angle, the participant would activate the switch to cease the motion. The participants performed maximal voluntary isokinetic internal and external rotation contractions on the isokinetic dynamometer to induce muscle fatigue. The criterion for muscle fatigue was a 50% drop in peak isokinetic torque over three consecutive repetitions. After the induction of muscle fatigue, the AJR and PJR were assessed in each participant. The results showed that muscle fatigue of the shoulder rotators caused a significant disturbance in shoulder proprioception. It was also found that there were no significant differences between dominant and non-dominant shoulders in proprioceptive impairment after muscle fatigue.

Carpenter et al. (1998) conducted a study to investigate the potential impact of muscle fatigue of the shoulder on the threshold to detection of passive movement direction (TTDPMD). Twenty healthy participants (11 men and 9 women) participated in this study. Shoulder proprioception was evaluated on the isokinetic dynamometer. Participants were placed seated with the shoulder in 90° of abduction, 90° of external rotation and at the scapula level. The isokinetic dynamometer from this position performed passive movement. Each participant was instructed to promptly deactivate the switch upon perceiving passive shoulder movement from the isokinetic dynamometer. The criterion for muscle fatigue was a 50% drop in peak isokinetic torque over three consecutive repetitions. The results showed a significant delay in TTDPMD from 0.92° to 1.59° (73% increase) simultaneously in both internal and external rotation. Specifically, the detection of passive internal rotation worsened by 0.70° and the detection of passive external rotation by 0.66°.

Sterner et al. (1998) published a study in the same year that examined the impact of muscle fatigue on shoulder proprioception. The shoulder proprioceptive outcome measures included AJR, PJR, and TTDPMD. The isokinetic dynamometer was used for the measurements. The study involved placing 20 participants supine while stabilizing their trunk and pelvis to restrict compensatory movements. The initial position of the shoulder was at 90° of abduction, 90° of elbow flexion, and a neutral shoulder rotation. Participants were instructed to determine the target angle by pressing a switch to stop the movement and remain there for 10 seconds to assess the AJR and PJR.

TTDPMD was performed in a neutral shoulder rotation position, and three trials were conducted in each direction at an angular velocity of 0.5˚/sec using a stop switch button. The participants performed five maximal concentric isokinetic contractions to induce muscle fatigue with an angular velocity of 180°/sec. From the five repetitions, the maximal voluntary contraction was recorded. The criterion for muscle fatigue was a 50% decline in isokinetic peak torque over three consecutive repetitions. The results showed that there were no significant differences between the experimental group and the control group, and shoulder proprioception was not affected by muscle fatigue.

Myers et al. (1999) also aimed to investigate whether rotator cuff muscle fatigue can affect shoulder proprioception and dynamic stability. Thirty-two healthy participants (16 men and 16 women) participated in the study. The outcome measures were the shoulder AJR and the dynamic shoulder stability. AJR was performed on the isokinetic dynamometer, and the dynamic shoulder stability was assessed through the ability to remain in a push-up position with one arm support on a force plate. During the dynamic stability test, each participant had to remain in the one-armed push-up position for 10 seconds. In the isokinetic dynamometer, the participants were supine, with 90° shoulder abduction and 90° elbow flexion. The target angles that each participant had to identify with eyes closed were three (30° internal rotation, 30° external rotation, and 75° external rotation), performing three trials per target angle. To induce muscle fatigue, maximal concentric isokinetic contractions of internal and external rotator muscles were performed with an angular velocity of 180°/sec. The criterion for muscle fatigue was a 50% decline in maximal isokinetic torque within three consecutive repetitions. The participants were divided into two groups: experimental and control group. The control group did not perform the muscle fatigue protocol. In the control group, the mean absolute angular error was 5.42° ± 2.94° in the initial measurements (pre-test values) and 5.020 ± 2.59° for the post-test values. On the contrary, the mean absolute angular ratio for the experimental group before fatigue was 4.72° ± 2.43° and 5.58° ± 2.23° after fatigue. Only the experimental group presented statistically significant differences. Regarding dynamic stability, a substantial increase in falls (inability to maintain the one-arm push-up position) after fatigue was found in the experimental group only.

Bjorklund et al. (2000) conducted a study to investigate the effect of shoulder muscle fatigue on joint position sense. The study involved 26 individuals, consisting of 13 males and 13 females.

Joint position sense was measured before and immediately after the fatigue protocol. Participants were instructed to target the horizontal shoulder adduction angles of 15 ° and 30 °, as well as horizontal shoulder abduction angles of 60 ° and 75 °, starting from a position of 45 ° (scapula level). To elicit fatigue, participants were positioned at a table and engaged in a repetitive activity, including pressing pistons and buttons, utilizing a manipulator weighing 300 grams. The results showed that the absolute error increased significantly after fatigue, and women had an overall higher error than men. In addition, total absolute error was considerably higher in horizontal shoulder adduction than horizontal abduction.

Lee et al. (2003) conducted a study to assess the impact of muscular fatigue of the shoulder rotators on shoulder proprioception. The 11 participants were positioned on the isokinetic dynamometer with their shoulders abducted by 90°, their elbows rotated 90°, their shoulders in the scapular plane, and their elbows flexed 90°. The repositioning sensation of the shoulder joint was measured both actively and passively (AJR and PJR) from this position. A 10-minute warm-up of push-ups and stretching was conducted to generate muscle fatigue. The measurement of maximal voluntary contraction was conducted over a series of five repeats. A 50% reduction in isokinetic peak torque over three consecutive repetitions was used as a criterion for fatigue. The results showed no significant differences in PJR in internal and external rotation and AJR in internal rotation. However, there were substantial errors in determining the target angle in AJR in external rotation (from 2.57 to 4.96°).

Lida et al. (2014) aimed to examine whether muscle fatigue of the rotator cuff muscles can significantly affect shoulder proprioception. For this purpose, 15 healthy men participated in the study. Participants were seated on the isokinetic dynamometer with their shoulder in 90° of abduction and 90° of elbow flexion. In order to assess muscle deactivation during PJR, electromyography was conducted on both the internal rotators (pectoralis major and latissimus dorsi) and external rotators (infraspinatus). The target angle for shoulder external rotation was precisely positioned between the initial position of the shoulder and the point of maximal external rotation. Similarly, for shoulder internal rotation, the target angle was positioned between the initial position and the point of maximal internal rotation. In AJR, participants were required to maintain their position at the target angle for 3 seconds. Conversely, participants were instructed to hit the stop motion switch during PJR. Concentric maximal effort isokinetic contractions were performed to induce muscle fatigue with an angular velocity of 180 ˚/sec. The criterion for muscle fatigue was a decrease in peak torque by 40% in 3 consecutive repetitions. The results showed a significant constant error interaction in both AJR and PJR. After experiencing fatigue of the shoulder's internal rotator muscles, there was a notable increase in the constant error observed during AJR, particularly in the direction of external rotation. Furthermore, it was observed that the constant error exhibited a substantial rise in the internal rotation direction following fatigue of the external rotator muscles in the shoulder. After the fatigue of the internal rotator muscles of the shoulder, the angle mislocalized from 2.68° (before fatigue) to 4.19° (after fatigue). Furthermore, after the fatigue of the shoulder external rotator muscles, the angle mislocalized from 2.32° (before fatigue) to 4.05° (after fatigue).

Kablan et al (2004) aimed to investigate the effect of rotator cuff muscle fatigue on shoulder proprioception in volleyball players. A total of forty participants, consisting of twenty experienced and twenty inexperienced volleyball players, were included in the study. Shoulder proprioception was assessed on the isokinetic dynamometer. The initial position of the subjects was seated and two initial positions were chosen for the shoulder: A) Ninety degrees abduction combined with ninety degrees external rotation and ninety degrees elbow flexion B) Ninety degrees abduction combined with neutral rotation and ninety degrees elbow flexion The target repositioning angles of the shoulder joint which were assessed actively and passively were 10, 15 and 20˚towards external and internal rotation of the shoulder. The fatigue protocol was implemented after determining the peak internal rotation torque. The shoulder was positioned at 90˚ of abduction and 90˚ of external rotation and the elbow at 90˚ of flexion. Participants were instructed to perform maximal concentric effort. The fatigue protocol was terminated when peak shoulder internal rotation torque was consistently reduced by 50%. Beginner volleyball players had baseline difference at ten to twenty degrees and fifteen to twenty degrees of external rotation prior to exhaustion. After fatigue, professional volleyball players showed reduced repositioning ability at 20˚, while inexperienced players showed significant differences at 10 and 15˚.

The objective of the study conducted by Weerakkody and Allen (2016) was to examine the impact of shoulder fatigue and brace on proprioception in cricket players. The study involved a total of 14 male cricketers. Outcome measures assessed before and after the fatigue protocol were shoulder joint position sense measured with a digital inclinometer. Target repositioning angles were 45°, 60°, and 90° of shoulder flexion. To induce fatigue, the participants performed an exercise with a regular cricket ball, moving the hand in a fast rotary motion. Furthermore, half of the subjects underwent the application of a shoulder brace. In both braced and unbraced groups the repositioning errors increased due to fatigue at all target angles. However the errors in unbraced participants where significantly higher at 45° and 60° of shoulder flexion.

Spargoli et al. (2017) examined the impact of muscle fatigue resulting from various forms of muscle contraction (eccentric and concentric) on shoulder proprioception. Twenty-two individuals, fourteen males, and eight females, participated in this study. Participants were placed in a standing position with the shoulder in 30º of abduction and 0˚ of external rotation at the scapula level. From this position, the AJR was measured (from 0 degrees external rotation to 30˚ external rotation (reference angle). In addition, each participant performed three maximal voluntary contractions. Concentric muscle fatigue was assessed by subjecting the shoulder to a range of internal rotation angles, specifically from 40° to 80°. The shoulder was manipulated to induce eccentric muscle fatigue by transitioning from an external rotation of 80° to an internal rotation of 40° to decelerate the movement. In both instances, the angular velocity employed was 180°/sec. In each type of muscle fatigue, sets of 15 repetitions were performed. The criterion for muscle fatigue was a drop in maximum torque to 30% of the initial value for three consecutive repetitions. The findings indicated no statistically significant disparities in shoulder proprioception impairment between the two forms of muscular fatigue.

In their study, Salo and Chaconas (2017) examined how fatigue in the upper extremities affected the performance of recreational weightlifters in the Upper Quarter Y-Balance Test. Twenty-four participants who regularly engaged in weight training three times a week were randomly divided into two groups: a control group and an experimental group. The experimental group underwent testing with the YBT-UQ, followed by an upper extremity exercise exhaustion regimen, and then underwent immediate retesting. The fatigue protocol led to a notable decrease in YBT-UQ scores compared to the non-fatigue protocol, as observed by the analysis of the interaction between group and individual directions, as well as the composite scores for both limbs. The tiredness group experienced a decrease in scores ranging from 2.04 cm to 12.16 cm for both upper limbs, individual reach distances, and composite scores. This indicates that fatigue significantly worsened the results on the YBT-UQ.

Bauer et al. (2020) aimed to investigate the impact of exercise-induced fatigue on YBT-UQ in handball players. The performance in YBT-UQ was reassessed following the completion of a fatigue protocol that involved performing numerous sets of push-ups until failure. The fatigue protocol resulted in significant decreases in the superolateral reach direction. Specifically, the throwing arm reach decreased by 5%, and the non-throwing arm reach decreased by 10%. The composite score also signicantly decreased, with the decrease in the throwing arm reach being 50% less than the non-throwing arm (2% vs 4%). However, no significant decreases were observed for the anteromedial and inferolateral reach directions.

Details of the aforementioned studies of the existing literature are illustrated in **table 2.2**

Table 1.2 Studies investigating the impact of exercise-induced fatigue on the proprioception and motor control of the upper limb.

Study	**Proprioceptive and/or motor control measurements**	**Impact of fatigue**
Voight et al (1996)	AJR, PJR	ARP:↑ 63.29% * PRP: ↑ 235.03% *
Carpenter et al., (1998)	TTDPM	↑ 74.72% *
Sterner et al (1998)	AJR, PJR, TTDPM	ARP: ↓ 31% PRP: ↓ 0.72% TTDPM: ↑ 55.49%
Myers et al (1999)	AJR, SADS test	↑ 18.22% * SADS test: A significant increase in falls (inability to maintain the one-arm push-up position) after fatigue
Bjorklund et al (2000)	AJR	The absolute error increased significantly after fatigue, and women had an overall higher error than men. Also, total absolute error was significantly higher in horizontal shoulder adduction than horizontal abduction.
Lee et al (2003)	AJR, PJR	ARP: ↑ 92.99% * Note: Only for external rotation PRP: No significant differences

Kablan et al (2004)	AJR, PJR	↑ 60.52% * Note: Elite players at 20˚ of internal rotation target angle ↑ 80% * Note: Beginner players at 10˚ of internal rotation target angle.
Lida et al (2014)	AJR, PJR	AJR: ↑ 56.34% * Note: Angular error of internal rotation PJR: ↑ 74.56% Note: Angular error of external rotation
Weerakondy and Allen (2016)	AJR	After exercise, the mean pre-exercise error increased at the 60° and 90° target angles.
Spargoli (2017)	AJR	↓ 2.70%
Salo and Chaconas (2017)	YBT-UQ	Significant decrease in YBT-UQ scores compared to the non-fatigue protocol, ($p \leq .006$), as well as the composite scores for both limbs ($p < .035$).
Bauer et al (2020)	YBT-UQ	SL throwing arm reach: ↓ 5%* SL Non-throwing arm reach: ↓ 10%* CS throwing arm: ↓ 2%* CS non-throwing arm: ↓ 4%*

Abreviations: AJR, active joint repositioning; PJR, passive joint repositioning; TTDPM, threshold to detection of passive movement; YBT-UQ, Y-balance test upper quarter; ↑, increase; ↓, decrease; *, p value < 0.05; SL, superolateral; CS, composite score.

The results of some studies agree that muscle fatigue can cause significant impairments in at least one outcome measure of shoulder proprioception, predisposing the individual to a shoulder injury (Voight et al., 1996; Carpenter et al., 1998; Myers et al., 1999; Lee et al., 2003; Lida et al., 2014). However, some other studies found no significant interaction between muscle fatigue and shoulder proprioception (Sterner et al, 1998; Spargoli et al, 2017). In needs to be pointed out that most research conducted on the shoulder joint did not include a sample population that frequently suffers from shoulder injuries, such as handball players but included healthy non-athlete participants.

The outcome measures assessed in the aforementioned studies were the active and passive shoulder joint repositioning sense and the threshold to detection of passive movement. The rotator cuff muscles' muscle onset latency (MOL) was not evaluated in any study. MOL is a significant outcome measure that assesses the reflexive activation of the muscle immediately after an external perturbation to the joint to prevent injury (Cavanagh & Komi, 1979). For example, suppose a thrower's shoulder is throwing the ball when the shoulder is in a position of abduction and external rotation of the shoulder, and the shoulder receives a blow from an opponent who will violently move the shoulder into excessive external rotation. In that case, the internal rotator muscles must react as quickly as possible to brake the excessive movement of the shoulder, preventing injury to the shoulder (e.g., anterior dislocation of the shoulder, tear of the rotator cuff). Finally, there is a scarcity of research examining the impact of shoulder muscle fatigue on the motor control of the upper extremities. Only two studies have assessed the effects of fatigue on shoulder stability and mobility by employing the Y-balance test upper quarter (YBT-UQ). Furthermore, performance was not assessed in previous research after shoulder muscle fatigue. Moreover, the majority of research utilized a concentric exercise-induced fatigue methodology. Thus far, just a single study (Spargoli, 2017) has assessed the impact of eccentric exercise-induced fatigue on shoulder proprioception. Due to this factor, the available evidence is restricted on the influence of eccentric exercise-induced fatigue on proprioception and motor control of the upper limb.

The current research aims to contribute to the knowledge of the above literature gaps. The thesis first looks at the literature for all identified risk factors for shoulder injuries. Then the study examines the impact of both concentric and eccentric exercise-induced shoulder fatigue on proprioception, motor control and performance of the upper limb. In addition to joint repositioning sense and threshold to detection passive movement, the effect of muscle fatigue on shoulder MOL and upper extremity isometric strength performance will be evaluated for the first time. Furthermore, professional handball athletes will participate. As previously said, there is a need for more research that focuses on handball athletes or athletes from other overhead sports such as volleyball, baseball, or cricket. This study, will examine the impact of concentric and eccentric shoulder fatigue in the YBT-UQ, for the first time in handball players.

2.20 Significance of the study

The study's results will provide valuable insights for coaches, trainers, physical therapists, and athletes regarding the impact of muscle fatigue on proprioception, motor control and performance. Furthermore, the study's findings will aid in the development of more effective exercise regimens to mitigate fatigue. Moreover, the study's findings can inspire coaches and trainers to incorporate proprioception, motor control and performance assessment tests into their training regimen. These tests should be administered by qualified healthcare professionals with expertise in the field. These assessment tools should be assessed during periods when the athlete is not experiencing fatigue and reassessed during periods of fatigue. Suppose the athlete has notable impairments in proprioception, motor control and performance during re-evaluation thenspecific interventions should be implemented to mitigate fatigue and enhance proprioception, motor control and performance through targeted exercises in order to reduce chances for injury.

2.21 Research questions

The following questions were formulated and guided the subsequent experimental work of this thesis:

- Does exhaustion of the rotator cuff muscles in handball players lead to reduced proprioception, which includes a diminished joint position sense, kinesthesia, and reflex reaction time of the shoulder?
- Can muscular fatigue lead to decreased motor control and performance in handball athletes?
- Do handball athletes and non-athletes differ in terms of how fatigue affects their proprioception, motor control, and performance?
- Are there differences between two different fatigue protocols (concentric vs. eccentric) in terms of their effect on proprioception, motor control, and performance?

2.22 Research objectives and hypotheses

The objectives of the present thesis are as follows:

- To investigate the impact of concentric exercise-induced rotator cuff fatigue on proprioception , motor control and performance of the upper limb in professional handball athletes.
- To investigate the impact of concentric exercise-induced rotator cuff fatigue on proprioception , motor control and performance of the upper limb in healthy non-overhead athletes individuals.
- To investigate the impact of eccentric exercise-induced rotator cuff fatigue on proprioception motor control and performanceof the upper limb in professional handball athletes.

The main null hypotheses of this thesis are as follows:

- H_10: Concentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the proprioception of the upper extremity in elite handball athletes.
- H_20: Concentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the motor control of the upper extremity in elite male handball athletes.
- H_30: Concentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the performance of the upper extremity in elite male handball athletes.
- H_40: Concentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the proprioception of the upper extremity in healthy young adults.
- H_50: Concentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the motor control of the upper extremity in healthy young adults.
- H_60: Concentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the performance of the upper extremity in healthy young adults.
- H_70: Eccentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the proprioception of the upper extremity in elite handball athletes.
- H_80: Eccentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the motor control of the upper extremity in elite male handball athletes.

- H_90: Eccentric exercise-induced fatigue of the rotator cuff does not have a notable impact on the performance of the upper extremity in elite male handball athletes.

The main alternative hypotheses of the current investigation are as follows:

- H_1: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the proprioception of the upper extremity in elite handball athletes.
- H_2: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the motor control of the upper extremity in elite handball athletes.
- H_3: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the performance of the upper extremity in elite handball athletes.
- H_4: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the proprioception of the upper extremity in healthy young adults.
- H_5: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the motor control of the upper extremity in healthy young adults.
- H_6: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the performance of the upper extremity in healthy young adults.
- H_7: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the proprioception of the upper extremity in elite handball athletes.
- H_8: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the motor control of the upper extremity in elite handball athletes.
- H_9: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the performance of the upper extremity in elite handball athletes.

Chapter 3.0: Risk factors for shoulder injuries in handball: Systematic review

Abstract

Background: One of the main characteristics of handball as a sport is the high rate of major injuries. Shoulder injuries are common; prevalence rates range from 17% to 41%.

Objective: To identify the most prominent risk variables linked to shoulder injuries in handball.

Methods: A thorough search was performed on multiple databases, such as PubMed, MEDLINE, CINAHL, Proquest, SPORTDiscus, Web of Science, EMBASE, and Scopus.. Methodological quality of each study was assessed using the Downs and Black Checklist. The Best Evidence Synthesis (BES) methodology was utilized to interpret the findings.

Results: Eight studies were included. The factors contributing to shoulder injuries in handball are strength imbalances (n=6), glenohumeral range of motion (ROM) imbalances (n=5), scapular dyskinesis (n=5), inappropriate dosage of training load (n=2), previous injury (n=1), sex (n=2), player's position, school grade, playing level (n=1), and changed shoulder joint position sense (n=1).

Conclusion: In summary, there is strong proof indicating that the weakness of the shoulder external rotator muscles and being a female significantly raise the likelihood of shoulder injury in handball players. However, the evidence supporting the other risk variables was only of moderate strength, mostly due to the methodological quality of the studies and the low number of research conducted.

Keywords: shoulder pain, sports injuries, Odds Ratios, Relative Risk, Risk of Injury

3.1 Background

Handball is one of the most popular team sports worldwide, particularly in Europe. In comparison to other sports, it ranks on the top five in terms of the number and significance of total injuries (Junge et al., 2009; Engebretsen et al., 2013; Seil et al., 2018). Matches are characterized by repeated bouts of high-intensity activity with frequent contact and collision between players. During a complete season, handball players perform at least 48,000 throwing motions, with the ball weighing 425 to 475 g and a median speed of 130 km/h (Fieseler et al., 2017). Biomechanical studies have reported that the forces imposed on a throwing shoulder during the throwing motion can be up to 1.5 times the individual's body weight (Fleisig, 1995; Michalsik et al., 2015; Povoas et al., 2017). Due to these excessive demands, the shoulder is one of the most commonly injured joints, with up to 30% of these injuries occurring acutely and 45% causing persistent symptoms (Doyscher et al., 2014; Almeida et al., 2013; Aasheim et al., 2018). Moreover, other studies reported a point prevalence of shoulder pain between 19% and 36% at game season start and an average weekly prevalence of around 28% during the season (Myklebust et al., 2013; Clarsen et al., 2014). In addition, 48% of handball players that report substantial shoulder problems are unable to participate in matches or training due to severe pain (Asker et al., 2018).

Due to these high rates of shoulder injuries, prospective cohort and cross-sectional studies investigated several potential risk factors for shoulder injuries in handball. These studies provide important information that may guide the development of prevention programs. So far, several risk factors for shoulder injuries in handball have been identified such as the training load (Asker et al., 2018; Moller et al., 2017; Giroto et al., 2017; Forthomme et al., 2011), scapular dyskinesis (Clarsen et al., 2014; Andersson et al., 2018; Asker et al., 2020), muscular imbalance (Clarsen et al., 2014; Andesson et al., 2018; Asker et al., 2020; Edouard et al., 2013), age, and player position (Asker et al., 2018; Tabben et al., 2019), previous injury (Giroto et al., 2017), joint position sense (Asker et al., 2020), sex differences (Asker et al., 2018), glenohumeral rotational deficits (Almeida et al., 2013; Clarsen et al., 2014; Andersson et al., 2018; Lubiatowski et al., 2018). However, no systematic reviews have investigated the risk factors for shoulder injuries and the methodological quality of the associated studies specifically in handball players. Previous systematic reviews related to this topic (Hickey et al., 2018; Asker et al., 2018; Keller et al., 2018; Johnosn et al., 2018; Kraan et al., 2019; Pozzi et al., 2020; Feijen et al., 2020; Hogan et al., 2021; Salamh et al., 2020) investigated only one risk factor for shoulder injuries, such as scapular dyskinesis (Hickey et al., 2018; Hogan et al., 2021) training volume (Feijen et al., 2020), glenohumeral internal and external rotation deficit (GIRD) (Keller et al., 2018; Johnson et al., 2018; Pozzi et al., 2020) in various overhead athletes. Therefore, there is a need for a systematic review dealing with the whole spectrum of potential risk factors for shoulder injuries in handball.

The main objectives of this study were to identify the most significant risk factors related to shoulder injuries in handball, recognize which of these are modifiable, assess the risk of bias in the relevant studies, and evaluate the evidence of the identified factors. The secondary aim is to propose recommendations based on the available evidence concerning potential injury prevention strategies.

3.2 Methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009). The PRISMA statement includes a 27-item checklist designed to improve reporting of systematic reviews and meta-analyses (Moher et al, 2009). The study protocol was prospectively registered (PROSPERO ID: CRD4202013138233).

3.2.1 Literature Search

A systematic review of peer-reviewed English-language literature evaluating risk factors for shoulder injuries in handball was performed using PRISMA guidelines and checklists. The following electronic international databases were searched: Pubmed, Medline complete, Cinahl, Proquest, Sport Discus, Web of Science, EMBASE, and Scopus. All databases were searched from 15 July 1995 to 15 July 2019, using the keywords (shoulder injur* or shoulder pain*) and (risk factor* or predispose* factor or contributing factor* or predict* or determin* or cause* or etiology) and (handball* or overhead athletes) using the Boolean 'AND/OR' operators. Both MESH terms and free text words were included in this search. The words overhead and handball were tested with the # option to test if alternative ways of writing these words existed and the results were the same. The results were inserted in a reference manager for removal of duplicates, screening, and selection. The reference list of the included studies were reviewed for other studies not identified in the original search. The studies ought to be in English and be published after 1995 and before the date the search commenced. The search was repeated on 24 April 2022 just before the final preparation of the publication in case further studies were published during the period. Grey literature was also searched via OpenGrey.eu, as well as clinical trial registries via the EU Clinical trials Register, Clinical Trials.gov, WHO International Clinical Trials Registry Platform, and the Australian New Zealand Clinical trials registry.

3.2.2 Eligibility criteria

The study selection criteria specifically referring to PICO are shown in table 3.1. Prospective cohort studies that were published from July 1995 until July 2019, written in English language and published in a journal with a peer-review process that aimed to investigate at least one modifiable or/and a non-modifiable potential risk factor for shoulder injuries specifically in handball players were considered for inclusion in the study. The participants or population of the included studies should have had the following characteristics: 1) Athletic population, 2) No medical restrictions to participating in handball training or competition, 3) More than 8 hours of training per week, 4) Free from any musculoskeletal upper extremity pain or injury during the period of initial testing, 5) No any history of fracture or surgery to either upper extremity. Moreover, handball players were regarded as all the participants that trained at least 8hrs/week (training time and competitive game time per week during the competitive period). All levels of competition were accepted (1st division, 2nd division, etc). Comparison with other overhead athletes, comparison with other throwers, other athletes in general, and comparison with non-athletes or the general population were acceptable. The main outcome measures were the odds ratios (OR) or relative risk ratios (RR) or prevalence risk ratios (PR) or hazard rate ratios (HR) to correlate the risk factors with shoulder injuries in handball players.

Table 2.1 Inclusion and exclusion criteria.

Inclusion Criteria	**Exclusion Criteria**
Studies	• No prospective cohort study • Previous shoulder surgery • Previous glenohumeral dislocation • Glenoid labrum tear • Rotator cuff tear • Fracture in the shoulder region in the last 6 months
• Prospective Cohort Studies • Peer-reviewed, English language • 1995 – 2019 • Assess at least one modifiable or/and a non-modifiable risk factor for shoulder injuries in handball players	
Population	
• Handball players of all sexes and ages • No medical restrictions • Free from any musculoskeletal upper extremity pain or injury before being enrolled in the study	

Exposure
• Handball exposure at least 8 hours/week (training time and competitive game time per week during the competitive period) • All levels of competition are accepted (1st division, 2nd division, etc)
Comparator
• Other overhead athletes or throwers • Other overhead athletes in general • Non-athletes • General population
Outcome measures
• Odds Ratios (OR) • Relative Risk Ratios (RR) • Prevalence Risk Ratios (PR) • Hazard Rare Ratios (HR)

3.2.4 Quality Assessment

The same two authors (SH and MS) independently scored the methodological quality of each included study using a modified version of the Downs and Black Checklist (Downs and Black, 1998). The Downs and Black Checklist is recommended in the Cochrane Handbook for the appraisal of non-randomised studies and was selected as it is one of the most widely used and well-validated tools for the assessment of both randomized and non-randomized studies (Morton et al., 2014). The checklist has been shown to have good intra-rater and inter-rater reliability (Downs and Black., 1998; Hootman et al., 2011). The original Checklist consists of 27 questions, but for this review, only the most relevant questions were used. Questions 4, 8, 9, 13, 14, 15, 17, 19, 23, 24, 26 and 27 are specific to intervention studies and were excluded. Of the remaining items, questions 1, 2, 3, 5, 6, 7, and 10 are specific for the reporting of aims, methods, data, and results. Questions 11 and 12 concern the external validity of the studies, while questions 16, 18, 20, 21, 22, and 25 assess the internal validity and bias. The same modifications have been used previously in a systematic review of factors associated with heel pain (Irving et al., 2006). Quality assessment scores were presented as a percentage of the criteria satisfied. During the assessment of methodological quality, disagreements between the two authors were first discussed and if no agreement was reached, a third reviewer (ICT) made the final decision. No case of unresolved disagreement existed but the third reviewer confirmed the final decision of all the included studies.

3.2.5 Data Extraction and Analyses

Briefly, the titles and/or abstracts of studies retrieved using the search strategy and those from additional sources were screened independently by two reviewers based on the inclusion and exclusion criteria outlined above. The full text of the potentially eligible studies was retrieved and independently assessed for eligibility by the two reviewers. Any case of disagreement was resolved through discussion.

A standardized form was used to extract data from the included studies for the assessment of the risk of bias and evidence synthesis. Extracted information included study setting; study population and participant demographics, baseline characteristics; details of the exposure and control conditions; study methodology; recruitment and study completion rates; outcomes and times of measurement; any other information for the assessment of the risk of bias. Two reviewers (SH and MS) extracted the data independently, and discrepancies were identified and resolved through discussion.

3.2.6 Strategy for data synthesis

The heterogeneity (different factors, different cut-off values, different assessment tools, etc) of the studies and the data (lack of 2x2 table in most studies, ORs calculated via logistic regression models with different inputs) did not allow for a metanalysis. A graphical representation of the results as presented in the study is shown wherever possible but without any attempt to calculate summary statistics. Instead, a qualitative assessment using the best evidence synthesis (BES) was used to formulate conclusions (Table 3.2). This method has been used in the past in other systematic reviews (Hickey et al., 2018; Asker et al., 2018) and consists of five levels of scientific evidence (Ezzo et al., 2000; van Tulder et al., 2003). Consistency was defined at priori as over 75% of studies agreeing on the same direction of results.

Table 3.2 Classification of evidence-based on best-evidence synthesis approach.

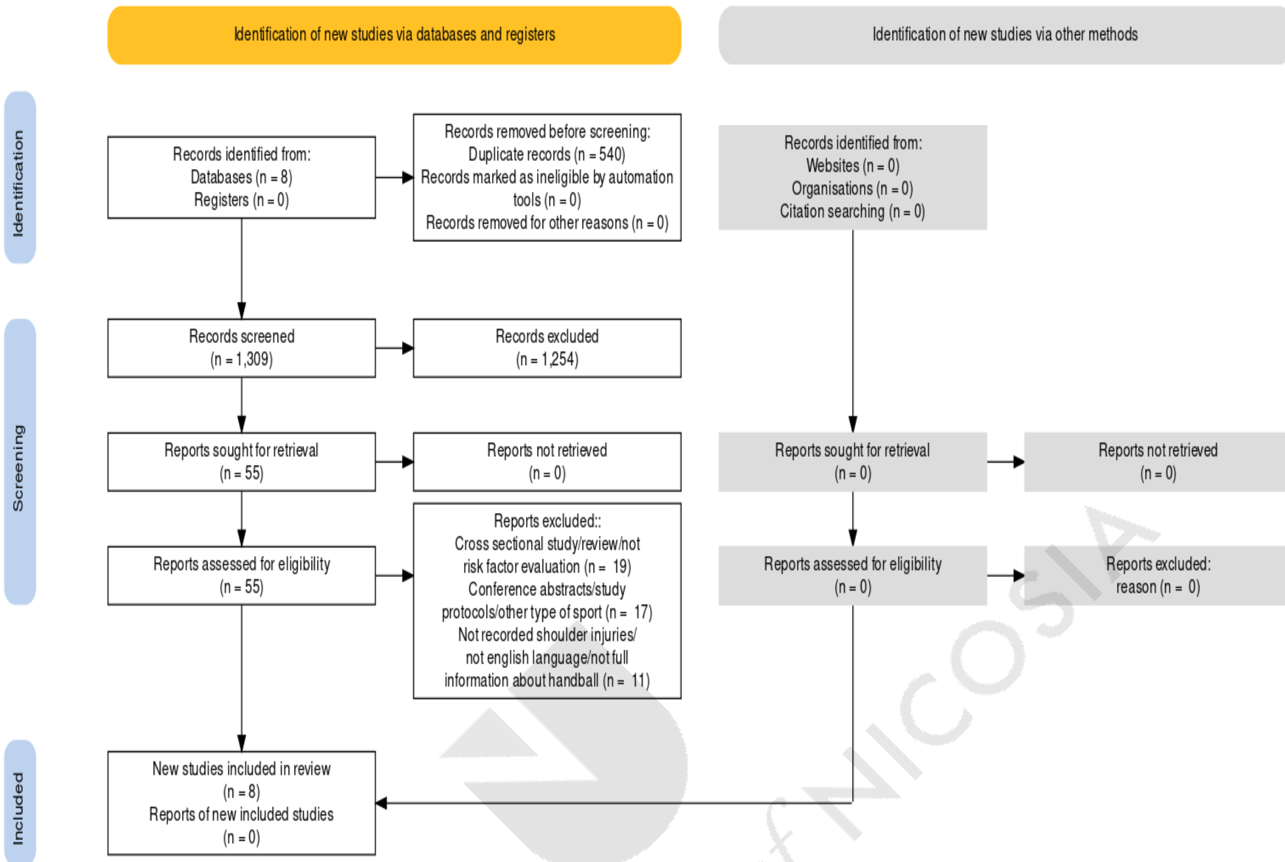
Best-evidence synthesis approach
1. Strong evidence: evidence provided by two or more high-quality studies and by generally consistent findings across these studies (≥75% of the studies reported consistent findings). 2. Moderate evidence: evidence provided by one high-quality study and/or multiple studies of acceptable quality and by generally consistent findings (≥75% of the studies reported consistent findings). 3. Limited evidence: evidence provided by one study of acceptable quality and/or one or more studies of borderline quality. 4. Conflicting evidence: inconsistent findings in multiple studies (<75% of the studies reported consistent findings). 5. No evidence: no admissible studies were found.

3.3 Results

3.3.1 Search Results and Selection

The initial search identified 1849 studies (figure 3.1). Removal of duplicates eliminated 540 studies while the title and abstract screening removed another 1254 studies. Fifty-five studies were reviewed in full text and eight of them were in accordance with the inclusion and exclusion criteria and therefore were included.

Figure 3.1. Flow chart of the included studies.



3.3.2 Methodological Quality

Quality assessment scores for the included studies ranged between 12 and 14 (Table 3.3). Percentage scores ranged between 75% and 88% (82% ± 6.4%). Four of the eight studies (Clarsen et al., 2014; Asker et al., 2018; Giroto et al., 2017; Achenbach et al., 2020) were rated of high methodological quality (> 85%) while the rest of the studies (Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020; Edouard et al., 2013) were rated of moderate methodological quality (50-85%). Three studies (Clarsen et al., 2014; Asker et al., 2020; Edouard et al., 2013) did not clearly report the hypothesis/aim/objective of the study - four studies did not report the distribution of principal confounders (Moller et al., 2017; Giroto et al., 2017; Andersson et al., 2018; Edouard et al., 2013) - three studies (Asker et al., 2018; Andersson et al., 2018; Edouard et al., 2013) did not report the actual probability values in the main outcome measures. Three studies (Moller et al., 2017; Asker et al., 2020; Achenbach et al., 2020) did not report the adequate adjustment for confounding in the analyses and one study (Andersson et al., 2018) did not use accurate main outcome measures.

Table 3.3 Quality assessment scores for the included studies.

	Questions																
Study	**1**	**2**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**16**	**18**	**20**	**21**	**22**	**25**	**Total**	**%**
Edouard et al (2013)	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	12	75
Clarsen et al (2014)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14	88
Giroto et al (2017)	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	14	88
Moller et al (2017)	1	1	1	0	1	1	1	1	1	1	1	1	1	?	0	12	75
Andersson et al (2018)	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	13	81
Asker et al (2018)	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	14	88
Achenbach et al (2020)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14	88
Asker et al (2020)	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	12	75

Abbreviations: 0, no; 1, yes

3.3.3 Study and Participant Characteristics

The demographic charcteristics of the studies are presented in table 3.4. Table 3.5 summarizes the most important findings of this review, while table 8 contains the full details of the studies included. A total of 2536 (males=1354, females=1182) participants of which 2522 handball athletes were included in this review. One study (Edouard et al., 2013) had the smallest sample of handball players while the sample of the other studies ranged from 138 to 679 handball players [mean (±) = 317 (201), median (IQR) = 334 (187)] (Table 3.4). Two studies investigated only male (Clarsen et al., 2014) or female athletes (Edouard et al., 2013). The age of the participants ranged between 14 and 24 years old. Four studies included adolescent athletes (Asker ey al., 2018; Moller et al., 2017; Asker et al., 2020; Achenbach et al., 2020). Two studies did not report dropouts during the follow-up period (Edouard et al., 2013; Achenbach et al., 2020). The handball experience of the athletes in four studies ranged between 8.2 and 14 years while four studies did not report on the experience of their subjects (Moller et al., 2017; Giroto et al., 2017; Andersson et al., 2018; Edouard et al., 2013). Two studies (Giroto et al., 2017; Achenbach et al., 2020) did not report the player's position.

Table 3.4. Demographic characteristics of the studies.

Study ID	**Sample (N)**	**Females**	**Males**	**Handball players**
Edouard et al (2013)	30	30	0	16
Clarsen et al (2014)	206	0	206	206
Giroto et al (2017)	339	183	156	339
Moller et al (2017)	679	304	375	679
Andersson et al (2017)	329	161	168	329
Asker et al (2018)	471	256	215	471
Achenbach et al (2020)	138	68	70	138
Asker et al (2020)	344	180	164	344
Mean (±)	***317 (201)***	***148 (107)***	***169 (110)***	***315 (204)***

Abbreviations: N, number of the participants; ±, standard deviation

The studies used different definitions for shoulder injuries except for two studies (Clarsen et al., 2014; Andersson et al., 2018). Moller et al (2017) assessed any new shoulder injury in the dominant arm, «defined as any handball-related shoulder problem irrespective of the need for time loss or medical attention». In the study by Edouard et al (2013) the shoulder injury was registered when the player consulted the National team physician and «was unable to take full part in handball activity or match play at least one day beyond the day of injury». All acute, traumatic, and overuse injuries were analyzed. One study (Andersson et al., 2018) assessed only overuse shoulder problems in the dominant arm, defined as any pain, ache, stiffness, instability, looseness, or other symptoms related to the shoulder, affecting the player's participation, training volume and performance, as well as the presence of pain over the previous 7 days. Importantly they excluded acute injuries. The same group in a previous study (Clarsen et al., 2014) calculated the prevalence of shoulder pain in both arms using the same operational definition and included in the analysis only those with moderate to severe restrictions in training, performance, or participation. In the study by Asker et al., (2018) shoulder problems were categorized into two types, any shoulder problems, and substantial shoulder problems. If a problem was reported in any of the four questions in the modified Swedish Oslo Sports Trauma Research Centre overuse injury (OSTRC) overuse injury questionnaire was categorized as any shoulder problem. For substantial shoulder problems, the authors used the same definition as Clarsen et al., (2014), namely «problems leading to moderate or severe reductions in training volume, or sports performance, or complete inability to participate in sport». Giroto et al., (2017) used different definitions for new injuries, previous injuries, overuse injuries, contact injuries, injuries without contact, injury severity and recurrent injuries. Importantly in their analysis, they compared three groups: non-injured athletes (reference group), athletes reporting a new traumatic injury, and athletes reporting a new overuse injury. In the study by Achenbach et al., (2020), the overuse shoulder injuries and re-injuries were used in the analysis and were defined as injuries with no identifiable traumatic event and injuries sustained at the same body site within 2 months after the first injury respectively. Asker et al., (2020) defined shoulder injury as reporting a score of 40 or more (OSTRC questionnaire) from the dominant shoulder at some point during the season. Furthermore, the OSTRC overuse injury questionnaire was modified to collect information about shoulder problems during the past two months and the past season (the original questionnaire focuses on shoulder problems during the past week).

The risk factors for shoulder injuries in handball identified in the included studies were: strength imbalances (Clarsen et al., 2014; Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020; Edouard et al., 2013; Achenbach et al., 2020), glenohumeral ROM imbalances (Clarsen et al., 2014; Moller et al., 2017; Andersson et al., 2018; Achenbach et al., 2020), scapular dyskinesis (Clarsen et al., 2014; Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020; Achenbach et al., 2020), incorrect dosage of training load (Moller et al., 2017; Giroto et al., 2017), previous injury (Giroto et al., 2017), sex (Asker et al., 2018; Giroto et al., 2017), player's position, school grade, playing level (Asker et al., 2018) and altered shoulder joint position sense (Asker et al., 2020).

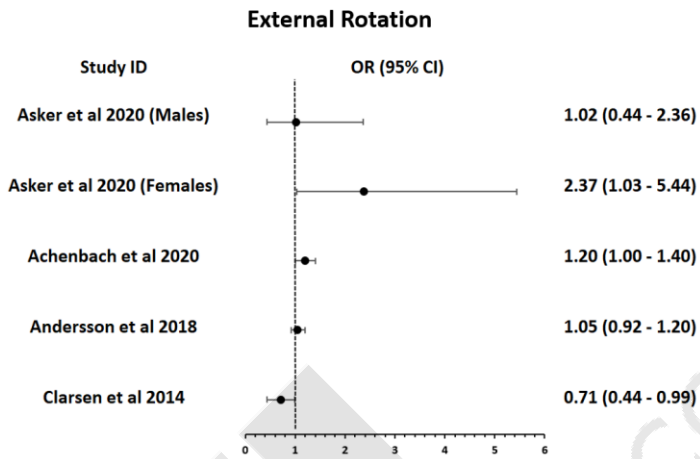
Four of the eight studies used the OSRTC overuse injury questionnaire (Clarsen et al., 2014; Asker et al., 2018; Andersson et al., 2018; Asker et al., 2020) to record shoulder injuries in handball. One study (Achenbach et al., 2020) used an online questionnaire that addressed any overuse injuries during a handball training session or match and the Western Ontario Shoulder Index (WOSI). One study (Giroto et al., 2017) used a weekly injury questionnaire that collected the date/situation of injury, and the injury in match/training. The Sports Injury Surveillance (SPEx) system was used in the study of Moller et al (2017). Finally, in the study of Edouard et al (2013), all new shoulder injuries in youth handball players were reported by the national team physician when a player consulted him/her for pain or injury or by medical interview by the physician every month. In the assessment of risk factors, four studies (Clarsen et al., 2014; Giroto et al., 2017; Andersson et al., 2018; Achenbach et al., 2020) used the odds ratios (O.R), two studies (Moller et al., 2017; Asker et al., 2020) the hazard rate ratios (H.R), one study (Edouard et al., 2013) the relative risk ratio (R.R) and one study (Asker et al., 2018) the prevalence rate ratios (P.R).

3.3.4 Synthesis of Results

3.3.4.1Muscle strength imbalances

Muscle strength imbalances as a risk factor for shoulder injuries in handball players were examined in two high-quality studies (Clarsen et al., 2014; Achenbach et al., 2020) and four moderate-quality studies (Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020; Edouard et al., 2013). One moderate quality study (limited evidence) (Edouard et al., 2013) found that female handball players with low ratios of concentric ER to concentric IR strength at 240°/s, and high ratios of eccentric IR to concentric ER strength at 60°/s had a 2.5 times higher risk of overuse and acute shoulder injury. Three out of four high-quality studies (strong evidence) agree there is an association between decreased ER isometric strength and overuse shoulder injuries in males (Clarsen et al., 2014; Achenbach et al., 2020) and females (Asker et al., 2020; Achenbach et al., 2020). Only one study (Andersson et al., 2018) found no significant association between external rotation strength and overuse shoulder injury (Figure 3.2). There was limited evidence (one moderate quality study) that reduced external rotation strength exacerbated the association between increased (increase between 20% and 60% per week) handball training load and overuse or acute shoulder injury among elite youth handball players (Moller et al., 2017).

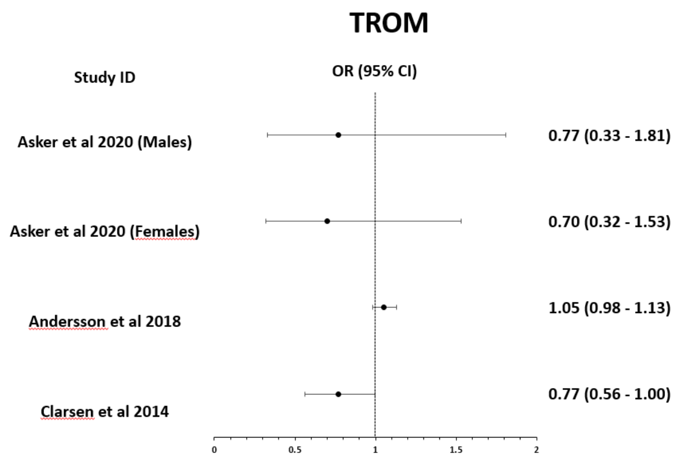
Figure 3.2.Graphical representation of the results for isometric ER strength as presented in the studies. (Note: Asker et al. calculated Hazard ratios instead of ORs).



3.3.4.2 Glenohumeral ROM imbalances

The association between various glenohumeral ROM imbalances and shoulder injuries was examined by two high-quality studies (Clarsen et al., 2014; Achenbach et al., 2020) and three medium-quality studies (Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020). There was moderate evidence that glenohumeral ROM imbalances and total range of motion (TROM) were not significantly associated with shoulder injuries (Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020). There was limited evidence that absolute TROM values rather than TROM differences (Figure 3.3) were significantly associated with overuse shoulder problems in elite male players only (Clarsen et al., 2014). There was limited evidence that greater internal rotation ROM was associated with overuse shoulder injury (Andersson et al., 2018). There was moderate evidence that an increased external rotation motion of more than 7.5° and a GIRD of more than 7.5° were risk factors for an overuse shoulder injury in youth female players (Achenbach et al., 2020).

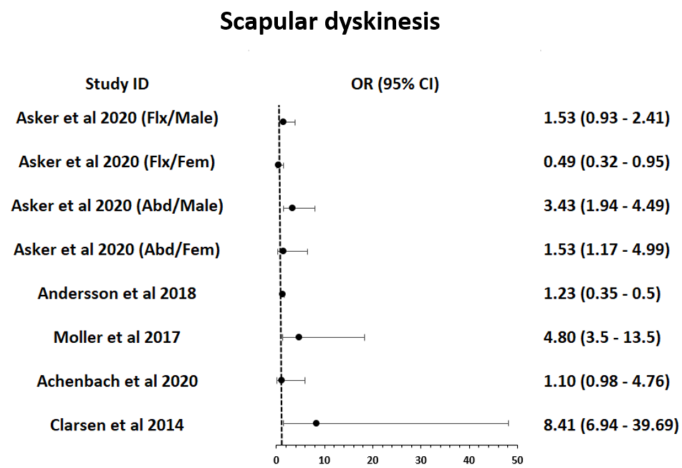
Figure 3.3. Graphical representation of the results for the TROM as presented in the studies. (Note: Asker et al. calculated Hazard ratios instead of ORs).



3.3.4.3 Scapular dyskinesis

Scapular dyskinesis was examined in two high-quality studies (Clarsen et al., 2014; Achenbach et al., 2020) and three moderate-quality studies (Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020). Overall 60% (3/5) of the studies pointed toward the direction of a significant association between shoulder injuries and scapular dyskinesis (Figure 3.4). Three studies found that obvious scapular dyskinesis was a risk factor for overuse (Clarsen et al., 2014; Andersson et al., 2018; Asker et al., 2020) and acute shoulder injuries (Andersson et al., 2018). Two studies found no significant association between scapular dyskinesis and overuse shoulder injury (Andersson et al., 2018; Achenbach et al., 2020). Overall there was conflicting evidence regarding the role of scapular dyskinesis in shoulder injuries in handball. There was limited evidence that scapular dyskinesis exacerbated the association between increased handball load and overuse or acute shoulder injury among elite youth handball players (Andersson et al., 2018).

Figure 3.4. Graphical representation of the results for the TROM as presented in the studies. (Note: Asker et al. and Moller et al. calculated Hazard ratios instead of ORs).



3.3.4.4 Shoulder joint position sense

The association between shoulder joint position sense and shoulder injury was examined in one medium-quality study (Asker et al., 2020). There was limited evidence that there was no association between joint position sense and overuse shoulder injuries in female or male players.

3.3.4.5 Training and match load

Excessive handball training and match loads were examined in one high-quality study (Giroto et al., 2017) and one medium-quality study (Moller et al., 2017). There was moderate evidence that an increase in handball load with an additional match per week was associated with overuse shoulder injury (Giroto et al., 2017). Moreover, there was limited evidence that an increase in handball load by >60% was associated with a greater shoulder injury rate and this association was stronger in players with reduced external rotation strength. Smaller increases in handball load between 20% and 60% were relevant only among players with reduced external rotational strength or scapular dyskinesis (Moller et al., 2017).

3.3.4.6 History of injury

The association between the history of injury and current shoulder injuries in handball players was examined in one high-quality study (Giroto et al., 2017). There was moderate evidence that the previous injury was associated with a higher risk of an overuse shoulder injury.

3.3.4.7 Sex

The association between sex and shoulder injuries was examined in two high-quality studies (Giroto et al 2017; Asker et al, 2018). There was strong evidence that the female sex has higher odds of traumatic shoulder injuries and a higher prevalence of shoulder injuries.

3.3.4.8 Player's position, school grade, playing level

The player's position, school grade, and playing level were examined in one high-quality study (Asker et al., 2018). There was moderate evidence that the prevalence of shoulder injuries was significantly higher in backcourt players, but no differences were found for school grade or playing level.

Table 3.5. Summary of the main results.

Independent Factors	Category	Injury type	Evidence of support	Grade of evidence	Details
Muscle imbalances	Isokinetic Ratios	Acute and overuse	1 moderate quality study	Limited evidence	Low conER/conIR strength at 240 °/s and high eccIR/conER strength at 60 °/s had a 2.5 times higher risk
	Isometric ER strength	Overuse	4 high-quality studies	Strong evidence	Decreased ER strength increases the risk
ROM imbalances	ER-IR ROM imbalance	Any shoulder injury	2 moderate-quality studies	Moderate evidence	No association with shoulder injuries
	TROM	Any shoulder injury and overuse injuries	3 moderate-quality studies	Moderate evidence	No association with shoulder injuries
	Greater IR	Overuse	1 moderate quality study	Limited evidence	16% increased risk per 5 degrees change
	ER> 7.5° and GIRD> 7.5°	Overuse	1 high-quality study	Moderate evidence	Higher risk in youth female players
Scapula Dyskinesis	Obvious scapula dyskinesis	Acute and overuse	2 high-quality and 3 moderate-quality studies	Conflicting evidence	3 out of 5 studies found a positive association
Joint position sense	Joint position error	Any shoulder injury	1 moderate quality study	Limited evidence	No association with shoulder injuries
Workload	1 additional match/week	Overuse	1 high-quality study	Moderate evidence	On average 31% increased risk for injury
	>60% increase in training load	Overuse	1 moderate quality study	Limited evidence	Increased risk of injury compared to those with <20% increase in training load
History of injury		Overuse	1 high-quality study	Moderate evidence	

Table 3.5 (continued)

Sex	Females	Acute	2 high-quality studies	Strong evidence	Higher prevalence of shoulder injuries and higher odds of traumatic injuries
Player's position	Backcourt	Any shoulder injury	1 high-quality study	Moderate evidence	Higher prevalence compared to 6m players
School grade	1st, 2nd, or 3rd year student	Any shoulder injury	1 high-quality study	Moderate evidence	No association with shoulder injuries
Playing level	Regional vs national	Any shoulder injury	1 high-quality study	Moderate evidence	No association with shoulder injuries
Interaction of Factors	**Injury type**	**Evidence of support**	**Grade of evidence**	**Details**	
ER strength and increased workload	Acute and overuse	1 moderate quality study	Limited evidence	Decreased ER strength increases the rate of shoulder injuries when load increases 20-60%/week or >60%/week	
Obvious scapular dyskinesis and increased workload	Acute and overuse	2 moderate quality studies	Limited evidence	Obvious scapula dyskinesis increases the rate of shoulder injuries when load increases 20-60%/week	

Table 3.6. Characteristics of the included studies.

Authors	Study type	Follow up duration	Recruited	Population characteristics	Dropouts	Risk factors (Method of evaluation)	Method of shoulder injury reporting	Association of risk factors with shoulder injuries
Edouard et al (2013)	Prospective Cohort Study	Season 2009 – 2010	16 F elite handball players and 14 healthy F non-athletes (Control group)	Age (18 ± 1 yrs) Height (174 ± 6 cm) Weight (70 ± 9 kg) BMI (23 ± 2 kg.m) Right-handed (n=11)	NR	Rotator muscle strength imbalances (Isokinetic dynamometer)	All new shoulder injuries were recorded by the national team physician and/or by monthly physician's medical interview.	ERcon/IRcon at 240 °/s and IRecc/ERcon at 60 °/s (RR 2.57, 95 % CI: 1.60–3.54; $P < 0.05$).
Clarsen et al (2014)	Prospective Cohort Study	Season 2011 – 2012 (September 2011 to May 2012)	206 M elite handball players	Age (24 ± 4 yrs) Height (189 cm) Weight (89 kg) Handball experience (14 years and 4 years in elite series)	N=42	1) TROM (digital inclinometer) 2) Isometric IR, ER, and abduction strength (digital handheld dynamometer) 3) Scapular control (. normal scapular control, slight scapular dyskinesis, or obvious dyskinesis.	OSTRC (email every 2 weeks).	Obvious scapular dyskinesis (OR 8.41, 95% CI 1.47 to 48.1, p<0.05), total rotational ROM (OR 0.77 per 5° change, 95% CI 0.56 to 0.995, p<0.05) and ER strength (OR 0.71 per 10 Nm change, 95% CI 0.44 to 0.99, p<0.05)
Giroto et al (2017)	Prospective Cohort Study	One season	339 elite handball athletes (156 M and 183 F)	Age (23.4 ± 4.6 yrs) Weight (76.7 kg) Height (1.77 m) BMI (24.2 kg/m^2)	N=27	1) Sex 2) Age 3) BMI 4) Previous injuries	Weekly exposure questionnaire	History of injury (OR: 2.42, 95% CI: 1.51–3.89), and an additional match per week (OR: 1.31, 95% CI: 1.05–1.62).Female

				Right-handed (84.9%) Left-handed (15.1%) Previous injuries last 6 months (46.6%)		5) Weekly exposure to strength training (hours/week) 6) Number of matches per week		athletes (OR: 1.56, 95% CI: 1.08–2.25), and an additional hour of training per week (OR: 1.09, 95% CI: 1.02–1.15)
Moller et al (2017)	Prospective Cohort Study	One season (2013-2014)	679 elite youth handball players (304 F and 375 M)	Age (16 ± 2 yrs) History of shoulder injury (n=43)	N=8	1) Handball load 2)Scapular control (normal or obvious scapular dyskinesia) 3)Rotational isometric strength (hand-held dynamometer) 4)Glenohumeral ROM side to side differences in TROM, IR, and ER	Injury and participation information was collected every week by SMS messaging.	>60% increase in load (HR 1.91; 95% CI 1.00 to 3.70) andreduced ER strength(HR 4.2; 95% CI 1.4 to 12.8). 20% - 60% increase in load with reduced ER strength (HR 4.0; 95% CI 1.1 to 15.2) or with scapular dyskinesis (HR 4.8; 95% CI 1.3 to 18.3).
Andersson et al (2018)	Prospective Cohort Study	One season (2014-2015)	329 elite handball players (168 M and 161 F)	Age (14 ± 5 yrs) Right-handed (78%)	N=39	1) Glenohumeral IR and ER ROM (digital inclinometer) 2) Isometric IR and ER rotation strength (handheld dynamometer) 3) Scapular dyskinesis (normal scapular control, slight scapular dyskinesis or obvious dyskinesis)	OSTRC (six times during the season)	Increased IR (OR 1.16 per 5° change, 95% CI 1.00 to 1.34)

Asker et al (2018)	Prospective Cohort Study	One season (2014 – 2015 or 2015 –	471 elite adolescent handball players (215 M and 256 F)	Age (16.4 ± 0.85 yrs) Height (176.8 cm) Weight (74.15 kg) BMI (23.8) Year of playing handball (9.1 years)	N=26	1)Sex 2)Player's position 3)School Grade 4)Playing level	OSTRC (every week)	Female (PR 1.46, 95% 1.04–2.06) and backcourt players (PR 1.58, 95% CI 1.08–2.32). School grade (PR 1.21 95% CI 0.88–1.67) or playing level (PR 1.09 95% CI 0.76–1.56)
Achenbach et al (2020)	Prospective Cohort Study	Season 2017 – 2018 (7 months)	138 (70 M and 68 F) elite youth handball players	Age (14.1 ± 0.8 yrs) Height (175.2 ± 8.2 cm) Weight (64.0 ± 9.6 kg) BMI (21.1 ± 2.0) Team handball experience (8.2 ± 2.2 years)	NR	1) GIRD, TROM, ER gain (manual goniometer) 2) IR strength, ER isometric and eccentric strength, ERecc/IRecc, and ER isometric/IR isometric (hand-held dynamometer) 3) Scapular movement present or absent and absent, moderate or severe scapular dyskinesis 4) Maximum throwing velocity (stationary radar gun)	A standardized questionnaire was emailed to all study participants at five time points	↓ isometric ER strength. eccentric ER strength were significant risk factors for overuse injury. ER gain of >7.5° and GIRD of >7.5° were significant risk factors for an overuse injury in girls. Scapular dyskinesis and maximum throwing velocity were not different among players with or without overuse injury.
Asker et al (2020)	Prospective Cohort Study	One or two seasons (2014-2015	344 students handball players	Age (16.55 ± 0.85 years,) Height (176.6 cm) Weight (74.7 kg)	N=127	1) Shoulder strength (isometric ER, IR, abduction) and eccentric ER (handheld dynamometer)	OSTRC (every week)	ER strength (F): 2.37 (95% CI 1.03- 5.44) ER strength (M): 1.02 (95% CI 0.44-2.36).

and/or 2015-2016)	(180 F and 164 M)	Handball experience (9.35 years)	2) Shoulder ROM (digital inclinometer) 3) Shoulder joint position sense 4) Scapular dyskinesia (video recording)	Isometric IR strength (F): 2.44 (95% CI 1.06-5.61) Isometric IR (M) 0.74 (95% CI 0.31-1.75) . Scapular dyskinesia (F): 1.53 (95% CI 0.36-6.52) Scapular dyskinesia (M): 3.43 (95% CI 1.49-7.92)

F, females; M, males; n, number of participants; NR, not reported; ER, external rotation; IR, internal rotation; ROM, range of motion; °/s, degrees per second; Ecc, eccentric; Con, concentric; TROM, total range of motion; GIRD, glenohumeral internal rotation deficit; BMI, body mass index; OSTRC, Oslo Sports Trauma Research Center; SPEx, Sports Injury Surveillance; OR, odds ratios; PR, prevalence ratios; RR, risk ratios; HR, hazard ratios P, probability value; CI, confidence intervals; ±, standard deviation.

3.4 Discussion

The purpose of this systematic review was to investigate risk factors for shoulder injuries in handball players. In comparison to other overhead sports (e.g baseball, volleyball, softball, tennis), there is a small number of studies having looked at handball. Overall, 8 prospective cohort studies were analyzed in this review (Edouard et al., 2013; Clarsen et al., 2014; Giroto et al., 2017; Moller et al., 2017; Andersson et al., 2018; Asker et al., 2018; Asker et al., 2020; Achenbach et al., 2020). Several potential risk factors were investigated in these studies. However, strong evidence was found only for the weakness of the external rotator cuff muscles and the female Sex that they increase the probability of shoulder injury in handball athletes.

3.4.1 Muscle strength imbalances and shoulder injuries

Three out of four high methodological quality studies agree that the decreased isometric strength of the shoulder external rotator muscles is significantly associated with overuse shoulder injuries in handball athletes (Clarsen et al., 2014; Andersson et al., 2018; Asker et al., 2020; Achenbach et al., 2020). The result seems to be independent of the method used to assess it and the variation in the sample among the positive studies. For example, there are differences in the mean ages of the participants. The average age of handball players in the studies was 24 years (Clarsen et al., 2014), 14 years (Achenbach et al., 2020), and 17 years (Asker et al., 2020). In addition, there are differences in the initial position of assessing muscle strength. In the study of Clarsen et al (2014) the participants were placed in a supine position, with the shoulder in a neutral position and with the elbow flexed in 90º. Instead, in the study of Asker et al (2020) the seated position was preferred with the shoulder abducted in 30º. On the other hand, Achenbach et al (2020) did not mention the initial position of the participants. Furthermore, in the study by Andersson et al (2018), although ER strength was not confirmed as a significant risk factor, male athletes were stronger than their female counterparts and showed a lower percentage of shoulder injuries and substantial shoulder injuries despite having a significantly higher exposure to handball training. Taken together these results suggest that isometric external rotation strength is an important variable to monitor both pre-season and during the season.

Studies have found that the strength of the rotator cuff muscles of the shoulder may be affected by the initial position of the shoulder due to the length-tension relationship of the muscles and the tension of the ligaments and the joint capsule (Forthomme et al., 2011; Greenfield et al., 1990; Edouard et al., 2011; Lin et al., 2015). Forthomme et al. (2011) reported that the ability of the rotator cuff muscle to produce power was greater at the 90^{o} of shoulder abduction compared to the 45^{o} of abduction. In the study of Lin et al. (2015) when the ratios of internal and external rotator muscle strength were evaluated at different abduction angles, rotational power was greater at the 70^{o} of shoulder abduction (Lin et al., 2015). Several studies choose to evaluate the rotator cuff muscle strength in shoulder positions below 90^{o}, however, ball throwing most often takes place around 90^{o} of abduction. Therefore, it is suggested that the evaluation of rotator cuff strength is more sport specific at 90^{0} of abduction.

Biomechanically, the shoulder external rotator muscles play an important role in stabilizing the shoulder during the cocking phase of ball throwing. If there is a weakness in the shoulder external rotator muscles, the humeral head is believed to slide upwards especially during ball throwing, due to the action of the deltoid muscle. This reduces the subacromial space, potentially leading to compression of the supraspinatus tendon (Leong et al., 2016; Bigliani and Levine, 1997). However, this traditional view of subacromial compression causing the pathophysiology of shoulder problems is not supported by evidence (Papadonikolakis et al., 2011). Specifically, humeral migration seems to be the result of rotator cuff deficiency not the cause of it (Keener et al., 2009) , bilateral full-thickness tears often cause unilateral problems (Yamagoochi et al., 2006), and contact between the rotator cuff and the coracoacromial arch is common in asymptomatic subjects (Yamamoto et al., 2010; del Grande et al., 2016), there is no correlation between acromiohumeral distance and pain and function in patients with RC disease (Navarro-Ledesma et al., 2017) and the most common side of partial tears is the articular not the bursal (Weber, 1997; Itoi and Tabata, 1992) aspect of the tendon.

A more plausible explanation for shoulder pain in overhead athletes is overload. During ball throwing, the deceleration of the internal rotation of the shoulder after the ball leaves the hand depends largely on the shoulder's external rotator muscles (Seil et al., 2018). Strength deficits of the external rotators will result in RC overload and reduced ability to decelerate the movement. There are also reports of a decrease in the strength of the external rotators in the dominant shoulder with a simultaneous increase in the strength of the internal rotator and the adductor muscles (Noffal, 2003). This results in muscle imbalance between the shoulder's internal and external rotator muscles and the possibility of shoulder injury (Wilk et al., 2002). In the study of Edouard et al (2013), it was found that the lower ratios of muscle strength between concentric external rotation and concentric internal rotation and the higher ratios between eccentric internal rotation and concentric external rotation were associated with a 2.5 times higher risk of overuse injury and acute shoulder injuries in women. A similar result was found in the study of Achenbach et al (2020), where the lower ratios of muscle strength between shoulder internal and external rotator muscles were associated with a higher risk of shoulder overuse injury in male handball players.

Up to 15% differences in internal rotation strength between the dominant and non-dominant sides as found in the study by Edouard et al. (2013), are considered a normal adaptation to sport (Edouard et al., 2011; Ellenbecker and Davies, 2000). The strength difference between internal and external rotators in the dominant arm is possibly the result of resistance training emphasizing the internal rotator muscles (pectoralis major, latissimus dorsi, teres major) due to the need to produce high internal rotation power during throwing. In addition, repeated throws of the ball can lead to an adaptive increase in the strength of the shoulder's internal rotator muscles. This increase of the internal rotation strength helps the athlete achieve faster ball speed, resulting in higher ball throwing efficiency (Bayios et al., 2001; Zapartidis et al., 2007) but can increase the risk of injury when not sufficiently balanced with the decelerating ability of the external rotators. Studies by Andrade et al. (2010) in handball players and Wang and Cochrane (2001) in volleyball players suggest that functional ratios (ERecc/IRcon), should be greater than 1. This reference value can be useful in developing fitness and rehabilitation programs, especially because it was associated with fewer shoulder injuries at least in volleyball players (Wang and Cochrane, 2001). Although Edouard et al (2013) did not confirm this suggestion in handball players, since they found reduced functional ratios in handball players and controls, it might still be valid due to the methodological differences between the two studies such as different isokinetic velocities, different Sex of the participants and different functional ratios in the non-dominant arm.

3.4.2 Glenohumeral ROM imbalances and Shoulder injuries

Handball players like other throwing athletes have a greater ER ROM to the dominant shoulder compared to the non-dominant shoulder (Almeida et al., 2013; Myklebust et al., 2013; Clarsen et al., 2014; Shanley et al., 2015; Winkelmann et al., 2021; Wilk et al., 2011; Manske et al., 2013). This greater range of motion during the cocking and acceleration phases is potentially related to faster ball throwing (Tillar and Ettema, 2006). However, increased external rotation of the shoulder is believed to cause retroversion of the humeral head due to the rotational loads, particularly when these occur in an immature skeleton (Borsa et al., 2008; Pieper, 1998). Consequently, most overhead athletes present with increased external rotation and reduced internal rotation ROM in the dominant arm (Glenohumeral Internal Rotation Deficit – GIRD) (Winkelmann et al., 2021). This deficit in the internal rotation often results in a reduction in overall shoulder rotation TROM and this is believed to increase the risk of shoulder injury in overhead athletes (Wilk et al., 2011). An alternative explanation for the reduced TROM is considered the posterior capsular and muscular tightness of the glenohumeral joint (Borsa et al., 2008; Thomas et al., 2011; Takenaga et al., 2015).

The glenohumeral ROM imbalances as a possible risk factor for shoulder injuries in handball players were investigated in 5 studies (Clarsen et al., 2014; Moller et al., 2017; Andersson et al., 2018; Asker et al., 2020; Achenbach et al., 2020). In general, the role of ROM imbalances and TROM in shoulder injuries was not supported by the studies included in this review. Clarsen et al. (2014) suggested that absolute TROM values rather than TROM differences were significantly associated with overuse shoulder problems in elite male players but a subsequent study by the same group, with the same methodology, in a larger sample of male and female players, failed to confirm this finding and suggested that only greater internal rotation ROM was associated with overuse shoulder injuries (Andersson et al., 2018). Only the study by Achenbach et al. (2020) found a significant correlation between increased external rotation and GIRD in the dominant shoulder with overuse shoulder injuries in female athletes. An explanation for the discrepancy with other overhead athletes might be that ball throwing in handball is performed with various techniques (e.g overarm and sidearm throw) compared to other throwing sports, and the shoulders of handball players are often exposed to contact and blockage while in an elevated position.

3.4.3 Scapular Dyskinesis and Shoulder injuries

Scapular dyskinesis is a common finding among people with shoulder pain and a variety of shoulder pathologies such as impingement syndrome, rotator cuff tears, glenoid labrum tears, and instability (Laudner et al., 2006; Cools et al., 2007; Struyf et al., 2014; Ludewig and Reynolds, 2009). It has also been shown to be common among athletes from a variety of overhead sports, such as baseball, swimming, and tennis (Laudner et al., 2010; Maor et al., 2017; Saini et al., 2020). However, it is common among symptom-free athletes (Struyf et al., 2014; Sciascia et al., 2010; Tate et al., 2009; Myers et al., 2013) as well as those with pain, and evidence of an association between scapular dyskinesis and shoulder symptoms among overhead athletes is lacking (Clarsen et al., 2014; Struyf et al., 2014; Myers et al., 2013). No clear evidence was found in the present study regarding the association between scapular dyskinesis and shoulder injuries in handball due to the conflicting results, the limited number of studies, and the methodological differences between studies. In contrast, Hickey et al. (2018) in the systematic review that they conducted, concluded that overhead athletes who present scapular dyskinesis have a 43% higher risk of causing shoulder pain compared to athletes who do not have scapular dyskinesis. However, only one study with handball players was included in that systematic review. In another, more recent systematic review Hogan et al. (2021) found that scapular dyskinesis was not a significant risk factor for a shoulder injury in throwing athletes from different sports (e.g baseball, rugby).

In the present review, 3 out of 5 studies showed that scapular dyskinesis was a significant risk factor for a shoulder injury in handball players (Clarsen et al., 2014; Moller et al., 2017; Asker et al., 2020). Perhaps the conflicting results arise due to the lack of consensus in assessing scapular dyskinesis. In the study by Clarsen et al. (2014) external weight (5 kg) was used for the assessment of scapular dyskinesis and participants performed 5 repetitions. In contrast, in the study by Asker et al. (Asker et al., 2020) a smaller external weight (2 kg for men and 1 kg for women) for 2 repetitions was used. Other studies did not provide sufficient information on how to assess scapular dyskinesis. Another source of variation is the categorization of dyskinesis with some studies using a binary classification (present or not) (Asker et al., 2020) and others using grades of severity (normal / mild dyskinesia / obvious dyskinesia) (Clarsen et al., 2014). It has been suggested that the evaluation of two options (normal or abnormal) is more reliable (Uhl et al., 2009). Furthermore, some studies used video while others did not (Achenbach et al., 2020) to assess scapular dyskinesia. Until these methodological issues are resolved, the relationship between scapular dyskinesis and shoulder injuries will probably produce conflicting results.

3.4.4 Training Load and Shoulder injuries

Research on the training load and its relationship to injuries in throwing athletes is in its early stages and most of the research was done on baseball, cricket, football, rugby, and volleyball (Bahr et al., 2014; Drew and Fitch, 2016; Colby et al., 2017; Orchard et al., 2015; Lyman et al., 2002). In the present review, only two included studies evaluated the effect of training load on shoulder injuries in handball players (Moller et al., 2017; Giroto et al., 2017). In the study by Giroto et al. (2017), it is apparent that the addition of an official match per week is significantly associated with overuse shoulder injuries. In the study of Moller et al. (2017) players who increased their weekly handball training load by 60% or more were twice more likely to suffer an overuse injury compared to players that increased their training load by 20%.

Another significant finding of the study by Moller et al. (2017) was the interaction of training load with other potential risk factors such as obvious scapular dyskinesis and reduced external rotation strength. These moderators seem to exacerbate the association between increased training loads and overuse injuries. These findings emphasize the multifactorial nature of athletic injuries and the importance of complex, nonlinear interaction between different factors which require a more dynamic system approach in injury prevention research (Bittencourt et al., 2016; Bekker and Clark, 2016).

3.4.5 Shoulder joint position sense and shoulder injuries

The association of reduced shoulder proprioception with shoulder injuries in handball athletes was investigated in only one moderate methodological quality study (Asker et al., 2020). However, no significant association was found between shoulder proprioception and shoulder injuries. One limitation of this study is that only one subcategory of proprioception was assessed (joint position sense). As it is well known, proprioception is divided into more subcategories, such as the sense of movement (kinesthesia), the sense of force, the sense of change in velocity, and the sense of vibration (Arzi et al., 2014; Franco et al., 2015). Further research is required to determine the effect of reduced proprioception in shoulder injuries in handball. This is especially important after an injury that is generally believed to disrupt proprioception (Jerosch and Wustner, 2002; Sahin et al., 2017).

3.4.6 History of previous injury and Shoulder injuries

A history of a previous injury is arguably one of the most important non-modifiable risk factors associated with various sports injuries. Examples of sports injuries that have been significantly correlated with a history of a previous injury are hamstring strains (Freckleton and Pizzari, 2013; van Beijsterveldt et al., 2013; Green et al., 2020), ankle sprains (Delahunt and Remus, 2019), shoulder dislocations (Hutchinson and McCormack, 2015) [95], and groin injuries (Whittaker et al., 2015). In the present review, only one high-quality study investigated the history of a previous injury as a possible risk factor for a future shoulder injury in handball athletes (Giroto et al., 2017). Aligned with the results in other injuries, professional handball players are 2.5 times more likely to sustain a new shoulder injury when they have a history of a previous injury. The study by Moller et al. (2017) also reported that a history of 2 or more previous injuries is a significant risk factor for future injury in 16-year-old handball players. However, all previous injuries (locations and types) were included in the analysis, and this makes it difficult to isolate the results for the shoulder. Some studies showed that a previous injury, such as an ankle sprain, increased the risk of developing a new and more serious injury in the same area (Wedderkopp et al., 1997; van Mechelen et al., 1996). Inadequate recovery from previous injuries could explain the reason that a previous injury is a significant risk factor for causing future injuries.

3.4.7 Sex and Shoulder injuries

Another non-modifiable risk factor that is commonly associated with sports injuries is Sex. Women athletes have been found to have higher rates of concussion (O' Connor et al., 2017) and ACL injuries (Myklebust et al.,1997; Walden et al., 2011) than men. In the present study, two high methodological quality studies (Asker et al., 2018; Giroto et al., 2017) agree that adolescent and mature female handball players have a greater risk of shoulder injuries than male players. Michalsik & Aagard (2015) found that female handball athletes perform higher training loads compared to men. In addition, kinematic differences in ball throwing have been found between men and women. Men perform ball throwing with a greater rotational speed of the trunk and with a greater range of motion of horizontal shoulder abduction during the cocking phase (Serrien et al., 2015). In addition, male handball players have a higher ball throwing speed on the wrist and hand compared to women (van den Tillar and Cabri, 2012). Perhaps these factors and (Maier et al., 2022) affect the risk of injury between the sexes.

3.4.8 Player's position and Shoulder injuries

In one high methodological quality study (Asker et al., 2018), a significant correlation between backcourt handball players and shoulder injuries was found. Other studies suggest the same finding concerning other injuries such as ACL injuries (Myklebust et al., 2003; 1998). This is perhaps because backcourt players had the highest overall incidence of injuries and the highest number of acute, non-contact, lower limb injuries compared to other player positions as Wedderkopp et al. (1997) showed. One possible explanation is that the majority of the ball moves in the attack are performed by defensive players who therefore perform a significant amount of cutting moves as well as jumping shoots (Seil et al., 2018). In addition, they engage in more aggressive contact compared to players in other positions (Seil et al., 2018).

3.4.9 Limitations

The present study has some limitations. First, only published studies that were written in English were used. Second, the small number of included studies, the differences in the risk factors assessed, and the considerable variability in methods and sample characteristics made it difficult to combine them in a meta-analysis. The heterogeneity of the studies also provided considerable difficulty in the interpretation of the results and the derivation of solid suggestions for injury prevention.

The studies included in this review suffer from several limitations. The operational definition of shoulder injury was not universal. In addition, several studies looked at only overuse and not at all shoulder injuries. Even the studies that looked at all shoulder injuries did not provide adequate separation between overuse and acute injuries as risk factors might be different for these types of injuries. There was very limited or no information on the specific diagnosis of the injuries included in each study. There was no universally agreed method to record new shoulder injuries between studies and this creates a challenge to compare the results. Some studies suffer from a considerable loss of data (e.g on a weekly basis) and therefore the number of injuries might be lower than the true one. Most studies evaluated individual risk factors but as already mentioned and confirmed by the study of Moller et al. (2017) the cause of athletic injury is usually multifactorial. Therefore, the results should be interpreted with caution.

3.4.10 Directions for future research

More studies are necessary to specifically investigate the risk factors for a shoulder injury in handball players. In addition, more studies should be conducted on younger handball players to understand the potentially modifiable risk factors to prevent shoulder injuries and extent the athletic career. Future studies should also include both female and male handball players so that differences in risk between sexes can be determined. There should be a consensus regarding technical (e.g position of measurements) and methodological issues (e.g definition of injury, assessment of scapular dyskinesis, method of injury surveillance) to produce solid results and avoid confusion.

3.4.11 Clinical suggestions and practical applications

Based on the results of this systematic review the following are suggested for the prevention of shoulder injuries in handball players:

1) Athletes should be evaluated with reliable measuring tools (e.g isokinetic dynamometer or handheld dynamometer) during the pre-season period to identify any strength deficits or imbalances and intervention should be applied to correct them.
2) The functional ratios between ERecc/IRcon above 1.0 can be a preliminary reference value for handball players and can be useful in developing fitness and rehabilitation programs,

although future studies are required to confirm its clinical utility. If lower functional ratios are present, a strengthening program for the ER muscles in eccentric contraction should be implemented.

3) The average weekly increase in training load should be monitored to avoid overuse. Important moderators such as scapular dyskinesia or weakness of the external rotators should be corrected as they make the athlete vulnerable to injury even with lower increases in training load.
4) It is recommended for handball athletes who have suffered a serious shoulder injury to perform a complete and correct recovery to enhance the mechanical strength of injured tissues at pre-injury levels. In addition, injured athletes need to have reliable and measurable assessment tools (e.g. isokinetic dynamometer) before returning to their sport after injury.
5) All of the recommendations are probably more important for backcourt and female players

3.5 Conclusions

Overall, from all risk factors evaluated in the existing studies, there was strong evidence that the weakness of the external rotator cuff muscles and the female Sex increase the probability of shoulder injury in handball athletes. Nevertheless, the evidence for the other risk factors was moderate to limited due to the lower methodological quality and the limited number of studies

Chapter 4.0: Effect of concentric exercise-induced fatigue on proprioception, motor control and performance of the upper limb in handball players

Abstract

Background: The last phases of a competitive game are when shoulder injuries most commonly happen, and fatigue is thought to be a major contributing factor, perhaps because of reduced proprioception and motor control. The purpose of this study was to investigate the effect of concentric fatigue on proprioception, motor control, and performance of the upper limb in handball players.

Methods: Forty-six right-handed handball players (all males, age 26.1 ± 5.54 years) were included in this test-retest laboratory experiment. Proprioception was assessed using joint reposition sense (JRS), threshold to detection of passive movement (TTDPM), muscle onset latency (MOL), motor control using Y balance test upper quarter (YBT-UQ) and performance using the athletic shoulder test (ASH) before and immediately after fatigue intervention. The fatigue protocol consisted of concentric, maximal effort, isokinetic contractions at 90^0/sec with sets of 30 repetitions of the right shoulder external and internal rotator muscles. Fatigue was determined by a 60% decline in the peak torque over three consecutive contractions despite reinforcing feedback and encouragement.

Results: A significant increase in absolute angular error (AAE) was observed in all target angles in both external rotation (ER) and internal rotation (IR) directions ($p < 0.01$). A similar significant increase in relative angular error (RAE) was observed in five out of six target angles after muscle fatigue. In addition, there was a significant increase in TTDPM in internal rotation after fatigue intervention (p=0.020). Variable changes were found in YBT-UQ and ASH tests. Specifically, statistically significant differences were found in anteromedial (AM) (p=0.041), superolateral (SL) reach directions (p=0.005), composite score (p=0.009) in the right hand and inferolateral (IL) reach direction in the left hand (p=0.020) in the YBT-UQ. In addition, there was a significant reduction in isometric strength (ASH test) in the I position of the right hand (p=0.010) and all positions of the left hand ($p<0.05$). Furthermore, there was an increase in MOL scores by 46.36 % and 48.33% for the posterior deltoid and infraspinatus muscle correspondingly after fatigue but the increase was not significant ($p > 0.05$).

Conclusions: Concentric fatigue of the rotator cuff muscles induces notable deficits in joint position awareness, kinesthesia, motor control, and performance of the upper extremity in elite male handball players. Although fatigue considerably reduces reflex reaction time the effect is not statistically significant.

Key words: Muscle fatigue, proprioception, handball, motor control, neuromuscular control

4.1 Introduction

Shoulder pain ranks as the third most common musculoskeletal problem observed in general medical practice, following low back pain and knee pain (Luime et al., 2004), and it is even more prevalent in athletic populations. For instance, the prevalence of shoulder pain in handball players is estimated to be between 19% to 36% before the start of the season, and 28% during the season (Clarsen et al., 2014; Myklebust et al., 2013). Furthermore, a significant proportion of handball players (48%) experiencing ongoing shoulder pain are unable to engage in games or training due to increased pain intensity (Asker et al., 2018). Dirx et al. (1992) reported an elevated occurrence of handball injuries in the latter half of matches. In addition, according to Asembo and Wekesa (1998), a majority of handball injuries (57%), happen during the final third of the game. The observed increase in injury occurrence during the final third of both practice sessions and games is postulated to be linked to alterations in neuromuscular control and proprioception due to fatigue (Brito et al., 2012; Hiemstra et al., 2001; Steib et al., 2013).

The impairment of proprioception resulting from muscle fatigue is thought to be linked to alterations in the release patterns of muscle afferents caused by the accumulation of metabolites, which can potentially disrupt the transmission of information through muscle spindles (Forestier et al., 2002). Additionally, there may be changes in the central processing of proprioception through group III and IV afferents (Taylor et al., 2000), as well as effects on the efferent pathways (Caron, 2003).

Neuromuscular control is the unconscious motor efferent response to sensory information received from proprioceptive sources (Myers and Lephart, 2000). The neuromuscular control of the shoulder joint involves the synchronized activation of muscles during functional activities, the simultaneous activation of shoulder muscles, the response of muscles to reflexes, and the modulation of muscle tone and stiffness (Myers and Lephart, 2002). Muscle forces play a crucial role in aligning the humeral head with the glenoid, while also maintaining a significant range of motion (Myers et al., 2006). Proprioception is a fundamental aspect of neuromuscular control Myers and Lephart, 2000) and it has a significant impact on muscular coordination, enabling precise movement and stability of the joints (Boerboom et al., 2008). Proprioception refers to the sensory input originating from peripheral regions of the body, such as the mechanical and dynamic constraints around the shoulder. This input plays a role in maintaining joint stability, controlling posture, and regulating motor function (Riemann and Lephart, 2002a, 2002b).

Patient populations with shoulder instability (Lephart et al., 1994; Rokito et al., 2010; Smith and Brunoli, 1989), impingement syndrome (Jerosch and Wustner, 2002), osteoarthritis (Cuomo et al., 2005), rotator cuff dysfunctions (Sahin et al., 2017), and adhesive capsulitis (Fabis et al., 2016) have been found to exhibit deficiencies in both the incoming proprioceptive input and outgoing motor responses.

Muscle fatigue refers to the gradual decline in the maximum force and power that muscles can generate (Abd-Elfattah et al., 2015). Fatigue is commonly categorized as either central or peripheral (McKenna & Hargreaves, 2008). Central fatigue refers to a decline in the intentional activation of muscles, which is caused by a decrease in the frequency and coordination of motoneurons, as well as diminished stimulation from the motor cortex. Peripheral fatigue refers to the reduction in the ability of muscle fibers to contract due to impaired transmission of muscle action potentials (Zając et al., 2015)

Previous studies show contrasting results with some demonstrating impaired joint position sense (Iida et al., 2014; Kablan et al., 2004; Lee et al., 2003; Myers et al., 1999), kinesthesia (Carpenter et al., 1998), and dynamic shoulder stability (Lee et al., 2003) due to fatigue, while others failed to observe a substantial disparity in shoulder proprioception pre and post- muscle fatigue (Spargoli, 2017; Sterner et al., 1998; Voight et al., 1996). The outcome measures that have been assessed in the above studies were the shoulder joint repositioning sense (JRS), the threshold to detection of passive movement (TTDPM) and the shoulder joint stability. It is not known if fatigue affects muscle onset latency (MOL) and motor control of the shoulder. Furthermore, none of the aforementioned investigations included handball athletes who are in a high-risk population for shoulder inuries (Hadjisavvas et al., 2024). The primary objective of this study was to examine the impact of concentric fatigue on the proprioception motor control and performance of the upper limb in handball players.

4.2 Methods

4.2.1 Hypotheses

The research and null hypotheses of the first experiment were as following:

- H_1: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the proprioception of the upper limb in handball players.
  $H_1$0: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the proprioception of the upper limb in handball players.
- H_2: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the kinesthesia of the upper limb in handball players.
  $H_2$0: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the kinesthesia of the upper limb in handball players.
- H_3: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the MOL of the upper limb in handball players.
  H_3O: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the MOL of the upper limb in handball players.
- H_4: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the performance of the upper limb in handball players.
  $H_4$0: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the performance of the upper limb in handball players.
- H_5: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the motor control of the upper limb in handball players.
  H_5O: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the motor control of the upper limb in handball players.

4.2.2 Type of research and sampling method

A quantitative research was used for the completion of the study. Utilizing the techniques of the natural sciences, quantitative research generates hard facts and numerical data. It uses statistical, computational, and mathematical techniques to establish a cause-and-effect relationship between two variables. Because the research can be precisely and accurately measured, it is also known as empirical research. The information gathered by the researcher can be categorized, ranked, or measured using different units of measurement. With the aid of quantitative research, raw data can be created into graphs and tables that facilitate the researcher's analysis of the findings (Ahmad et al., 2019).

The participants who took part in the study were selected through the convenience sampling method. Convenience sampling describes the data collection process from a research population that is effortlessly reachable to the researcher (Rahi, 2017). Convenience sampling yields various benefits. First, the researchers can consume less effort to select the participants compared to other non-random sampling techniques. Second, convenience sampling requires the researcher to select participants at a very low cost. Third, the researchers invest less time since the sample taken from the target population is readily accessible. Finally, they do not need to prepare a list of all the population elements (Alvi, 2016). This kind of sampling, however, is susceptible to systematic errors and sampling biases. In this sense, convenience samples were tainted by bias from both self-selection and non-coverage. If empirical studies employ non-probability convenience samples, even though they are successful in avoiding non-coverage and obtaining a sampling frame that includes a random pool of subjects, the researchers are typically unable to conduct self-selection because individuals choose whether or not to participate in the interview or complete the survey. Furthermore, it is impossible to interpret the p-value in a meaningful way (Hirschauer et al., 2020). Alvi (2016) also argued that target population categories are comprehensive enough to be divided into an unlimited number of categories within themselves that are comparatively dissimilar from each other and cannot be representative of one another. Moreover, the variability of the participants in the sample can be controlled or measured. Since the population under study is quite familiar, the researcher may be enticed to generalize. However, the research findings cannot be generalized beyond the sample when using this technique (Acharya et al., 2013). Because of the above drawbacks, researchers often consider convenience sampling as a research limitation (Koerber & McMichael, 2008).

The study’s target population consisted of handball players. This particular sample was selected because, in contrast to other throwing sports (e.g baseball, volleyball, cricket), there was a larger gap in the literature regarding the effect of rotator cuff muscle fatigue on proprioception, motor control, and performance of the upper extremity. Initially, the main researcher (S.H) contacted the sports coordinator of the University of Nicosia (A.P) by telephone in order to obtain contact numbers of various handball coaches. After this, the main researcher called each coach. Each coach received an explanation of the study's goal and methodology. Each coach provided a list of phone numbers for all of the handball players. After then, the primary investigator got in touch with every handball player that was accessible. The procedure, purpose, and benefits of the study were explained to each one. A specified date and time to visit the study site was provided to handball players who verbally consented to participate. The investigation was conducted in a calm setting in a specially created laboratory of the University of Nicosia's Physiotherapy Program.

4.2.1 Subjects

Forty-six right-handed male handball players from the first and second division participated in this study. The optimal number of participants was determined using specialized software (G*power 1.3.9.4). With a significance coefficient of 0.05 and a moderate correlation between repeated measures (before and after fatigue) with an effect size of 0.3, a sample size of 30 individuals yields a power of 82% or 0.82. Therefore, even accounting for a 10% attrition rate of participants during the study, the number of 46 individuals is deemed sufficient. The participants in the study were physically active professional handball athletes who engaged in a minimum of three training sessions per week and regularly competed in official matches. The exclusion criteria (table 4.1) encompassed those with a recent shoulder injury within the past six months, previous shoulder surgery, neurological disorders, congenital stiffness, cervical radiculopathy, shoulder dislocation, intra-articular fracture, rotator cuff tear, and labral tear. In addition, every individual who reported discomfort in more than 2 clinical tests or isometric contractions during the initial evaluation was eliminated from the study and instructed to consult a physician for a definitive musculoskeletal diagnosis. The study received ethics approval by the National Bioethics Committee of Cyprus (ΕΕΒΚ/ΕΠ/2020/40).

Table 4.1. The inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
• Professional male handball players • At least three training sessions per week • Participation in official matches	• Recent shoulder injury within the past six months • Previous shoulder surgery • Neurological disorders • Congenital stiffness • Cervical radiculopathy • Shoulder dislocation • Intra-articular fracture • Rotator cuff tear and labral tear • Discomfort in more than 2 clinical tests or isometric contractions during the initial evaluation

4.2.2 Experimental protocol

The present investigation utilized a pre-test and post-test design. Handball players were initially approached via telephone following the authorization of the team coach and management, who supplied the players' information. After receiving verbal consent, they were invited to the laboratory of the Physiotherapy Program at the University of Nicosia, where the testing occurred. Initially, the main researcher assessed the participants to determine if they met the specific criteria for inclusion in the study. If subjects met the study participation criteria, they were provided with the specific consent form to read and sign. Anthropometric measures were conducted with an electronic scale (Tanita WB 3000) to evaluate weight, and a statiometer (Seca, Hamburg, Germany) to determine height. Participants were instructed to wear minimal attire, excluding socks and shoes. Subsequently, the main investigator, who is an expert in Sports and Musculoskeletal Physiotherapy, conducted a screening assessment to verify the participants' shoulder health to carry out the tests and fatigue protocol. The screening examination included assessment of active and passive shoulder movements, manual isometric muscle tests and orthopedic special tests (Neer's test, Hawkins-kennedy test, infraspinatus test, belly press test, lift off test, speed's test, Yergason's test, Load and shift test, apprehension test, sulcus sign, Crank test, anterior slide test) (Magee, 2014). The active and passive shoulder movements (flexion, extension, abduction, adduction, external rotation, internal rotation, horizontal adduction, horizontal abduction) were performed while each participant was in a standing position. In addition, all shoulder movements were assessed with manual isometric muscle test (5sec duration, 'break' test). Each orthopedic special test was performed as following:

- Neer's test: The patient's arm was passively and firmly raised fully in the scapular plane while the examiner medially rotated it. Shoulder pain with this maneuver indicates a positive test.
- Hawkins-kennedy test: As the subject stands with the arm flexed to 90˚, the examiner passively rotate the shoulder medially. Shoulder pain indicates a positive test.
- Infraspinatus test: The participants had their arms in side, with the elbows flexed to a 90˚ angle. Against the examiner's resistance, the participant was instructed to externally rotated both forearms. If the subject experienced shoulder pain with this movement, the test was considered positive.
- Belly press test: The participants were instructed to placed the palm of their hand on their upper abdomen, just below the xyphoid process, while standing with their elbow flexed to a 90˚ angle. The participants were instructed to internally rotated them shoulder with as much force as possible to press the palm of the hand against the abdomen. If the participant experienced shoulder pain, the test was considered positive.
- Lift-off test: The participant was instructed to placed the dorsum of the hand, in the region of the mid-lumbar spine. The participant lifts their hand off their back and performs internal rotation as the examiner applies pressure to their hand as part of the testing movement. If the participant was unable to resist lifting the hand off their back or experienced shoulder pain, the test was considered positive.
- Speed's test: The participant's arm was placed in shoulder flexion, external rotation, with full elbow extension, and forearm supination by the examiner. From this position, the

examiner applied manual resistance to the participant's arm downward. If pain in the bicipital tendon or groove is replicated, the test was deemed positive.

- Yergason's test: The participant was in a standing position, with 90˚ of elbow flexion and with the forearm in full pronation. From this position, the participant was instructed to externally rotate and supinate their arm against the manual resistance. If a pain was replicated in the bicipital groove, the test was deemed positive.
- Load and shift test: With one hand, the examiner secures the scapula to the thorax, and with the other, grasps the humeral head. The anterior glenohumeral joint line was covered by the index finger. A "load and shift" of the humeral head across the stabilized scapula was applied by the examiner in two directions: anteromedially to evaluate anterior stability and posterolaterally to evaluate posterior instability. Excessive translation of the humeral head with this movement is regarded as an indication of glenohumeral joint laxity and was considered positive.
- Apprehension test: The individual was placed in a supine position. The examiner maintained neutral rotation while flexing the patient's elbow to 90˚ and abducting the participant's shoulder to 180˚ in the frontal plane and 90˚ in the sagittal plane. While closely observing the participant, the examiner then gradually applied an external rotation force to the arm until it reached 90˚. A positive test result is defined as participant apprehension from this maneuver rather than pain. A pathology other than instability, like posterior impingement of the rotator cuff, may be indicated by pain during the maneuver but no apprehension.
- Sulcus sign: The participant stood for the test with their shoulder in a neutral position (0 degrees rotation). The distal portion of the humerus is then pulled caudally by the examiner. When the sulcus appears in the subacromial space more than 1 cm while the humeral head translates inferiorly, the test was deemed positive.
- Crank test: The participant's arm was 90˚ flexed. The examiner holds the flexed elbow or forearm while standing next to the affected shoulder forearm. One hand applied joint load along the humerus' axis, and the other hand rotated the humerus while the shoulder was raised in the scapular plane. If symptoms (usually pain) were reproduced during the

maneuver (usually external rotation) with or without a click, the test was considered positive.

- Anterior slide test: With the thumbs pointing posteriorly, the participant stood with their hands on their hips. In order for the final segment of the index finger to cross the anterior aspect of the acromion at the glenohumeral joint, one hand was placed on top of the participant’s shoulder. A force that is directed forward and slightly upward was applied to the arm while the other hand is positioned behind the participant's elbow. If the participant experienced pain at the anterior aspect of the shoulder beneath the examiner's hand, or if they experienced a popping or clicking sensation in the same location, or if they replicated their familiar symptoms that arise during their overhead activities, the test was deemed positive.

An isokinetic dynamometer (Humac Norm, CSMI solutions, USA) was utilized to measure joint repositioning sense (JRS), threshold to detection of passive movement (TTDPM), and muscle onset latency (MOL). Moreover, the isokinetic dynamometer was used to induce and quantify muscle fatigue. The isokinetic dynamometer had shown good to excellent reliability with intraclass-correlation coefficient (ICC) of 0.72-0.94 for shoulder tests (Habets et al., 2018). The Y balance – upper quarter (YBT-UQ) test and the athletic shoulder (ASH) test were used for the assessment of motor control and performance respectively (Ashworth et al., 2018; Westrick et al., 2012). All outcome measures were assessed before and immediately after the acute fatigue intervention. Furthermore, the same tests were used in second (see chapter 5) and third experimental study (see chapter 6) except the MOL that was used only in the first experimental study (chapter 4).

4.2.3 Proprioception Tests

4.2.3.1 Joint repositioning sense (JRS)

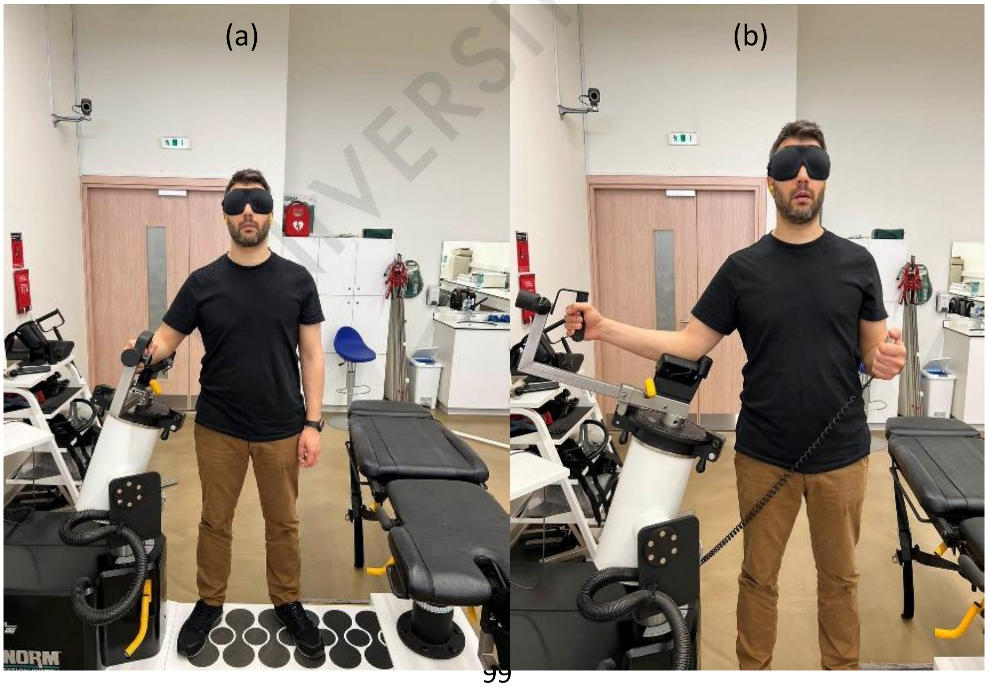
The JRS was assessed while each participant was in a standing position on the isokinetic dynamometer. The most accurate method for assessing shoulder proprioception, according to weighted average (WA) ICC calculations, is the isokinetic dynamometer (ICC of 0.92 ± 0.08)

(Ager et al., 2017). The shoulder was positioned at 30° of abduction, with 0° of external rotation, in the plane of the scapula (30° anterior to the frontal plane). The elbow was flexed at 90°, in a neutral position, and secured to the arm device (figure 4.1). The height of the dynamometer and the length of the arm device were personalized to each subject in order to align the axis of rotation of the dynamometer with the axis of rotation of the shoulder joint (reference point the acromion). The personalized test position was recorded and reproduced in the post-fatigue measurements. This setup allowed movement at the shoulder joint to be isolated to internal and external rotation along the shaft of the humerus. In order to minimize visual and auditory stimuli, the participants wore night masks and earplugs. Prior to each measurement, every participant completed two sets of 15 repetitions of shoulder internal and external rotation exercises using the dynamometer at an angular speed of 90 degrees per second as a warm-up activity. Subsequently, six shoulder repositioning angles were measured for each participant, comprising three angles in internal rotation and three angles in external rotation of the shoulder. The strongest WA ICCs for intrasession and intersession reliabilities are supported by IR (ICC of 0.88 ± 0.01) and ER (ICC of 0.83 ± 0.04) protocols (Ager et al., 2017). The six target angles that were chosen for all participants were as follows: 1) 15˚ external rotation, 2) 30° external rotation, 3) 45° external rotation, 4) 15˚ internal rotation, 5) 30° internal rotation, 6) 45° internal rotation. Shoulder rotation was not combined with shoulder abduction, as well as the most extreme angles (e.g 90˚ of ER and IR) were not selected because the isokinetic dynamometer did not allow it. The examiner positioned the shoulder at each target angle, maintaining this posture for 3 seconds, and then restored the participant's shoulder to its initial position in a passive manner. The subject was instructed to accurately reproduce the desired angle (active manner) and sustain it for a duration of 3 seconds before reverting to the initial position. Each participant conducted three trials for each target angle, and the average value was recorded. The passive/active method of the JRS assessment was chosen for two reasons. First, the majority of the studies used this method (Ramsay and Riddoch, 2001; Herrington et al., 2008; Kaya et al., 2012; Morgan and Herrington, 2014; Fabis et al., 2016). Second, this method has excellent reliability (ICC of 0.92 ± 0.1) (Ager et al., 2017) The JRS was assessed using two types of errors: the absolute angular error (AAE), which is the absolute difference between the test position and the position reproduced by the subject, and the relative angular error (RAE), which is the signed arithmetic difference between the test and response position.

4.2.3.2 Threshold to detection of passive movement (TTDPM)

Ager et al., (2017), in their systematic review, concluded that the TTDPM is the most reliable method for the assessment of shoulder kinesthesia (0.92 ± 0.04). With the subject positioned in the exact same position as in the JRS on the isokinetic dynamometer, the visual and auditory stimuli were removed. The participant's shoulder was passively moved into internal rotation by the isokinetic dynamometer at an angular velocity of 0.5°/s. The selection of this speed is based on the belief that it optimally activates slow-adapting joint mechanoreceptors while minimizing the activation of muscle receptors (Lephart et al., 1994; Lee et al., 2003)). Participants were directed to press a button to halt the movement when they perceived the initiation of shoulder internal rotation (see figure 4.1). Every participant conducted three trials and the average value was recorded.

Figure 4.1 (a): Initial assessment position of the participant on the isokinetic dynamometer; (b): Assessment of TTDPM on the isokinetic dynamometer.

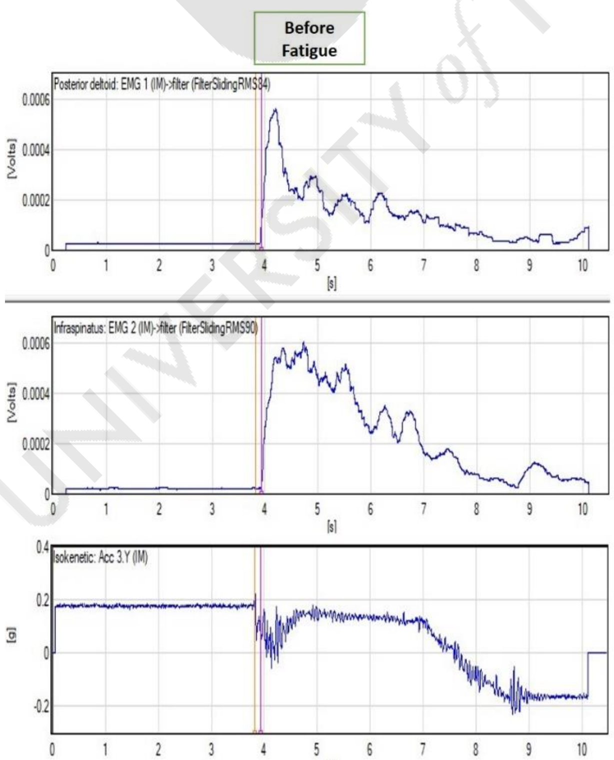


4.2.3.3 Muscle Onset Latency (MOL)

The infraspinatus and posterior deltoid MOLs were assessed using surface electromyographic (EMG) electrodes during a sudden free fall of the forearm/isokinetic arm unit. Two Delsys Trigno lab EMG sensors were used to measure the EMG activity. Another Delsys Trigno Lab sensor with a built-in triaxial accelerometer that was firmly attached to the dynamometer was used to detect the movement of the dynameter's arm. To ensure optimal contact of the EMG sensors and maximal signal-to-noise ratio, the skin was shaved with a razor and was cleaned with alcohol. The sensors contain bipolar, gel-free electrodes with a diameter of 10 mm and communicate wirelessly with the computer using Delsys software (DELSYS EMGworks Analysis). The infraspinatus sensor (figure 4.2) was placed two fingertips below the scapular spine and the posterior deltoid sensor (figure 4.2) was placed 2 fingertips below the rear corner of the acromion as descripted by Cram (Criswell and Cram, 2011). Both sensors were stabilized in place using double sided adhesive tape (Criswell and Cram, 2011). Then the EMG signal of the examined muscles at rest and in maximum contraction was assessed, to identify any errors in the placement of the electrodes. Subsequently, each participant was placed on the isokinetic dynamometer, with eyes closed and ears shut,at 30° of shoulder abduction, 60° of external rotation, in the plane of the scapula (30° anterior to the frontal plane), with the elbow flexed at 90°, in mid-pronation and was strapped to the arm device. While recording for a random number of seconds between 3-5, the arm of the dynamometer was dropped passively, while measuring the start of the movement with the accelerometer and the muscle reaction with the EMG. The MOL was calculated as the difference between the onset of movement of the isokinetic arm and the onset of muscle activation (figure 4.3). Muscle activation was considered to begin when the SEMG amplitude increased 3 standard deviations above the mean of the resting amplitude (figure 4.3). The assessment of the infraspinatus and posterior deltoid MOL was performed before and after fatigue intervention.

Figure 4.2. The EMG electrodes placement for the INF muscle and PD muscle.

Figure 4.3. Method of meausurement of MOL. EMG of the posterior deltoid (top graphs) and infraspinatus (middle graphs). Movement of the isokinetic arm (bottom graphs) was marked with an orange vertical line. The onset of muscle activation was marked with a purple vertical line. The time difference between these lines represents MOL. (DELSYS EMGworks Analysis).



4.2.4 Motor control and performance tests

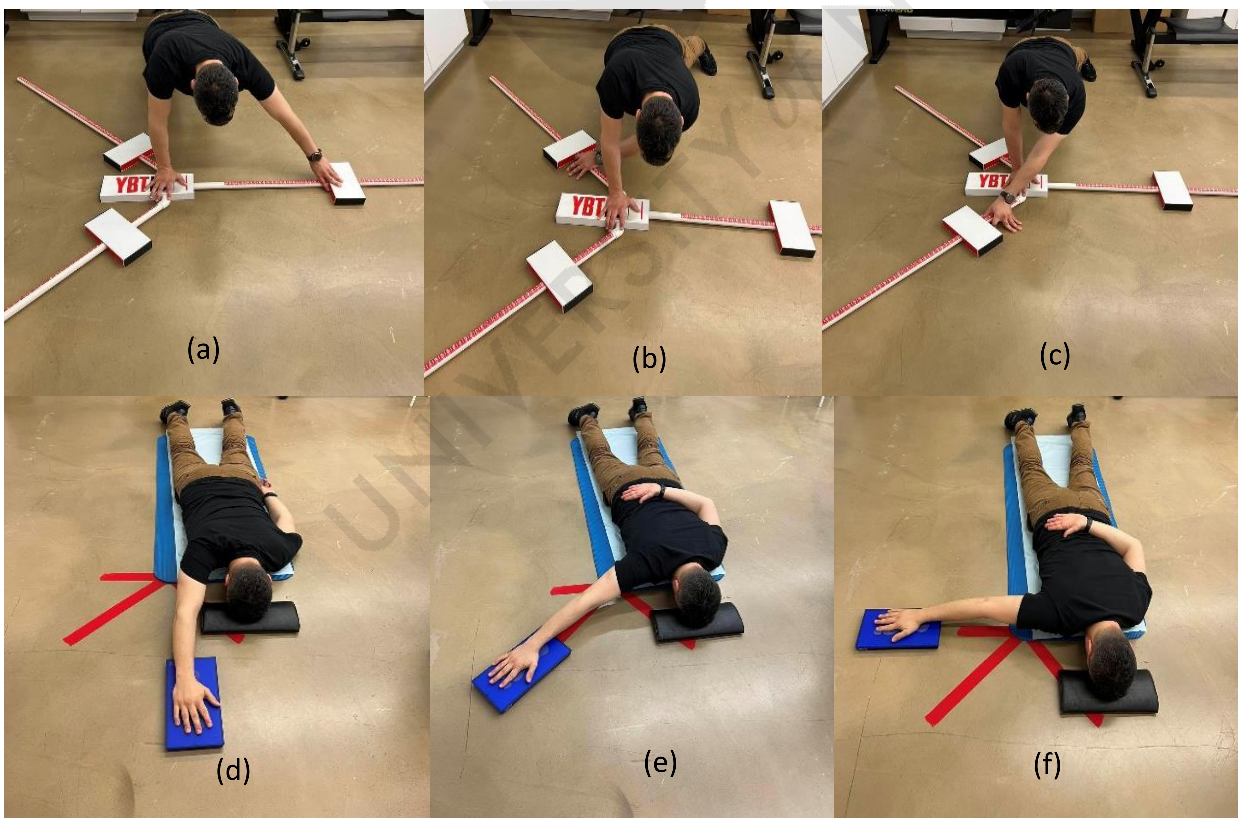
4.2.4.1 Y Balance test – Upper Quarter (YBT-UQ)

The YBT-UQ is a comprehensive assessment that necessitates physical strength, flexibility, neuromuscular coordination, balance, stability, and range of motion. The experiment utilized a YBT kit^{TM}, comprising of three interconnected tubular plastic bars that were labeled with markings at half centimeter intervals. Each bar had a moveable indicator plate, which the subject moved by pushing with their hand/fingers. The test was conducted by initiating the subject in a push-up stance with their feet positioned at a distance equal to the breadth of their shoulders. The objective of the test was for the participant to maintain a push-up position on the central platform of the YBT device and move the indicator plate in the anteromedial (AM), superolateral (SL), and inferomedial (IL) directions (figure 4.4) using the other hand. Following a warm-up test consisting of three attempts in each direction, three additional attempts were conducted in each direction. The maximum reach distances in each direction were added together to obtain a composite reach distance (sum of the lengths of all three reach directions, divided by the length of the upper extremity limb, and multiplied by 100), which was then adjusted to account for the length of the upper limb. This facilitated an analysis of the overall proficiency demonstrated in the assessment. Prior to the test, the length of the subject's upper limb, from the 7th cervical vertebrae to the tip of the middle finger, was measured using a tape measure. In cases where the subject made more than four unsuccessful attempts, a score of zero was documented for that particular trial. A participant's attempt was deemed a failure if they engaged in any of the following actions: throwing instead of pushing the box, returning to the beginning push-up posture without maintaining control, making contact with the floor using their hand prior to pushing the box, or having their feet lose contact with the ground. All individuals successfully completed the trials during the test without any failures. The YBT-UQ test (Gorman et al., 2012; Westrick et al., 2012) demonstrated high reliability (ICC 0.80 – 1.0) and showed no disparity in performance between the dominant and non-dominant limbs. These findings suggest that the YBT-UQ is a dependable instrument for evaluating sports performance during the recovery process of shoulder, upper extremity, and spine injuries.

4.2.4.2 The Athletic Shoulder test (ASH test)

The ASH test was developed to evaluate the isometric strength of the shoulder. The test was conducted according to the methodology outlined by Ashworth et al. (2018). Before commencing the initial data collection, participants were presented with the placements of both arms and instructed on the correct application of force. The participants were given instructions to exert force into the force plate with maximum speed and intensity. Prior to data collection, participants attempted two warm-up rounds at a level of exertion below their maximum capacity, in order to develop a sense of body alignment. In each of the three positions, the palm of the hand was fully supported by the force plate, with the forearm in a pronated posture and the elbow fully extended (figure 4.4). Upon receiving a cue to exert force, the participant proceeded to elevate their fingers off the force plate and exerted downward pressure solely through the heel of their hand. A valid trial was considered when the isometric contraction was executed without any rotation of the trunk and lower body towards the side of examination. The test was conducted in the sequential order of I, Y, and T, with each measurement lasting three seconds and a twenty-second interval between each measurement (Ashworth et al., 2018). For each test position, the ASH test showed excellent reliability (ICC of 0.94-0.98), confirming its use as a trustworthy instrument to measure force production and transfer across the shoulder girdle (Ashworth et al., 2018). The measurement of each arm position was conducted three consecutive times before transitioning to the subsequent position. The body position was assessed at each position in order to avoid any potential compensation. The duration of the tests conducted at each arm position was roughly 69 seconds, whereas the total duration of the data collection session, including repositioning, was around 8 minutes. Upon the participant's assumption of the measurement posture, a verbal cue indicating readiness was provided to initiate the collection process and commence the seven-second collection period of the force plate. Upon the force plate detecting activity for a duration of two seconds, participants were provided with a verbal "go" signal and initiated a rapid and forceful push into the force platform for a period of three seconds. Following a duration of 3 seconds, a verbal "stop" signal was provided to indicate the conclusion of the trial and the commencement of the twenty-second period of rest. Every participant was directed to exert maximum force and speed on the force plate. The ASH Test consists of three positions in which the body assumes a prone position and utilizes the arm to make an I, Y, and T formation. The "I" position involves the participant with their shoulder raised 180 degrees above their head, the "Y" position raised 135 degrees above their head, and the "T" position raised 90 degrees to their side. When in the "I" position, the arm is positioned at the side, with the palm facing upwards and the forearm in a supinated position. In the "Y" and "T" postures, the arm on the opposite side was positioned behind the back, with the elbow bent, the forearm raised, and the palm facing upwards. The selection of the opposite arm's location was made in order to limit contralateral compensatory attempts aimed at generating greater force. In order to establish a consistent neck posture, a 4 cm bolster was employed. In each position, participants placed their forehead on the bolster. Repetitions were not included if the participant executed a countermovement or compensation on the other side. As an illustration, in the event that the subject elevated one or both feet from the ground while performing the isometric hold, the repeat was deemed non valid.

Figure 4.4. The YBT-UQ (a to c) and the ASH test (figures d to f); (a): anteromedial (AM) reach; (b): the inferolateral (IL) reach; (c): the superolateral (SL) reach; (d): the "I" position; (e) the "Y" position; (f) the "T" position.



4.2.5 Exercise-induced fatigue protocol

Each subject was placed in the standing position on the isokinetic dynamometer. The right shoulder was placed at 30° of abduction, 0° of external rotation, in the plane of the scapula (30° anterior to the frontal plane), with the elbow flexed at 90°, in mid-pronation and was strapped to the arm of the device. Each participant actively performed maximal voluntary, concentric, isokinetic contractions from 60° of shoulder internal rotation to 60° of shoulder external rotation to induce concentric muscle fatigue of the shoulder external and internal rotator muscles. This test was performed in the same position as the one used to induce fatigue. Initially the examiner instructed each participant to perform 10 submaximal (20% of maximal voluntary contraction) concentric contractions with an angular speed of 90 degrees per second to familiarize themselves with the specific movement. Next, peak isokinetic torque of internal and external rotators was recorded by asking the subject to perform 10 repetitions with maximal effort. This value was the reference value for the induction of fatigue. After a 5 minutes rest, each participant performed sets of 30 maximal effort concentric isokinetic contractions with 90 degrees per second angular speed of the external and internal rotator muscles. The criterion to consider muscle fatigue was the drop of the isokinetic peak torque to 40% of the reference value (60% reduction) and remained below this value, irrespective of positive reinforcement, for 3 consecutive repetitions. If the subject exceeded the reference value of peak torque in the first set, then the reference value was instantly updated, and the same rule was used for the induction of fatigue. The sets needed to induce fatigue varied between one and five, most commonly three. The same protocol was used in a previous study (Spargoli, 2017). After the test, muscle fatigue was assessed by the percentage decrease in peak torque between the first ten and the last ten repetitions (mean peak torque of first ten repetitions - mean peak torque of last ten repetitions / mean peak torque of first ten repetitions) during the thirty repetitions sets of isokinetic exercise at 90 deg/sec.

4.2.6 Statistical analysis

Jamovi (Version 2.3.26) was used for statistical analysis. Descriptive statistics were used to calculate means and standard deviations (SDs) of the collected variables. The mean is a straightforward arithmetic average of the specified set of numbers or values. The standard deviation quantifies how much a variable's values deviate from its mean. Shapiro-Wilk test was used to assess data for normality prior to the analysis. Originally, the Shapiro-Wilk (1965) test was limited to samples with fewer than fifty. This test was the first to identify deviations from normality brought on by kurtosis, skewness, or both (Althouse et al. , 1998). Its strong power characteristics have made it the test of choice (Mendes and Pala, 2003). The paired samples t-test was used to compare the mean differences before and immediately after the fatigue intervention for the absolute angle error (AAE), the relative angle error (RAE), the threshold to detect passive movement (TTDPM), the MOL, the YBT-UQ and the ASH test scores. For the non-normally distributed variables, the Wilcoxon test was used for pre-post fatigue intervention comparisons. Statistical significance was set at $p < 0.05$ and the 95% CI was calculated for all mean differences. A statistical test's p value is a numerical value that indicates the likelihood of discovering a specific set of observations in the event that the null hypothesis were correct. In hypothesis testing, P values are used to assist in determining whether to reject the null hypothesis. The likelihood of rejecting the null hypothesis increases with a smaller p value. A confidence interval is the likelihood that a population parameter will fall between a range of values for a specific percentage of the time. Confidence intervals with 95% or 99% of expected observations are frequently used by analysts. Therefore, if a statistical model yields a point estimate of 10.00 with a 9.50 to 10.50 95% confidence interval, it indicates that there is a 95% chance that the true value falls within that range. The same statistical analysis was used in the second and third experimental study (see chapter 5 and 6)

4.3 Results

All handball players (n=46) completed all measurements without dropping out. The demographic characteristics of the participants are presented in table 4.2.

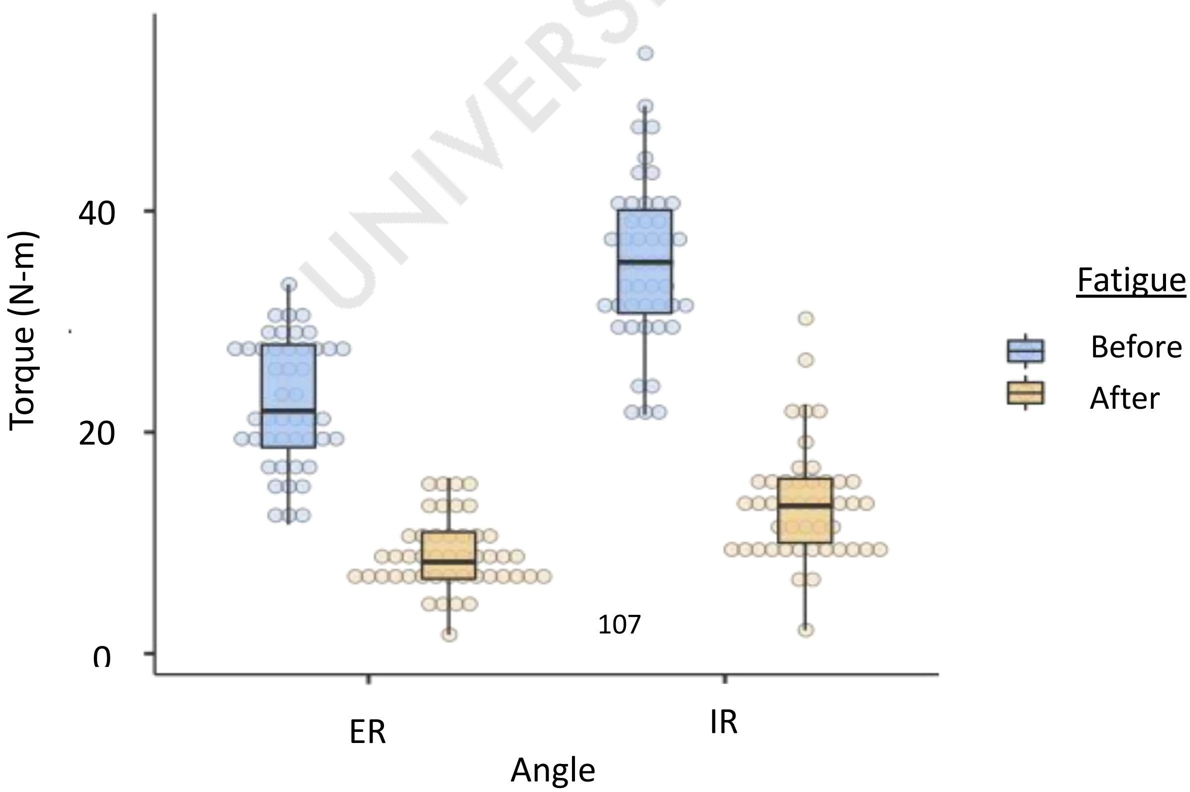
Table 4.2. Demographic characteristics of the participants.

N	Gender	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Experience (years)
46	Male	26.1 ± 5.54	180 ± 5.53	84.9 ± 13.3	26.2 ± 3.95	11.8 ± 4.79

Abbreviations: N, number of participants; ±, standard deviation.

The peak torque of shoulder internal rotation and shoulder external rotation decreased by 61.90% (figure 4.5) and 60.92% (figure 4.5) correspondingly after muscle fatigue, as indicated by the fatigue index. The mean value of external rotation peak torque during the initial ten and final ten repetitions was recorded as 33.4 N (± 5.65) and 15.9 N (± 3.27), respectively. The mean internal rotation peak torque during the initial and final 10 repetitions was 54.3 N (± 7.32) and 30.3 N (± 5.16) respectively.

Figure 4.5. The shoulder external rotation (ER) and internal rotation (IR) before and after fatigue intervention.



Moreover, following fatigue intervention, a significant increase in absolute angular error was observed in all target angles in both ER and IR directions ($p<0.01$) (Table 4.3). A similar significant increase in relative angular error was observed in five out of six target angles after muscle fatigue ($p<0.01$). No significant difference was observed in IR45˚ ($p=0.101$) (Table 4.3).

Table 4.3. Joint reposition sense AAE and RAE scores pre- and post- fatigue intervention.

Type of error	Target angles	Pre-Fatigue	Post Fatigue	p value	Mean Difference (95% CI)
AAE	ER15^{O}	1.91 ± 0.957	4.72 ± 1.976	< .001	-2.81 (-3.500, -2.122)
AAE	ER30^{O}	2.64 ± 1.208	5.35 ± 2.487	< .001	-2.71 (-3.440, -1.979)
AAE	ER45^{O}	2.69 ± 1.360	5.91 ± 3.327	< .001	-3.22 (-4.250, -2.187)
AAE	IR15^{O}	1.97 ± 1.006	3.11 ± 1.481	< .001	-1.15 (-1.580, -0.707)
AAE	IR30^{O}	2.60 ± 1.254	4.69 ± 2.429	< .001	-2.09 (-2.750, -1.426)
AAE	IR45^{O}	2.17 ± 0.902	3.51 ± 2.028	< .001	-1.50 (-2.340, -0.670)
RAE	ER15^{O}	-0.06 ± 1.230	3.68 ± 3.230	< .001	-3.76 (-4.720, -2.794)
RAE	ER30^{O}	1.20 ± 2.130	3.59 ± 4.340	< .001	-2.39 (-3.600, -1.185)
RAE	ER45^{O}	0.05 ± 1.990	4.56 ± 4.600	< .001	-4.51 (-5.810, -3.205)

RAE	IR15^O	-0.09 ± 1.430	1.85 ± 2.390	< .001	-1.95 (-2.700, -1.197)
RAE	IR30^O	0.34 ± 2.480	3.33 ± 3.760	< .001	-2.99 (-4.080, -1.900)
RAE	IR45^O	-0.15 ± 1.750	0.86 ± 3.770	0.101	-1.03 (-2.270, 0.210)

Abbreviations: JRS, joint repositioning sense; AAE, absolute angular error; RAE, relative angular error; ER,external rotation; IR, internal rotation; ±, standard deviation; CI, confidence interval

In addition, there was a significant increase in TTDPM in internal rotation after fatigue intervention (p=0.020) (Table 4.4).

Table 4.4. TTDPM scores pre- and post- fatigue intervention.

Movement	Pre-Fatigue	Post Fatigue	p value	Mean Difference (95% CI)
IR	5.91 ± 3.640	7.39 ± 6.290	0.020	-1.50 (-2.500, -8.630)

Abbreviations: TTDPM, threshold to detection of passive movement; IR, internal rotation; ±, standard deviation; CI, confidence interval

Regarding the YBT-UQ, statistically significant differences were found in anteromedial (AM) (p=0.041) and superolateral (SL) reach directions (p=0.005) in the right hand and in inferolateral (IL) reach direction in the left hand (p=0.020) (Table 4.5). Furthermore, the composite score demonstrated a statistically significant difference only in the right hand (p=0.009) (Table 4.5).

Table 4.5. The YBT-UQ scores pre and post- fatigue intervention.

Hand Position	Pre Fatigue	Post Fatigue	p value	Mean Difference (95% CI)
AM Right	94.5 ± 10.950	92.8 ± 11.050	0.041	2.50 (1.190, 4.500)
IL Right	83.4 ± 12.590	80.9 ± 12.280	0.073	2.47 (-0.240, 5.200)
SL Right	65.1 ± 10.530	62.2 ± 12.870	0.005	2.93 (0.942, 4.930)
AM Left	92.6 ± 11.130	93.2 ± 10.800	0.428	-0.50 (-2.500, 1.00)
IL Left	83.5 ± 9.640	80.8 ± 11.160	0.020	2.73 (0.462, 5.020)
SL Left	67.0 ± 11.040	65.6 ± 11.700	0.114	1.43 (-0.356, 3.230)
CS right	87.3 ± 11.400	84.7 ± 11.600	0.009	2.56 (0.681, 4.440)
CS left	87.3 ± 10.600	86.0 ± 10.800	0.110	1.28 (-0.301, 2.870)

Abbreviations: YBT-UQ, Y balance test upper quarter; AM, anteromedial; IL, inferolateral; SL, superolateral; CI, confidence interval; CS, composite score; ±, standard deviation.

There was a significant reduction of isometric strength in the I position of the right hand (p=0.010) and to all positions of the left hand (p<0.05) in the ASH test (Table 4.6).

Table 4.6. ASH test scores pre and post- fatigue intervention.

Variable	Pre Fatigue	Post Fatigue	p value	Mean Difference (95% CI)
I Right	13.02 ± 3.490	11.86 ± 3.330	0.010	1.15 (0.287, 2.023)
Y Right	10.59 ± 2.450	10.10 ± 2.480	0.107	0.49 (-0.110, 1.100)
T Right	9.42 ± 2.010	9.05 ± 2.030	0.103	0.37 (-0.078, 0.828)
I Left	12.70 ± 3.320	11.27 ± 3.040	< .001	1.54 (1.095, 1.975)
Y Left	9.85 ± 2.270	9.07 ± 2.280	0.002	0.77 (0.304, 1.238)
T Left	9.21 ± 1.970	8.47 ± 2.130	0.005	0.73 (0.238, 1.234)

Abbreviations: ASH, the Athletic Shoulder Test; ±, standard deviation; CI, confidence interval; I,Y and T, hand positions during the ASH test.

Moreover, following muscular fatigue, there was an elevation in the reaction time (MOL) of the posterior deltoid and infraspinatus muscle (Table 4.7). Nevertheless, this rise was not statistically significant ($p>0.05$).

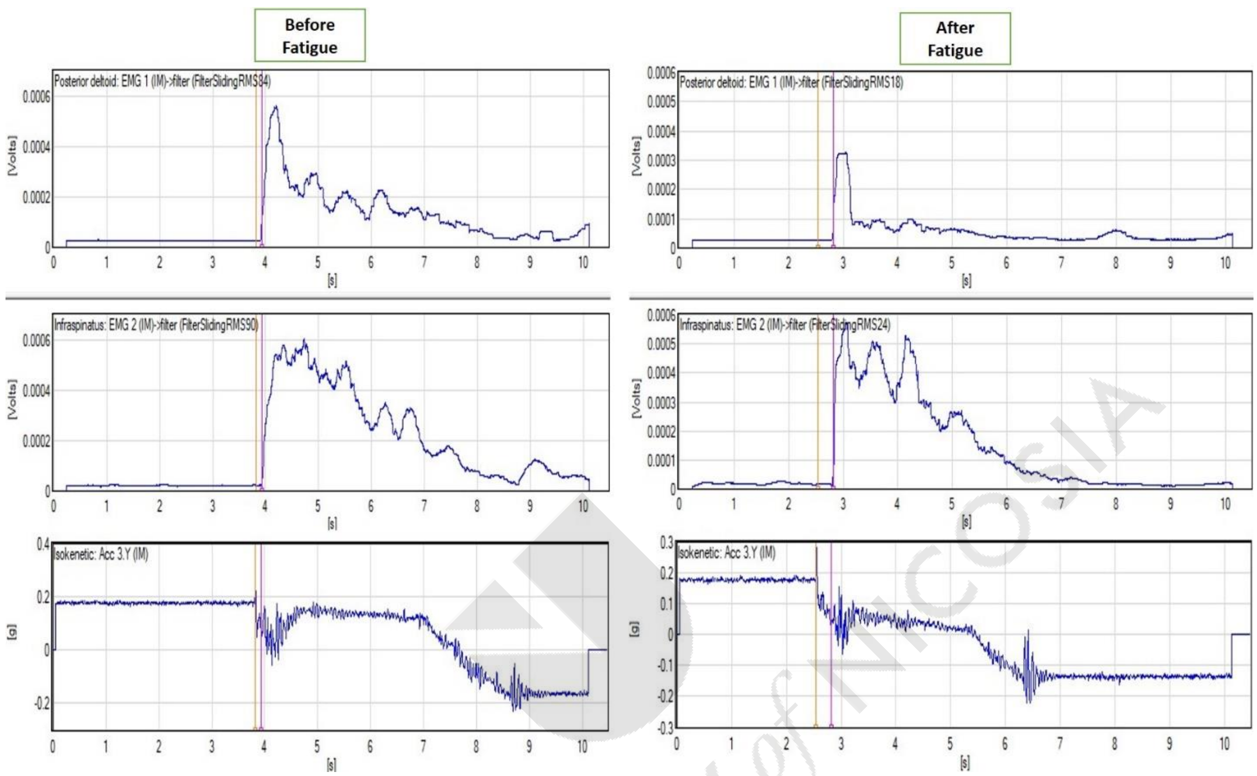
Table 4.7. MOL scores pre and post- fatigue intervention.

Variable	Pre Fatigue	Post Fatigue	p value	Mean Difference (95% CI)
PD MOL	0.179 ± 0.137	0.262 ± 0.218	0.088	-0.0391 (-0.1018, 0.00780)
INF MOL	0.180 ± 0.138	0.267 ± 0.220	0.092	-0.0392 (-0.0960, 0.00586)

Abbreviations: MOL, muscle onset latency; ±, standard deviation; CI, confidence interval; PD, posterior deltoid; INF, infraspinatus.

Figure 4.6 illustrates a case where there was a rise in the reflex reaction time of the posterior deltoid and infraspinatus muscle after fatigue.

Figure 4.6. MOL before (left panel) and after fatigue (right panel) from one subject. EMG of the posterior deltoid (top graphs) and infraspinatus (middle graphs) and movement of the isokinetic arm (bottom graphs) (DELSYS EMGworks Analysis).



4.4 Discussion

The objective of this study was to examine the impact of concentric muscle fatigue on the proprioception, motor control and performance of the upper limb in handball players. The null hypotheses were rejected. The major findings of the present study indicate that concentric fatigue of the rotator cuff muscles induces notable deficits in proprioception motor control, and performance. Moreover, fatigue leads to a minor reduction of neuromuscular control.

Multiple studies provide evidence that proprioceptive training is effective in preventing sports injuries, particularly ankle sprains (Hübscher et al., 2010; Schiftan et al., 2015) and anterior cruciate ligament injuries (Zech et al., 2012) but no evidence exists that proprioception is a risk factor for shoulder injury (Asker et al., 2020; Hadjisavvas et al., 2022). In addition, systematic reviews have found that an excessive amount of training can lead to shoulder problems in overhead athletes (Hadjisavvas et al., 2022; McKenzie et al., 2023; Tooth et al., 2020).

The peak incidence of injury is observed during the last third of training and matches in soccer (Ekstrand et al., 2011) and handball (Asembo and Weseka, 1998; Dirx et al., 1992). These changes are believed to be associated with alterations in proprioception and neuromuscular control as a result of fatigue (Hiemstra et al., 2001; Steib et al., 2013). Furthermore, research has demonstrated that fatigue can have a detrimental impact on athletes' performance in several functional assessments, including proprioception tests (Jahjah et al., 2018; Webster et al., 2017; Wright and Arnold, 2012), balance tests (Johnston et al., 2018; Zech et al., 2012) and muscle strength tests (Scanlan et al., 2018) making athletes more susceptible to injury.

The results of the present study show that after the induction of fatigue, JRS is significantly reduced. These findings provide evidence for the "dysfunctional mechanoreceptor" idea, which suggests that muscular fatigue might decrease the sensitivity of the muscle spindle, leading to notable disruptions in proprioception (Voight et al., 1996). This notion has received support from other investigations (Iida et al., 2014; Lee et al., 2003; Myers et al., 1999). The cause of this malfunction is not completely understood. Fatigue-induced alterations in local muscle metabolism may be a potential explanation for this impairment (Pedersen et al., 1997). Pedersen et al. (1997) found that elevated levels of lactic acid, creatine-kinase, bradykinin, arachidonic acid, and serotonin inside the muscles during muscle fatigue can potentially disrupt the proper functioning of muscle spindles and, consequently, affect proprioception. Due to the greater intensity of local blood flow and metabolic changes, muscle mechanoreceptors are more susceptible compared to articular receptors (Pedersen et al., 1997).

The current study's findings somewhat align with the results of previous research (Björklund et al., 2000; Iida et al., 2014; Kablan et al., 2004; Lee et al., 2003; Myers et al., 1999). Lee et al. (2003) discovered that with the onset of muscular fatigue, there was a notable and statistically significant rise in position errors for shoulder external rotation, but not internal rotation. On the contrary, the study by Kablan et al. (2004) found that novice volleyball players made considerably more position errors in internal rotation compared to external rotation after experiencing shoulder muscular fatigue. On the other hand, Lida et al. (Iida et al., 2014) discovered that the position inaccuracy considerably increased in both internal and external shoulder rotation following the fatigue intervention. Similar results were found by Myers et al. (1999), who discovered a significant impairment of shoulder joint repositioning sense in both directions of shoulder rotation after fatigue. Furthermore, Voight et al. (1996), found that shoulder muscle fatigue can significantly affect the shoulder joint repositioning sense in the direction of external rotation although only in the target angle of 75˚ that was the only one assessed.

However, some studies did not find any significant differences in the JRS before and after fatigue intervention (Spargoli, 2017; Sterner et al., 1998). Spargoli (2017) expected that eccentric exercise would have a stronger impact on shoulder proprioception compared to concentric exercise. However, there were no significant differences seen neither between the eccentric and concentric groups nor before and after the fatigue intervention. Furthermore, there was no statistically significant difference ($p > 0.05$) observed in the absolute angular inaccuracy comparing the pre- and post-fatigue measurements in either of the groups. In addition, Sterner et al (1998) failed to verify that fatigue in the shoulder muscles can have a significant negative impact on JRS during both active and passive movements. Certain methodological differences might account for the variation in the results.

The present study evaluated the impact of muscular fatigue on shoulder kinesthesia using the TTDPM,and found that it had a negative effect. One potential reason is because muscle fatigue leads to decreased sensitivity of muscle receptors, which are primarily responsible for kinesthetic information (Proske and Gandevia, 2012). Prior research has verified that muscle spindles serve as the principal receptors in kinesthesia (Clark et al., 1979; Grigg et al., 1973; Landgren and Silfvenius, 1969). The findings of the current investigation are consistent with the results of Carpenter et al (1998), who found that the mean TTDPM (both internal and external rotation combined) increased by 73% after the fatigue intervention. Carpenter et al (1998), employed a distinct evaluation posture for the subjects (seated) and a higher angular velocity of 1 deg/sec on the isokinetic dynamometer, which was greater than the current study's velocity of 0.5 deg/sec. In addition, the current study exclusively employed male handball players, whereas Carpenter et al. employed healthy non-athlete volunteers (Carpenter et al., 1998). Despite the methodological differences between the current study and the Carpenter et al. study, results were identical, which suggests a higher level of generalizability of the finding. On the other hand, Sterner et al. (1998)

did not verify that fatigue in the shoulder muscles had a substantial impact on TTDPM. The variation in the initial assessment position (supine) and the selection of a distinct sample (healthy non-athletes) in the Sterner et al. study (1998) may account for the disparity observed in the outcomes.

Muscle fatigue not only impairs proprioception, but also leads to a decrease in shoulder stability and mobility. Following the muscular fatigue intervention, the YBT-UQ test showed a greater impact on the right hand (SL, AM, CS), which was the limb that was exercised, compared to the left hand. One potential reason is that exhaustion may impact the mechanoreceptors in the stability muscle group, leading to a reduced ability of the shoulder to co-contract in the closed kinetic chain position. This, in turn, can limit the individual's performance in the single- arm push-up position (Myers et al., 1999). In the current investigation, fatigue was induced in the right upper limb therefore the right side was more affected than the left side. The negative impact of the unilateral fatigue protocol on motor control in the exercised limb is in agreement with other studies in which they had used bilateral fatigue protocols and found significant impairments of motor control in both upper limbs (Bauer et al., 2020; Salo and Chaconas, 2017).

Salo and Chaconas (2017) observed a significant decrease in YBT-UQ scores for all reaching directions in both limbs after performing bilateral exercises like shoulder press, machine row, prone push-up, and pull-up exercises. Nevertheless, this study employed a distinct exhaustion methodology for weightlifters as opposed to handball players. In a more recent study conducted by Bauer et al (Bauer et al., 2020), it was shown that handball players experienced significantly decreased YBT-UQ scores, specifically in the SL reach direction for both upper limbs after undergoing a fatigue protocol involving push-up activities. In contrast, Bauer et al. (Bauer et al., 2020) induced fatigue by using push up exercises. Myers et colleagues (1999), conducted a study to investigate the impact of shoulder muscular fatigue on shoulder stability using the single-arm dynamic stability (SADST) test. The results showed that there were no significant differences in sway velocity between the pre-test and post-test measurements. However, there was a notable rise in the occurrence of falls following the fatigue intervention. This led to the conclusion that fatigue can impair the co-contraction ability of the shoulder while in the closed kinetic chain position. However, the study conducted by Myers et al. (1999), utilized a different assessment tool (SAD) to evaluate shoulder stability, whereas the current study used the YBT-UQ.

Another significant finding from the current study was that shoulder muscular fatigue resulted in a decrease in shoulder isometric strength. Specifically, the ASH test showed a significant decrease in muscle strength at the "I" position of the right hand and in all positions of the left hand. Currently, there has been no research undertaken to examine the impact of rotator cuff muscle fatigue on the ASH test. Muscle fatigue did not have a substantial impact on the other assessment positions of the right hand ("T", "Y"). One potential reason is that the ASH test was the final assessment conducted following the exhaustion regimen, and it is plausible that there was a restoration of muscle strength. Chang et al. (2006) supported this idea, concluding that the restoration of shoulder muscular strength occurred at a faster rate compared to the recovery of shoulder joint position sense following fatigue (Chan et al., 2006). The reduction in the force production of the left, non-fatigued side is difficult to interpreter. Perhaps it has to do with reduced stabilization from the opposite side (right) during the test post fatigue. This is purely speculatively thought, as no studies exist which support this claim.

The study suggests that fatigue in the rotator cuff muscles increases the delay in the reflex response time of the shoulder external rotator muscles (infraspinatus and posterior deltoid) in response to external disruptions. Specifically, the percentage delay of MOL for the posterior deltoid muscle was 46.36% and 48.33% for the infraspinatus muscle after fatigue intervention. Fatigue is thought to decrease muscle reflex responses via affecting intrafusal characteristics, presynaptic inhibition of Ia afferents, and intrinsic features of motoneurons (Granata et al., 2004; Behrens et al., 2013). Although the result was not statistically significant there is no way to judge if it is clinically significant as no reference value exists for the delay of muscle onset. No research has been conducted to investigate how rotator cuff muscle fatigue affects reflex reaction time. However, the present study revealed higher percentage values of delay in MOL compared to previews studies (Granata et al., 2004; Chang et al., 2006; Behrens et al., 2013; Melnyk and Gollhofer, 2007; Sun et al., 2021) despite the lack of statistical significance. Prior research has investigated how lower limb muscle fatigue affects the reflex reaction time after tibial translation of the hamstring muscles. Behrens et al (Behrens et al., 2013) found that due to fatigue the percentage delay of the biceps femoris and semitendinosus reflex reaction time was 4.29% and 4.69% respectively in women. On the other hand, other researchers (Melnyk & Gollhofer, 2007), found that the percentage delay of the biceps femoris muscle was 12.05%. Sun et al (Sun et al., 2021), investigated the impact of fatigue (90 minutes of soccer game) on MOL of the peroneal muscle The results showed that the percentage delay of the peroneal muscle reflex activation time was 21.06%. Other researchers (Fong et al., 2020) revealed a 14.06% delay in reflex reaction time of tibialis anterior muscle after 90 minutes of soccer game. The erector spinae, is another muscle group that the reflex reaction time was investigated after fatigue. Zuriaga et al (2010), demonstrated 14.51% and 7.04% delay in the reflex reaction time of the erector spinae muscle at the L3 spinal level. Granata and Slota (Granata et al., 2004), investigated the effect of fatigue on MOL of internal obligue and rectus abdominis muscle. In this case, the internal oblique muscle showed 9.75% faster reflex reaction time compared to the pre fatigue value. Nevertheless, the rectus abdominus muscle demonstrated a 46.05% delay. These results suggest that the outcome of the current study, although statistically not significant, shows a clear effect of fatigue in muscle reaction time.

The current investigation needs to acknoweledge several limitations. Initially, the study exclusively involved adult male handball players, leaving the impact of muscle fatigue on proprioception in female and juvenile handball players unexplored. Furthermore, muscle fatigue was induced within a controlled laboratory setting using an isokinetic dynamometer. The muscle fatigue encountered by handball players during real-life conditions, such as repetitive throwing motions, sprinting, and jumping, differs from that observed in laboratory settings. These limitations need to be considered when using the results of the study.

4.5 Conclusions

Concentric fatigue of the rotator cuff muscles can lead to notable deficits in joint position awareness, kinesthesia, and motor control of the upper extremity in elite male handball players. Moreover, fatigue might lead to a large but not statistically significant reduction in reflex reaction time. Further research is required to solidify the adverse impact of fatigue on proprioception and neuromuscular control of the upper limb.

Chapter 5.0: Concentric exercise-induced fatigue of the shoulder impairs proprioception but not motor control or performance in healthy young adults

Abstract

Background: Most shoulder injuries occur during the latest stages of a competitive game and fatigue is believed to be a critical factor possibly due to impaired motor control and proprioception. Proprioception is the perceptual ability of the position and movement of the body segments without the need for visual input. Muscle fatigue is believed to reduce proprioceptive acuity by raising the muscle spindle discharge threshold and interfering with afferent signals therefore affecting motor control. The purpose of this study was to investigate the effect of concentric fatigue on proprioception and motor control of the shoulder in healthy young adults.

Methods: Twenty right-handed male students, aged 18 to 40 yrs, were included in the present investigation. Proprioception, motor control and performance tests were conducted before and immediately after fatigue intervention, including joint repositioning sense (JRS), threshold to detection of passive movement (TTDPM), Y-balance Upper Quarter test (YBT-UQ), and Athletic shoulder test (ASH test). The protocol of fatigue involved performing concentric maximal effort isokinetic contractions with sets of 30 repetitions for the shoulder external and internal rotator muscles. The participants were subjected to exercise until a 60% decrease of the peak torque of the subject's maximal voluntary contraction was reached throughout three consecutive muscular contractions.

Results: A significant impairment in absolute angular error (AAE): ER15˚: Mean diff = -3.12 (95% CI: -4.33, -1.904), $p < 0.001$; ER30˚: mean diff = -2.47 (95% CI: -3.44, -1.497), $p < 0.001$; ER45˚: mean diff = -2.65 (95% CI: -4.31, -0.985), p = 0.004; IR15˚: mean diff = -1.37 (95% CI: -1.91, -0.819), $p < 0.001$; IR30˚: mean diff = -1.93 (95% CI: -2.98, -0.885), p = 0.001; IR45˚: meanDiff = -1.63 (95% CI: -2.73, -0.540), p = 0.006. A significant increase was also observed in relative angular error (RAE) was observed in five out of six target angles after muscle fatigue: ER15˚: mean diff = -3.417 (95% CI: -5.05, -1.7861), $p < 0.001$; ER30˚: mean diff = -1.833 (95% CI: -3.61, -0.0578), p = 0.044; ER45˚: ES= -2.983 (95% CI: -5.22, -0.7468), p = 0.012; IR15˚: mean diff = -1.633 (95% CI: -2.73, -0.5327), p = 0.006; IR30˚: mean diff = -2.317 (95% CI: -4.06, -0.5688), p = 0.012. No significant difference was observed in IR45˚: mean diff = 0.217 (95% CI: -2.01, 2.4473), p = 0.841. Moreover, there was no significant differences in kinesthesia (TTDPM) and motor control (YBT-UQ) and performance (ASH Test) before and after fatigue intervention ($p > 0.05$).

Conclusions: Concentric fatigue of the shoulder rotator cuff muscles can negatively affect joint position sense in healthy young males. Kinesthesia, motor control, and performance seem to be unaffected by muscle fatigue.

Key words: Muscle fatigue, proprioception, shoulder, motor control, neuromuscular control

5.1 Introduction

Proprioception is a sensorimotor perception that our body depends for safe and intentional movements when traversing our environment (Li and Wu, 2014). Proprioceptive information is processed at both conscious (cerebral) and unconscious (peripheral and cerebellar) levels. Conscious proprioception plays a role in activating muscles during voluntary movements, whereas unconscious proprioception allows us to subconsciously monitor our body's location (Johnson et al., 2008). Proprioception is typically categorized into the sub modalities of sense of tension (resistance), movement sense (kinesthesia), and joint position sense (Ager et al., 2020). Shoulder proprioception deficit might result in a heightened vulnerability to shoulder injuries (Zanca et al., 2015). Numerous variables have been suggested as potential factors contributing to proprioception impairment, with muscular fatigue being identified as a significant contributor (Proske, 2019)

Muscle fatigue can be defined as the decline in physical performance when activity becomes more challenging, and the muscles are unable to maintain the required force output (Elfattah et al., 2015) Fatigue can arise from several levels of the motor pathway and is typically categorized into central and peripheral components. Peripheral fatigue occurs as a result of alterations that take place at or beyond the neuromuscular junction. Central fatigue arises from the central nervous system, leading to a reduction in the neural drive to the muscle (Gandevia, 2001). Muscle fatigue is believed to reduce proprioceptive sensitivity by raising the muscle spindle discharge threshold and interfering with afferent signals (Proske, 2019)

Previous research has demonstrated that muscle fatigue in the upper limb can notably reduce JRS (Lee et al., 2003; Lida et al., 2014) as well as increase the TTDPM (Carpenter et al., 1998). Conversely, other research has shown that muscle fatigue has no significant impact on shoulder proprioception and kinesthesia (Lee et al., 2003; Sterner et al., 1998; Spargoli, 2017). Studies on the impact of upper limb fatigue on motor control are scarce (Myers et al., 1999; Salo and Chaconas, 2017; Bauer et al., 2020). Myers and colleagues suggested that there was no notable reduction in neuromuscular control during the single arm dynamic stability test before and after the fatigue intervention. In contrast two other studies (Salo and Chaconas, 2017; Bauer et al., 2020) found reduced stability and mobility of the upper limbs in the YBT-UQ after fatigue.

In summary, there is no definitive consensus regarding the impact of muscular fatigue on proprioception of the upper limb due to contradictory results and methodological variations between studies. Furthermore, there were few studies that utilized motor control and performance testing. The Athletic Shoulder test evaluated in the current study has not been utilized in any previous investigations. If the research hypothesis of the current study is confirmed, the results will assist health professionals in implementing preventive interventions aimed at minimizing the deleterious effects of muscular fatigue on proprioception motor control, and performance. The primary objective of this study was to examine how concentric fatigue impacts proprioception, motor control, and performance of the upper limb in healthy male volunteers.

5.2 Methods

5.2.1 Hypotheses

The research and null hypotheses of the second experiment were as following:

- H_1: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the proprioception of the upper limb in healthy young adults.
  $H_1$0: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the proprioception of the upper limb in healthy young adults.
- H_2: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the kinesthesia of the upper limb in healthy young adults.
  $H_2$0: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the kinesthesia of the upper limb in healthy young adults.
- H_3: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the performance of the upper limb in healthy young adults.
  $H_3$0: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the performance of the upper limb in healthy young adults.
- H_4: Concentric exercise-induced fatigue of the rotator cuff has a significant impact on the motor control of the upper limb in healthy young adults.

H_4O: Concentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the motor control of the upper limb in healthy young adults.

5.2.2 Type of research and sampling method

A quantitative research was used for the completion of the study (more details about the type of research is described in chapter 4, subchapter 4.2.2)

The participants who took part in the study were selected through the convenience sampling method (more details about the sampling methdod is described in chapter 4, subchapter 4.22).

The study's target population consisted of healthy young adults students from the university of nicosia. The main researcher (SH) is an adjunct faculty member of the University of Nicosia in the bachelor degree Physiotherapy program. It was therefore simple to reach in this population. The primary researcher communicated with each student in real time, speaking with them face-to-face to explain the study's methodology and obtain their verbal agreement to participate. After orally consenting to the study, the participants were assigned a specified time and date to visit the study location. The investigation was conducted in a calm setting in a specially created laboratory of the University of Nicosia's Physiotherapy Program.

5.2.3 Subjects

Twenty males right-handed healthy volunteersparticipated in the study. All participants were University of Nicosia students. Participants who signed the consent form were included in the study unless there were specific exclusion criteria. The research had been approved by the National Bioethics Committee of Cyprus under reference number ΕΕΒΚ/ΕΠ/2020/40.

5.2.4 Inclusion and exclusion criteria

Eligible participants should had been healthy adults males aged between 18 and 40 years old (table 5.1). The exclusion criteria comprised a participation in an overhead sport, history of shoulder injury within the past six months, shoulder surgery, neurological issues, congenital stiffness, cervical radiculopathy, shoulder dislocation, intra-articular fracture, rotator cuff tear, and labral tear. Subjects who experienced discomfort in more than 2 clinical tests or isometric contractions during the initial evaluation were excluded from the study and recommended to consult a physician for a definitive musculoskeletal diagnosis.

Table 5.1. The inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Healthy male adults • 18 to 40 yrs	• Participation in an overhead sport • History of shoulder injury in the past six months • Shoulder surgery, neurological issues, congenital stiffness, cervical radiculopathy, shoulder dislocation, intra-articular fracture, rotator cuff tear, and labral tear • > 2 positive clinical tests or isometric contractions during follow-up.

5.2.5 Experimental protocol

The present investigation utilized a pre-test and post-test design trial. An advertisement with a leaflet was used to recruit the sample. Students that volunteered, were contacted face to face by the lead investigator that provided further information on the study's process, purpose, and benefits. The investigation was conducted in a laboratory at the Physiotherapy Program of the University of Nicosia. The principal researcher and his team evaluated participants initially to determine their suitability for the study based on the specific inclusion and exclusion criteria. Each person who formally participated in the study was provided with a specific consent form (EEBK 03) to read and sign. Subsequently, the anthropometric traits (weight, height, and body mass index) of each participant were assessed with an electronic scale (Tanita WB 3000) and a stadiometer

(Seca, Hamburg, Germany). A screening examination was conducted on each subject, which involved evaluating active and passive shoulder movements, isometric muscle tests, and various orthopedic special tests such as Neer's test, Hawkins-Kennedy test, infraspinatus test, belly press test, lift-off test, speed test, Yergason test, Load and shift test, apprehension test, sulcus sign, Crank test, and anterior slide test. The examinations were conducted in accordance with the guidelines outlined in a well-accepted orthopedic physical evaluation manual (Magee, 2014). If the subject experienced pain in more than two clinical tests or isometric contractions, they were excluded from the study (more details about the screening examination are described in chapter 4, subchapter 4.2.2).

An isokinetic dynamometer (Humac Norm, CSMI solutions, USA) was utilized to quantify joint repositioning sense (JRS) with an active reproduction, threshold to detection of passive movement (TTDPM), and fatigue intervention. The Y balance test –upper quarter (YBT-UQ) and the athletic shoulder test (ASH) were utilized to assess motor control and performance respectively. All outcome measures were evaluated before and immediately after the fatigue intervention.

5.2.6 Measurements process

The shoulder internal and external rotation JRS was evaluated using an isokinetic dynamometer. JRS was evaluated through active reproduction of position, following the method used in a prior study (Spargoli, 2017). The right shoulder was placed at 30°, externally rotated at 0° in the scapular plane (30° anterior to the frontal plane), with the elbow flexed at 90° and with the forearm in mid-pronation, secured to the arm device of the isokinetic dynamometer. The height of the dynamometer and the length of the arm device were customized for each individual for comfort. Subjects were blinded to eliminate visual cues. Before each measurement, all participants performed two sets of 15 repetitions of shoulder internal and external rotation exercises using the dynamometer at an angular speed of 90 degrees per second as a warm-up. Afterward, six shoulder reference angles were assessed for each participant, including three angles in internal rotation (15, 30, and 45 degrees) and three angles in external rotation (15, 30, and 45 degrees). The examiner placed the shoulder at each specific angle, held it for 3 seconds, and then gently returned the participant's shoulder to its starting position. The participant was directed to precisely replicate the specified angle and maintain it for 3 seconds before returning to the starting position. Each participant performed three trials for each target angle, and the mean value was recorded. To performed statistical analysis for the JRS two types of errors were calculated: the absolute angular error (AAE), which is the absolute difference between the test position and the position reproduced by the subject, and the relative angular error (RAE), which is the signed arithmetic difference between a test and response position.

The TTDPM was assessed with the same initial position on the isokinetic dynamometer. The shoulder was placed in 60° of shoulder external rotation and passive motion in the direction of internal rotation was started in this position . The angular velocity of the passive movement was 0.5°/s. Previews studies, support that with this angular velocity, the slow adapting mechanoreceptors (capsulo-ligamentous) maximally stimulated, while the fast-adapting mechanoreceptors (muscle spindles) minimally stimulated (Lee et al., 2003; Lephart, 1994). A stop-movement button (of the isokinetic dynamometer) was given to each participant during the test to push when they detected the onset of the passive motion. Each participant performed three trials, and the mean value was recorded.

In order to assess the motor control of the upper limb, the YBT-UQ was used. Two published studies (Gorman et al., 2012; Westrick & Carow, 2012) found the YBT-UQ to be reliable (ICC 0.80 – 1.0). Before the test, the participant's upper limb length (distance between 7th cervical spine process and edge of the middle finger) was measured with a tape measure. After that, the examiner explained and performed the test to the participants. Each participant was placed initially in a push-up position with feet shoulder-width apart. Then, they remained in this position with one hand on the central platform of the YBT device and with the other hand push the indicator plate as far as possible in 3 directions. The three reach directions were the anteromedial (AM), inferolateral (IL) and superolateral (SL). For familiarization and warm up, the subjects performed the test one time with the right and left arm. After the warmup, three trials were performed in each direction and the best effort was recorded. Also, the greatest reach distances for each of the directions were summed to yield a composite reach distance, which was normalized to upper limb length for analysis of the overall performance on the test. If the participant had more than four failed attempts, then a score of zero was recorded for that trial. An attempt was considered a failure if the participant did the following: pushed suddenly the box, return to the initial push up position without control, touched the floor with their hand before pushing the box, their feet were not in contact with the ground. During the test, the same instructions were given to all participants.

The isometric strength performance of the upper limb was assessed with the ASH test. The ASH test is a functional test, which aims to assess the isometric strength of the upper limb in three different postures (“I”, “Y”, “T”). This test was found to be reliable with intra-class correlation coefficients of 0.86 to 0.97 (Tooth et al., 2022). Each participant was placed in a prone position with the forehead and palm of the hand resting on a 4-centimeter high pad and a portable force plate respectively. To record the isometric strength during the test, participants were asked to push their palm on the portable force plate (K-Force Plates, Kinvent, Montpellier, France) with as much force as possible for three seconds and the peak force for each testing position was extracted and normalized to bodyweight. In the "I" position, the shoulder was placed in full abduction (in line with the body), the forearm in pronation, and the "heel" of the hand acted as the main point of contact with the force platform. In the “Y” position and “T” position, the arm was placed in 135° and 90° abduction, respectively. In all tests, the elbow had to be fully extended. The contralateral arm was placed behind the back so that the elbow could not be fixed to the floor and provide stability against trunk rotation for the “Y” and “T” tests, while in the “I” test the arm remained at the participant's side due to the lower torsional forces of the trunk.

5.2.7 Exercise-induced fatigue protocol

The participants were positioned upright on the isokinetic dynamometer. The right shoulder was positioned at 30° of abduction, 0° of external rotation, in the scapular plane (30° anterior to the frontal plane), with the elbow flexed at 90°, with the forearm in mid-pronation, and secured to the arm device. Each participant engaged in maximal voluntary concentric isokinetic contractions from 60° of shoulder internal rotation to 60° of shoulder external rotation and back to elicit muscle exhaustion in the shoulder external and internal rotator muscles. The test was conducted in the same position as the fatigue protocol. The examiner first directed each participant to do 10 submaximal concentric contractions at 20% of their maximal voluntary contraction, at an angular speed of 90 degrees per second, to become familiar with the specific exercise. The highest isokinetic torque of the internal and external rotators was measured by instructing the patient to complete 10 repetitions with maximum force. This figure served as the benchmark for inducing fatigue. After a 5-minute rest period, each participant completed sets of 30 maximal effort concentric isokinetic contractions at an angular speed of 90 degrees per second for the external and internal rotator muscles. Muscle fatigue was determined by a decrease in isokinetic peak torque to 40% of the reference value (a 60% reduction) and staying below this value for 3 consecutive repetitions, regardless of positive reinforcement. If the subject surpassed the peak torque reference value in the first set, the reference value was immediately adjusted, and the same approach was applied for inducing fatigue. The number of sets required to cause exhaustion ranged from one to five, with three being the most common. This protocol was utilized in previous research (Lida et al., 2014). Muscle fatigue was also evaluated post-test by calculating the percentage decrease in peak torque between the first and last ten repetitions during the thirty-repetition sets of isokinetic exercise at 90 deg/sec.

5.2.8 Statistical analysis

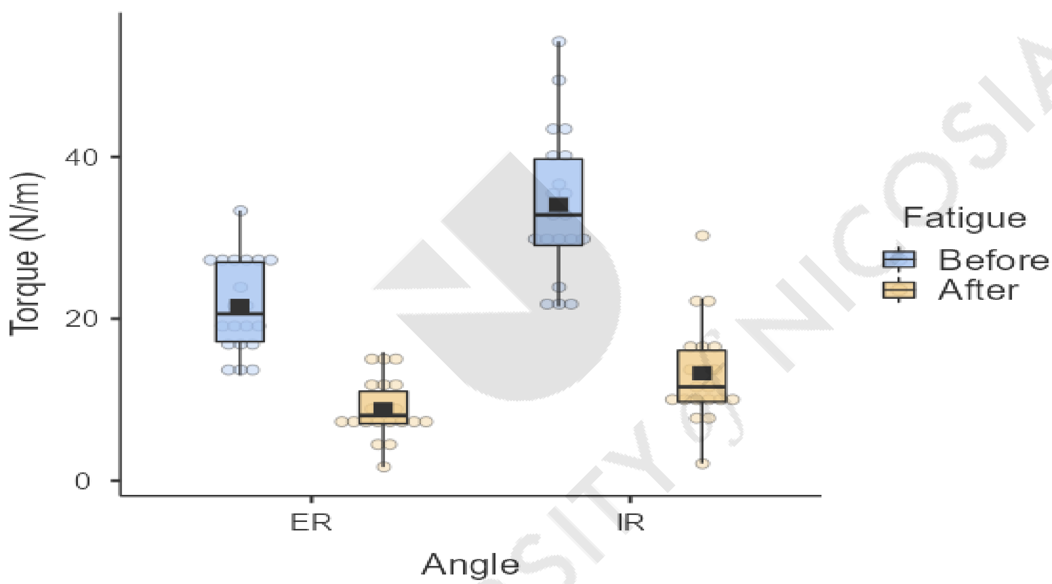
Statistical analysis was conducted using Jamovi version 2.3.26. Descriptive statistics were utilized to compute the means and standard deviations of the gathered variables. The Shapiro-Wilk test was utilized to evaluate the normality of the data before doing the study. A paired t-test was employed to analyze the mean differences before and after the fatigue intervention for various measures including absolute angle error (AAE), relative angle error (RAE), threshold to detection of passive movement (TTDPM), YBT-UQ, and the ASH test. The Wilcoxon test was utilized for comparing pre-post fatigue intervention results in variables that were not regularly distributed. A significance level of $p < 0.05$ was established, and the 95% confidence interval was computed for all mean differences.

5.3 Results

The participants had an average age of 26.8 (± 5.53) years, height of 181 (± 4.06) cm, weight of 86.3 (± 13.9) kg, and body mass index of 26.3 (± 4.2) kg/m2

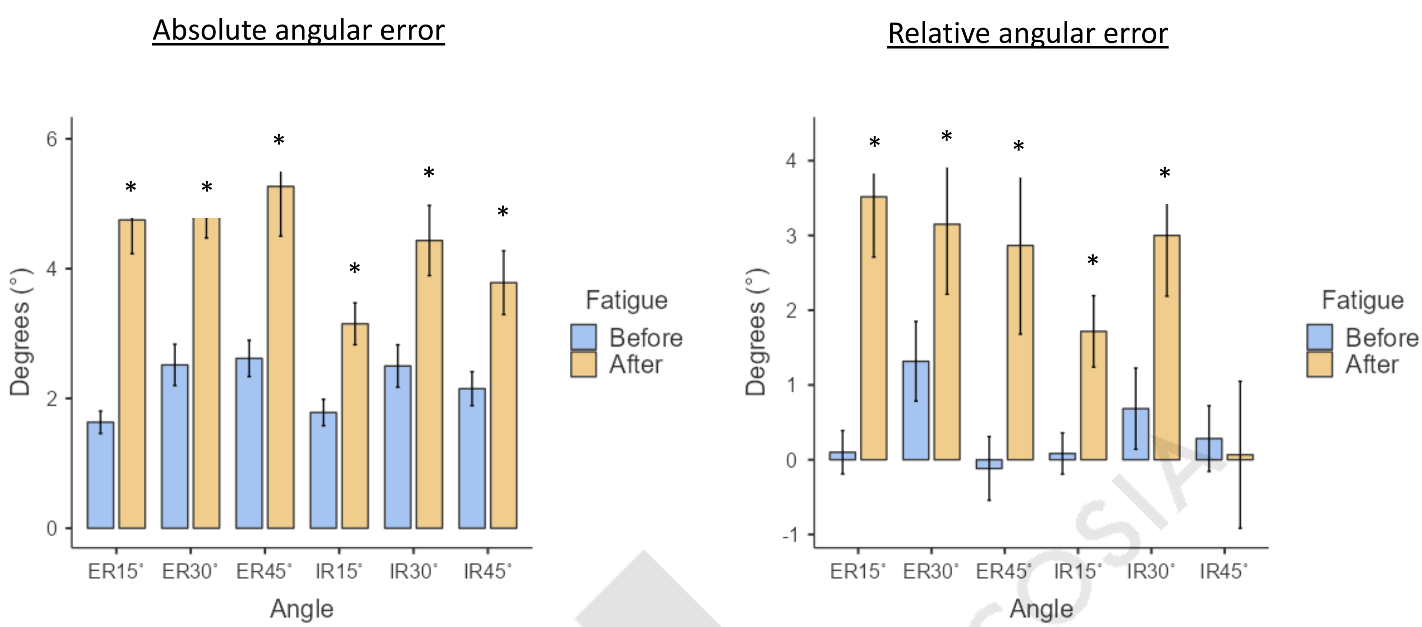
The peak torque of shoulder internal rotation and shoulder external rotation decreased by 61.11% (figure 5.1) and 59.14% (figure 5.1) correspondingly after muscle fatigue, comparing the first ten repetitions to the last ten repetitions.

Figure 5.1. The torque of the shoulder's external rotation (ER) and internal rotation (IR) pre and post fatigue intervention.



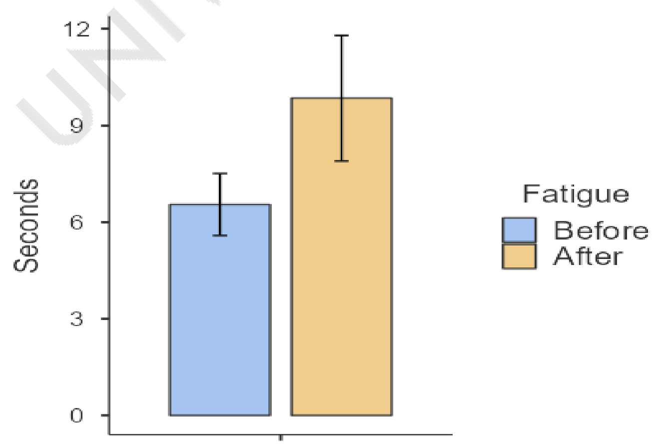
Following the fatigue intervention, there was a statistically significant increase ($p<0.05$) in AAE at all target angles [ER15˚: Mean diff = -3.12 (95% CI: -4.33, -1.904), $p < 0.001$]; [ER30˚: mean diff = -2.47 (95% CI: -3.44, -1.497), $p < 0.001$]; [ER45˚: mean diff = -2.65 (95% CI: -4.31, -0.985), $p = 0.004$]; [IR15˚: mean diff = -1.37 (95% CI: -1.91, -0.819), $p < 0.001$]; [IR30˚: mean diff = -1.93 (95% CI: -2.98, -0.885), $p = 0.001$]; [IR45˚: mean Diff = -1.63 (95% CI: -2.73, -0.540), $p = 0.006$] as shown in figure 5.2 In addition, following fatigue, there was a statistically significant rise ($p < 0.05$) in the RAE at five out of six target angles (ER 15˚, ER 30˚, ER 45˚, IR 15˚, IR 30˚), except for IR 45˚ ($p=0.841$) (figure 5.2).

Figure 5.2. The absolute angular error and relative angular error scores of six target angles before and after fatigue intervention. The asterisk indicate statistical significant difference (p < 0.05).



Futhermore, there was an increase in mean values for TTDM after experiencing fatigue (figure 5.3). However, the increase observed was not statistically significant [mean (SD) pre = 6.90 (4.45), mean (SD) post = 9.60 (8.77), mean difference = -2.00 (95% CI: -6.00, 5.55), p=0.070].

Figure 5.3. The threshold to detection of passive motion score before and after fatigue intervention.



There were no statistically significant differences ($p > 0.05$) in the mean values of all hand positions in the YBT-UQ before and after fatigue (table 5.2).

Table 5.2. The YBT-UQ scores before and after fatigue intervention.

Hand position	Before fatigue (cm)	After fatigue (cm)	p value	Mean difference (95% CI)
AM Right	90.9 ± 10.78	89.5 ± 12.01	0.511	1.350 (-2.864, 5.56)
IL Right	81.8 ± 13.44	79.1 ± 13.15	0.202	2.750 (-1.600, 7.10)
SL Right	61.2 ± 10.72	58.5 ± 14.34	0.297	2.500 (-1.50, 8.00)
AM Left	89.5 ± 10.44	89.3 ± 10.04	0.956	0.100 (-3.613, 3.81)
IL Left	81.8 ± 9.29	78.9 ± 11.92	0.197	2.900 (-1.637, 7.44)
SL Left	63.3 ± 12.63	61.9 ± 11.94	0.336	1.400 (-1.565, 4.37)
CS Right	83.6 ± 11.2	81.3 ± 12.8	0.129	2.36 (-0.754, 5.48)
CS Left	83.9 ± 10.5	82.3 ± 11.2	0.324	1.57 (-1.670, 4.80)

Abreviations: AM, anteromedial; IL, inferolateral; SL, superolateral; CI, confidence interval; CS, composite score; ±, standard deviation

Moreover, following fatigue there was a significant reduction ($p=0.044$) in isometric strength specifically in position "I" of the left arm. No statistically significant differences ($p < 0.05$) were seen between the mean values before and after fatigue in the remaining hand evaluation positions (table 5.3).

Table 5.3. The ASH test scores before and after fatigue

Hand position	Before fatigue (N)	After fatigue (N)	P value	Mean difference (95% CI)
I Right	12.70 ± 3.34	11.82 ± 2.24	0.238	0.8820 (-0.6339, 2.398)
Y Right	10.35 ± 2.24	10.12 ± 2.07	0.664	0.520 (-0.65500, 2.495)
T Right	9.37 ± 1.89	9.45 ± 2.01	0.818	0.312 (-0.7270, 0.581)
I Left	12.30 ± 2.72	11.25 ± 2.41	0.044*	0.488 (0.0326, 2.075)
Y Left	9.80 ± 1.99	8.93 ± 2.11	0.057	0.430 (-0.0305, 1.768)
T Left	9.38 ± 1.95	8.74 ± 2.60	0.159	0.438 (-0.2750, 1.557)

Abreviations: I, Y and T, starting hand positions during the ASH test; N, newton; SL; CI, confidence interval; ±, standard deviation; asterisk indicates significant differences due to fatigue

5.4 Discussion

The study aimed to examine how concentric muscle fatigue in the shoulder rotator cuff affects proprioception and motor function in male healthy students. The null hypothesis (H_10) was rejected. However, the remaining null hypotheses (H_20, H_30, H_40) were not rejected. The primary findings of the current investigation indicate that concentric fatigue has a detrimental effect on the perception of joint repositioning and, to a lesser degree, kinesthesia in a group of healthy male non-athlete participants. Furthermore, it was shown that fatigue did not have a significant impact on the motor control and isometric strength performance of the upper limb. Proprioception encompasses all submodalities such as joint position sense, kinesthesia, and sensation of force, playing a crucial role in regulating movement, balance, and joint stability (Riemann and Lephart, 2002).

Muscle fatigue can impact proprioception by reducing the sensitivity of muscle spindles, leading to a disruption in afferent signals (Ribeiro & Oliveira, 2007). Furthermore, the decline in proprioceptive sensitivity following exhausting physical activity may be attributed, in part, to alterations in the central processing of proprioceptive signals due to Central Nervous System fatigue mechanisms. Central fatigue can decrease the precision of motor control and disrupt voluntary muscle-stabilizing activity needed to counteract applied joint stresses (Miura et al., 2004). Additionally, it has been proposed that the increased amount of injuries occurring towards the end of practice sessions or matches may be linked to changes in lower limb neuromuscular control and joint dynamic stability caused by fatigue-induced modifications in joint proprioception (Hiemstra et al., 2001).

5.4.1 The effect of fatigue on shoulder JPS

The joint position sense appeared to be negatively affected by muscle fatigue. Following fatigue, both the AAE (all target angles) and RAE (five out of six target angles) showed a considerable increase. One potential explanation for this finding is that muscular fatigue can elevate the activation threshold of the muscle spindle, due to the increase of intramuscular concentrations of lactic acid, creatine-kinase, bradykinin, arachidonic acid, and serotonin. Previous investigations have also partly corroborated this notion (Kablan et al., 2004; Lee et al., 2003). Lee et al (2003) found a substantial increase in position inaccuracy during the JRS test for shoulder external rotation when muscular fatigue set in, but no such increase was seen for shoulder internal rotation. On the contrary, the study by Kablan et al. (Kablan et al., 2004) found that novice volleyball players made considerably more position errors in internal rotation compared to external rotation after experiencing shoulder muscular fatigue. The current investigation verified that muscle fatigue can affect joint position awareness in both external and internal rotation. The methodological differences between the present study and the previous two studies may explain this result. Firstly, the standing position was selected in the current investigation to generate muscular fatigue and evaluate proprioception. In contrast, the other studies used the supine position (Lee et al., 2003) and the sitting position (Kablan et al., 2004). Additionally, variations existed in the target angles for the shoulder joint repositioning sense. The current study utilized three specific target angles (15˚, 30˚, and 45˚) for shoulder internal and external rotation. Lee et al (2003) employed two target angles: 45˚ of internal rotation and 90˚ of external rotation. Kablan et al (2004) utilized three target angles: 10˚, 15˚, and 20˚ in both external and internal rotation. Furthermore, there were variations in the fatigue procedure, including the angular speed of the isokinetic dynamometer and the criteria used to determine muscle fatigue. The angular velocity selected for the current study's fatigue procedure was 90 degrees per second. On the other hand, the other studies utilized angular speeds of 180 deg/sec (Lee et al., 2003) and 60 deg/sec (Kablan et al., 2004). Also, the percentage decrease of peak torque for the fatigue confirmation was higher (60%) in the present study compared to the other investigations (50%) (Kablan et al., 2004; Lee et al., 2003).

Further investigations (Iida et al., 2014; Myers et al., 1999) supported the results of the current study, that muscle fatigue can affect the joint repositioning sense equally in shoulder internal and external rotation. However, there were methodological differences between these studies and the current study, including the initial shoulder assessment position, the target angles during the active joint repositioning sense test, the fatigue protocol suggesting the result is robust and independent of methodology. In a study conducted by Voight et al. (1996), the effects of shoulder muscular exhaustion on active and passive joint repositioning sensation were investigated at a specific target angle of 75˚ of external rotation, resulting in considerable impairment in both tests.

Some studies revealed no significant differences before and after fatigue interventions, despite the JRS (Spargoli, 2017; Sterner et al., 1998). Spargoli (2017) hypothesized that eccentric exercise would have a more pronounced effect on shoulder proprioception than concentric exercise. However, no significant changes were seen in either group before and after the fatigue intervention. Additionally, Sterner et al (1998) did not confirm that fatigue in the shoulder muscles can significantly reduce the joint repositioning sense in both active and passive reproduction. The researchers explained that changes were noticed in both the articular and muscular mechanoreceptors, not simply the muscular receptors (Sterner et al., 1998).

5.4.2 The effect of fatigue on shoulder TTDPM

Following fatigue intervention, the mean TTDPM demonstrate a 39.13% (± 8.77˚) increase. However, this increase, was not statistically significant. A possible explanation for this finding as suggested by Skinner et al (1986), was that the reduced sensitivity of muscle mechanoreceptors due to fatigue resulted in adaptive increased activation of articular mechanoreceptors to retain the kinesthetic sense unchanged. When intramuscular receptors are unable to detect passive movement, some of the remaining kinaesthetic sensibility is likely facilitated by slowly adapting receptors within the joint capsule around the shoulder joint (Ferrell et al., 1987). Furthermore, the slow passive motion (0.5 ˚/sec) selected for the TTDPM test is thought to effectively activate slow adapting joint mechanoreceptors while minimizing muscle receptor stimulation (Lee et al., 2003; Lephart et al., 1994).

The current study's findings are consistent with previous research by Sterner et al. (1998), who also did not find significant differences in TTDPM before and after a fatigue intervention. The study by Carpenter et al (1998) reported contrasting results, showing that the mean TTDPM (internal and external rotation combined) increased to 1.59° (± 0.59°), a 73% increase following the fatigue intervention. However, it is crucial to recognize that there were methodological differences between the current study and the research conducted by Carpenter et al. (1998), making it difficult to compare the results. Carpenter et al (1998) used a different evaluation position (sitting) and a higher angular velocity of 1 deg/sec on the isokinetic dynamometer, which was higher than the current study's velocity of 0.5 ˚/sec. Furthermore, the current study included male only volunteers, while Carpenter et al. (1998) included both males and females.

5.4.3 The effect of fatigue on ASH test

In this study, muscle fatigue in the rotator cuff muscles did not have a significant impact on isometric strength of the upper extremities during the ASH test. The ASH test was the last assessment done after the fatigue program, and it is possible that there was a recovery of muscle strength. Chang et al. (2006) found that shoulder muscle strength recovered faster than shoulder joint position sensation after exhaustion. Researchers suggest that muscular fatigue might cause a decrease in energy levels inside muscle tissue, leading to a rapid fall in muscle strength (Chang et al., 2006). After a short rest, biochemical metabolism restored bioenergy reserves. Sterner et al (1998) also validated this observation, reporting a rapid restoration of peak torque after the fatigue intervention.

5.4.4 The effect of fatigue on YBT-UQ

The assessment of stability and mobility of the upper limb through the YBT-UQ appears to be unaffected by muscle fatigue. The quick recovery of shoulder muscle strength prior to doing this test may account for this observation. Myers and colleagues (1999) conducted a study to examine how shoulder muscular fatigue affects shoulder stability through the single-arm dynamic stability (SADST) test. The data indicated a significant increase in falls after the fatigue intervention. Researchers suggest that tiredness could affect the mechanoreceptors in the stability muscle group, resulting in a decreased capacity of the shoulder to cocontract in the closed kinetic chain position. This discovery aligns with the results of Salo and Chaconas (2017), who noted a notable reduction in YBT-UQ scores for all reaching orientations in both limbs following shoulder press, machine row, prone push-up, and pull-up exercises. A recent study by Bauer et al. (2020) demonstrated that handball players showed a significant drop in YBT-UQ scores, particularly in the SL reach direction for both upper limbs, after completing a fatigue protocol that included push-up activities. Fatigue was induced in the upper right limb during the experiment. Bauer et al (2020) caused tiredness by employing the push-up activity. The push-up exercise causes fatigue in both arms at the same time. The researchers explained that the SL reach direction was the last one examined in the sequence of the three reach directions. This led to an extended duration in maintaining the weight-bearing one-arm push-up position, potentially hindering the recovery process. Additionally, the SL reach orientation closely mirrors the technique employed in overhead throwing.

5.4.5 Limitations

The present study had some limitations. Firstly, no control group was used to compared the outcome measures between the fatigued and non-fatigue group. Secondly, only male adult participants were included in the study and the effect of muscle fatigue on proprioception in females and adolescents is still unknown. Thirdly, muscle fatigue was performed in laboratory environment (isokinetic dynamometer). It is known that the induction of muscle fatigue in real conditions is different to laboratory conditions. This could be a confounding factor in the results. Furthermore, there was a time gap of around fifteen minutes between the muscle fatigue intervention and the final two tests (ASH test, YBT-UQ), perhaps allowing for muscle strength recovery.

5.5 Conclusions

Fatigue of the shoulder rotator cuff muscles might impair joint position awareness due to concentric contractions. However, muscle fatigue did not seem to have a significant impact on kinesthesia, motor control, and performance. Further research is needed to study the effects of the upper limb fatigue on all aspects of proprioception (joint position sensation, kinesthesia, sense of force or tension) and motor control using upper limb functional performance assessments.

Chapter 6.0: Effect of eccentric exercise-induced fatigue on proprioception, motor control and performance of the upper limb in handball players

Abstract

Background: During the deceleration phase in throwing, the rotator cuff undergoes significant tensile forces as a result of its eccentric action, potentially resulting in injury. It is widely thought that fatigue, particularly during eccentric exercise, has a detrimental effect on proprioception. The purpose of this study was to investigate the effect of eccentric exercise-induced fatigue on proprioception and motor control of the upper limb in handball players.

Methods: A total of thirty-three male professional handball players participated in the recruitment process. The testing procedure comprised of four components: the evaluation of shoulder joint repositioning sense (JRS), the threshold to detection of passive movement (TTDPM), the Y-balance upper quarter test (YBT-UQ) and the athletic shoulder test (ASH). Prior to and immediately following the fatigue intervention, all outcome measures were evaluated. The fatigue protocol consisted of eccentric maximal effort isokinetic contractions with sets of 15 repetitions of the shoulder external and internal rotator muscles. Fatigue was determined by a 60% decline of the peak torque over three consecutive contractions.

Results: Following fatigue, a notable rise ($p < 0.05$) in absolute angular error (AAE) was detected in five of the six target angles (ER15˚, ER30˚, ER45˚, IR15˚, and IR30˚). Nevertheless, there was no statistically significant disparity in the absolute angular inaccuracy between the pre and after fatigue intervention when considering the target angle IR45˚ ($p = 0.967$). Furthermore, there was a significant increase in TTDPM ($p = 0.011$). The YBT-UQ test revealed statistically significant disparities in all reach directions towards the right hand. Nevertheless, there were no statistically significant differences observed in any of the reach orientations of the left hand ($p > 0.05$). In addition, the composite score (CS) showed a statistically significant difference only for the right hand ($p < 0.001$). Furthermore, after the fatigue intervention, there was a notable decrease in the isometric strength in the ASH test average scores for all hand positions on the right side and for two locations on the left side ($p < 0.05$). There were no significant differences ($p = 0.063$) in the "T" Left hand position.

Conclusions: Eccentric exercise-induced fatigue of the rotator cuff muscles can cause significant impairments in joint position awareness, kinesthesia, motor control, and performance of the upper extremity in elite male handball players.

Key words: Eccentric exercise-induced fatigue, proprioception, handball, motor control.

6.1 Introduction

Research in the field of biomechanics has shown that the forces exerted on the anatomical tissues surrounding the shoulder joint during throwing a ball can be as high as 1.5 times the weight of a handball athlete (Fieseler et al., 2017; Karcher & Buchheit, 2014). Due to the substantial load, the shoulder often sustains injuries, with 30% of these injuries being acute and 45% being severe, leading to persistent pain (Almeida et al., 2013; Doyscher et al., 2014). During the time of deceleration in throwing motion, the rotator cuff undergoes significant tensile forces as a result of its eccentric action, potentially resulting in injury (Dugas and Andrews, 2003).

An eccentric contraction occurs when the internal force exerted on the muscle is insufficient to counterbalance the external force applied to the muscle (Douglas et al., 2017; Lindstedt et al., 2001). This leads to the active elongation of the muscle fibers when subjected to a certain load (Vogt and Hoppeler, 1985). There is data indicating that eccentric exercise disrupts proprioception including the perception of tension and awareness of limb position (Brockett et al., 1997).

The term proprioception pertains to the conscious perceptions linked to the movements of our bodies as we navigate our environment (Riemann and Lephart, 2002). Proprioception encompasses the perception of the body's position and movement, which are sometimes grouped together as the kinaesthetic sense (Ager et al., 2020). Additionally, there are the sensations of effort and heaviness experienced when we raise objects, as well as the perception of muscular force (Prochazka, 2021) all of which are submodalities of proprioception. Research has demonstrated that muscle fatigue has a negative impact on joint proprioception and hinders neuromuscular control in the lower limbs (Shokri et al., 2018; Vila-Chã et al., 2011) and upper limbs (Lee et al, 2003; Lida et al 2014).

Fatigue is characterized as the incapacity of the muscle to sustain the necessary degree of strength throughout physical activities (Abd-Elfattah et al., 2015). Alternatively, it can be described as a decrease in the ability of muscles to produce force under voluntary command (Edwards, 1981). Boyas et al. (2013) have proposed a set of principles to describe muscular exhaustion resulting from physical activity, specifically referred to as "exercise induced fatigue." These ideas emphasize that exhaustion is not caused by a single process, but rather by a combination of complicated mechanisms such as anomalies in the central nervous system (central fatigue), malfunction in the peripheral neural system, or diseases of the skeletal muscles (Zając et al., 2015).

It is widely thought that fatigue, particularly during eccentric exercise, has a detrimental effect on proprioception (Brockett et al., 1997; Proske, 2019). This observation can be attributed to the reduced sensitivity of muscle spindles resulting from the damage inflicted upon the muscle fibers during eccentric activity (Proske, 2019).

Previous research has examined the impact of eccentric exercise-induced fatigue on proprioception. Brockett et al. (1997) examined the impact of exercise on position sense by employing a novel 'arm curl' apparatus. The study revealed that the arm that was exercised eccentrically consistently positioned itself in the direction of extension compared to the arm that was exercised concentrically. Walsh et al. (2004) conducted a study to examine the effects of eccentric fatigue on the biceps brachii. On the subsequent day, the eccentric exercise resulted in a decrease of -15% in maximum voluntary muscular torque. The unsupported matching task experienced a notable rise in matching mistakes. However, this increase was not observed in counterweighted matching or horizontal matching. On the other hand, Semmler et al (2007), conducted a study which revealed that engaging in eccentric exercise of the elbow flexor muscles led to a twofold augmentation in the coactivation of the triceps brachii muscle during all submaximal contractions. The data presented in this study revealed that engaging in eccentric exercise leads to a decline in motor control and changes in neural activity in the elbow flexor muscles. In a study conducted by Spargoli (2017), there was no significant difference in absolute angular error between the concentric and eccentric groups after conducting sets of fifteen consecutive external rotator muscle contractions in either the concentric or eccentric action. Furthermore, there was no statistically significant difference observed in the absolute angular inaccuracy comparing the pre- and post-fatigue measurements in either of the groups. In their study, Givoni et al. (2007) conducted eccentric fatigue on the knee. Participants were instructed to descend six flights of stairs, taking two steps at a time, until they completed 11 circuits, which accounted for a total of 792 steps. The researchers observed that immediately following the exercise, the participants exhibited a tendency to align their indicator leg with the reference position by moving it further in the direction of flexion. Da Silva et al. (2023) conducted two submaximal bouts of unilateral eccentric contractions of the knee flexors until they reached a 20% decrease in maximal voluntary isometric contraction force. They observed a significant increase in position-matching errors in a seated posture of 40°. Twenty-four hours after exercise, despite the recovery of knee flexors neuromuscular function, there was a significant increase in position matching errors in the prone position at 40°, along with the presence of muscle soreness. Shokri et al (2018) compared the effect of concentric and eccentric fatigue of the quadriceps muscle on the force sense and joint position sense of the knee. After the exercise intervention, there was a significant increase in force sense error and position sense error following eccentric contractions. However, concentric contractions only affected position sense (Shokri et al., 2018). Position sense improved after concentric contractions, while it deteriorated following concentric contractions. In a study conducted by Vila Cha et al. (2011), the absolute error in the non-weight bearing matching task at 120 degrees of knee extension was significantly higher immediately after eccentric exercise and 24 hours after exercise compared to the baseline. This finding occured following four sets of 25 maximum voluntary eccentric knee extension contractions at a speed of 60º/sec between 170 and 90º of knee extension. In the non-weight bearing repositioning task at 120˚, the absolute error was found to be higher both immediately and 24 hours after exercise compared to the baseline. Hence, in both activities that did not involve bearing weight, the participants exhibited a tendency to align the limb that was exercised in a more extended position following eccentric exercise. On the contrary, the repositioning errors in the weight bearing task were not influenced by eccentric exercise (Vila Cha et al., 2011). The impact of eccentric exercise, specifically Nordic hamstring curls and lunges, on the lower quarter Y-balance test was examined by Singh et al. (2023). The researchers observed that eccentric exercise did not have a significant impact on the dynamic balance.

Based on a comprehensive analysis of the current literature, only a limited number of studies have examined the impact of eccentric exercise-induced fatigue on shoulder proprioception (Spargoli, 2017). In addition, there has been no research conducted to examine the impact of eccentric exercise-induced fatigue on the motor control of upper extremities. Hence, it is imperative to do this investigation. The results of the current study will aid coaches and trainers in comprehending the harmful consequences of muscle fatigue on shoulder proprioception and motor control, hence heightening an athlete's susceptibility to injury.

The main objective of this study was to investigate the effects of eccentric exercise-induced fatigue exerted on the shoulder rotator muscles on the proprioception, motor control, and performance of male handball players.

6.2 Methods and materials

6.2.1 Hypotheses

The research and null hypotheses of the first experiment were as following:

- H_1: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the proprioception of the upper limb in handball players.
  H_10: Eccentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the proprioception of the upper limb in handball players.
- H_2: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the kinesthesia of the upper limb in handball players.
  H_20: Eccentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the kinesthesia of the upper limb in handball players.
- H_3: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the performance of the upper limb in handball players.
  H_30: Eccentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the performance of the upper limb in handball players.
- H_4: Eccentric exercise-induced fatigue of the rotator cuff has a significant impact on the motor control of the upper limb in handball players.
  H_4O: Eccentric exercise-induced fatigue of the rotator cuff does not have a significant impact on the motor control of the upper limb in handball players.

6.2.2 Type of research and sampling method

A quantitative research was used for the completion of the study (more details about the type of research is described in chapter 4, subchapter 4.2.2)

The participants who took part in the study were selected through the convenience sampling method (more details about the sampling methdod is described in chapter 4, subchapter 4.2.2). All handball players who had participated in the first experimental study (see chapter 4), they asked if can also participated in the third experimental study (present chapter). The 20 out of 44 handball players had positively answered that can particicipate and finally they included in the experimental process. Due to the smaller sample size (n=20) compared to the first experimental study (n=44), an effort was made to find at least 10 more participants. Thirty participants is the ideal number for the recruitment process (see subchapter 6.2.1). In order to find the 10 additional participants, the main researcher (SH) he asked the 20 available handball players, if they known other handball players who can participated in the present study. After this the main researcher recorded all contact numbers from prospective participants. Then, via telephone contact, another 13 handball athletes agreed to participate in the present study. The participants who verbally agreed to participate in the study were given a specific date and time to come to the study site. The study location was in a quiet environment in a specially designed laboratory of the Physiotherapy Program of the University of Nicosia.

6.2.3 Subjects

During the period of June to August 2023, a total of thirty-three male professional handball players participated in the study. The ideal number of participants was determined using specialized software (G*power 1.3.9.4). Given a significant coefficient of 0.05 and a moderate correlation between repeated measures (before and after tiredness) with an effect size of 0.3, a sample size of 30 persons results in a power of 82% or 0.82. Hence, taking into consideration a 10% attrition rate of participants during the study, the total of 33 individuals was considered adequate. The exclusion criteria (table 6.1) for participation encompassed individuals having a recent shoulder injury within the past six months, previous shoulder surgery, neurological disorders, congenital stiffness, cervical radiculopathy, shoulder dislocation, intra-articular fracture, rotator cuff tear, labral tear, and two or more positive orthopedic clinical test during the initial assessment (more details about the screening examination are described in chapter 4, subchapter 4.2.2). The researchers gained ethical permission from the Cyprus Ethics Committee (ΕΕΒΚ/ΕΠ/2020/40). The study exclusively conducted proprioceptive tests on the dominant shoulder, specifically the right shoulder. The testing procedure comprised of four components: the evaluation of shoulder ARS, the TTDPM, the YBT-UQ and the ASH test. To assess the JRS and the TTDPMD, an isokinetic dynamometer was used. Furthermore, the fatigue protocol was also performed on the isokinetic dynamometer. The assessment of motor control and performance involved the utilization of the YBT-UQ and the

ASH test respectively. Prior to and immediately following the fatigue intervention, all outcome measures were evaluated.

Table 6.1. The inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
• Professional male handball athletes	• Shoulder injury within the past six months • Previous shoulder surgery • Neurological disorders • Congenital stiffness • Cervical radiculopathy • Shoulder dislocation • Intra-articular fracture • Rotator cuff tear or labral tear • Two or more positive orthopedic clinical test during the initial assessment.

6.2.4 Meausurement of JRS

On the isokinetic dynamometer, each participant was placed in standing position with 30˚ of shoulder abduction, 0˚ of external shoulder rotation in the plane of the scapula. In addition the elbow was positioned at 90˚ of flexion, between pronation and supination of the forearm (neutral position). The arm device was used to strap the participant's arm. The length and height of the isokinetic dynamometer was adjusted separately for each participant. In order to facilitate the assessment procedure, the axis of rotation of the isokinetic dynamometer was positioned in line with the acromion. This alignment allowed for the isolation of shoulder internal and external rotation motions. In order to minimize visual and auditory stimuli, the participants donned a mask and inserted earplugs. Each participant performed submaximal eccentric isokinetic contractions in both external and internal rotation (2 sets of 15 repetitions, 90 degrees/second) as a warm up. In both shoulder external and internal rotation three target angles (total six) were assessed: 1) 15˚ external rotation, 2) 30° external rotation, 3) 45° external rotation, 4) 15˚ internal rotation, 5) 30° internal rotation, 6) 45° internal rotation. From 0˚ of shoulder rotation (starting position), the assessor positioned the shoulder at one target angle and maintaining in this position for three seconds. During the three seconds, each participant had to memorize the repositioning angle. After this period, the examiner moved the shoulder to the starting position. The participant thereafter engaged in deliberate external rotation of the shoulder, transitioning from the initial angle to the target angle, and consistently maintaining the target angle for a duration of 3 seconds. This process was repeated in the same manner for all target angles. Three trials were performed in each target angle and the mean value was used in the analysis.

6.2.5 Meausurement of TTDPM

The experimental conditions employed for the TTDPM test closely resembled those utilized for the repositioning test. During the test, the participant was also equipped with earmuffs and mask in order to mitigate auditory stimuli. At first, the arm was positioned in a 60-degree angle of external rotation of the shoulder. The researcher activated the lever arm of the dynamometer at a random time interval ranging from 1 to 10 seconds which indicated the commencement of the testing procedure. The equipment facilitated the passive movement of the arm in the direction of internal rotation, maintaining a constant speed of 0.5 degrees per second. The participant was directed to push the stop button to halt the movement of the lever arm once he perceived the movement of the arm. Each individual performed three trials, and the mean duration, measured in seconds, of the perception of initiation of movement was recorded.

6.2.6 Meausurement of YBT-UQ

The YBT-UQ is a comprehensive assessment that necessitates physical strength, flexibility, neuromuscular coordination, balance, stability, and range of motion. The experiment utilized a YBT kit^{TM}, comprising of three interconnected cylindrical tubular plastic bars that were labeled with markings at half centimeter intervals. Each bar has a moveable indicator plate, which the subject moves by pushing with their hand/fingers. The test was conducted by initiating the subject in a push-up stance with their feet positioned at a distance equal to the breadth of their shoulders. The objective of the test was to maintain a push-up position on the central platform of the YBT device and exert maximum force on the indicator plate in the anteromedial (AM), superolateral (SL), and inferomedial (IL) directions using the other hand. Following a warm-up test consisting of three attempts in each direction, three additional attempts were conducted in each direction. The maximum reach distances in each direction were added together to obtain a composite reach distance, which was then adjusted to account for the length of the upper limb. This facilitated an analysis of the overall proficiency demonstrated in the assessment. Prior to the test, the length of the subject's upper limb, from the seventh cervical vertebrae to the tip of the middle finger, was measured using a tape measure. In cases when the subject made more than four unsuccessful attempts, a score of zero was documented for that particular trial. A participant's attempt was deemed a failure if they engaged in any of the following actions: exerting force on the box, returning to the beginning push-up posture without maintaining control, contacting the floor using their hand prior to pushing the box, or having their feet in lose contact with the ground. All individuals successfully completed the trials during the test without any failures. The YBT-UQ test demonstrated high reliability (ICC 0.80 – 1.0) and showed no disparity in performance between the dominant and non-dominant limbs (Gorman et al., 2012; Westrick and Carow, 2012).

6.2.7 Meausurement of ASH test

The ASH test was developed to evaluate the isometric strength performance of the shoulder. The test was conducted according to the methodology outlined by Ashworth et al. (2018), with participants lying face down on the floor and their foreheads touching a 4 cm elevated cushion. The hand's palm was positioned atop a force plate. The participant's hand in this test was positioned in three configurations ("I", "Y", and "T"). When in the "I" position, the shoulder is fully abducted (aligned with the body), the forearm is in pronation, and the "heel" of the hand serves as the primary point of contact with the force platform. The arm was positioned at an abduction angle of 135° in the "Y" position and 90° in the "T" position. The elbow was required to be fully extended in all tests. The arm on the other side was positioned behind the back to prevent the elbow from being anchored to the floor and to offer support against trunk rotation during the "Y" and "T" tests. However, during the "I" test, the arm was kept at the participant's side because the trunk experienced lesser twisting forces. Subjects were instructed to exert maximum force on a portable uniaxial force plate (K-Force Plates, Kinvent, Montpellier, France) for a duration of three seconds at each test position. Data on force was gathered at a frequency of 300 Hz. The maximum force was obtained for each test and adjusted to bodyweight.

6.2.8 Eccentric exercise-induced fatigue protocol

Each subject was placed in the standing position on the isokinetic dynamometer. The shoulder was placed at 30° of abduction, 0° of external rotation, in the plane of the scapula (30° anterior to the frontal plane), with the elbow flexed at 90°, in mid-pronation and was strapped to the arm device. Each participant actively performed maximal voluntary eccentric isokinetic contractions from 60° of shoulder internal rotation to 60° of shoulder external rotation and back to induce eccentric muscle fatigue of the shoulder external and internal rotator muscles. Initially the examiner instructed each participant to perform 10 submaximal (20% of maximal voluntary contraction) eccentric contractions with angular speed 90 degrees per second to familiarize themselves with the specific movement. Next, peak isokinetic torque of internal and external rotators was recorded by asking the subject to perform 10 repetitions with maximal effort. This value was the reference value for induction of fatigue. After a 5 minutes rest period each participant performed sets of 15 maximal effort eccentric isokinetic contractions with 90 degrees per second angular speed of the external and internal rotator muscles. During the eccentric exercise for shoulder external rotation, participants were advised to resist a forced internal rotation caused by the dynamometer. They were asked to exert maximum effort from 60° of external rotation to 60° of internal rotation. Furthermore, during the eccentric exercise for shoulder internal rotation, participants were advised to resist a forced external rotation caused by the dynamometer. They were instructed to perform this resistance exercise strongly, moving from 60° of external rotation to 60° of internal rotation.

The criterion to consider muscle fatigue was the drop of the isokinetic peak torque to 40% of the reference value (60% reduction) and remain below this value, irrespective of positive reinforcement, for 3 consecutive repetitions. If the subject exceeded the reference value of peak torque in the first set, then the reference value was instantly updated and the same rule was used for the induction of fatigue. The sets needed to induced fatigue varied between one and five most commonly three. After the test, muscle fatigue was assessed by the percentage decrease in peak torque between the first ten and the last ten repetitions (mean peak torque of first ten repetition - mean peak torque of last ten repetition / mean peak torque of first ten repetition) during the 15 repetitions sets of isokinetic exercise at 90 deg/sec.

6.2.9 Statistical analysis

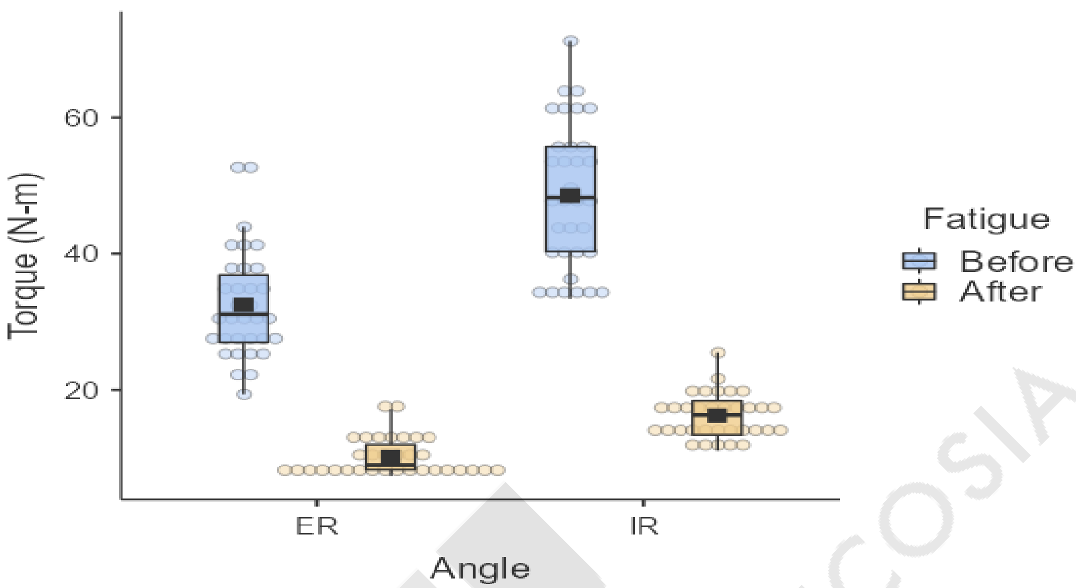
Jamovi (Version 2.3.26) was used for statistical analysis. Descriptive statistics were used to calculate means and standard deviations (±) of the collected variables. Shapiro-Wilk test was used to assess data for normality prior to the analysis. The paired samples t-test was used to compare the mean differences before and immediately after the fatigue intervention for the absolute angle error (AAE), the relative angle error (RAE), the threshold to detect of passive movement direction (TTDPMD), YBT-UQ and the ASH test scores. For the non-normally distributed variables, the Wilcoxon test was used for pre-post fatigue comparisons. Statistical significance was set at $p < 0.05$ and the 95% CI was calculated for all mean differences.

6.3 Results

A total of 33 professional male handball players (age= 25.7 ± 5.38 years; height= 179 ± 5.30 cm; weight= 83.5 ± 13.0 kg; body mass index= 26.0 ± 4.02 kg/m^2) from the first and second division of the Cypriot handball federation participated in the recruitment process. There were no drop-outs.

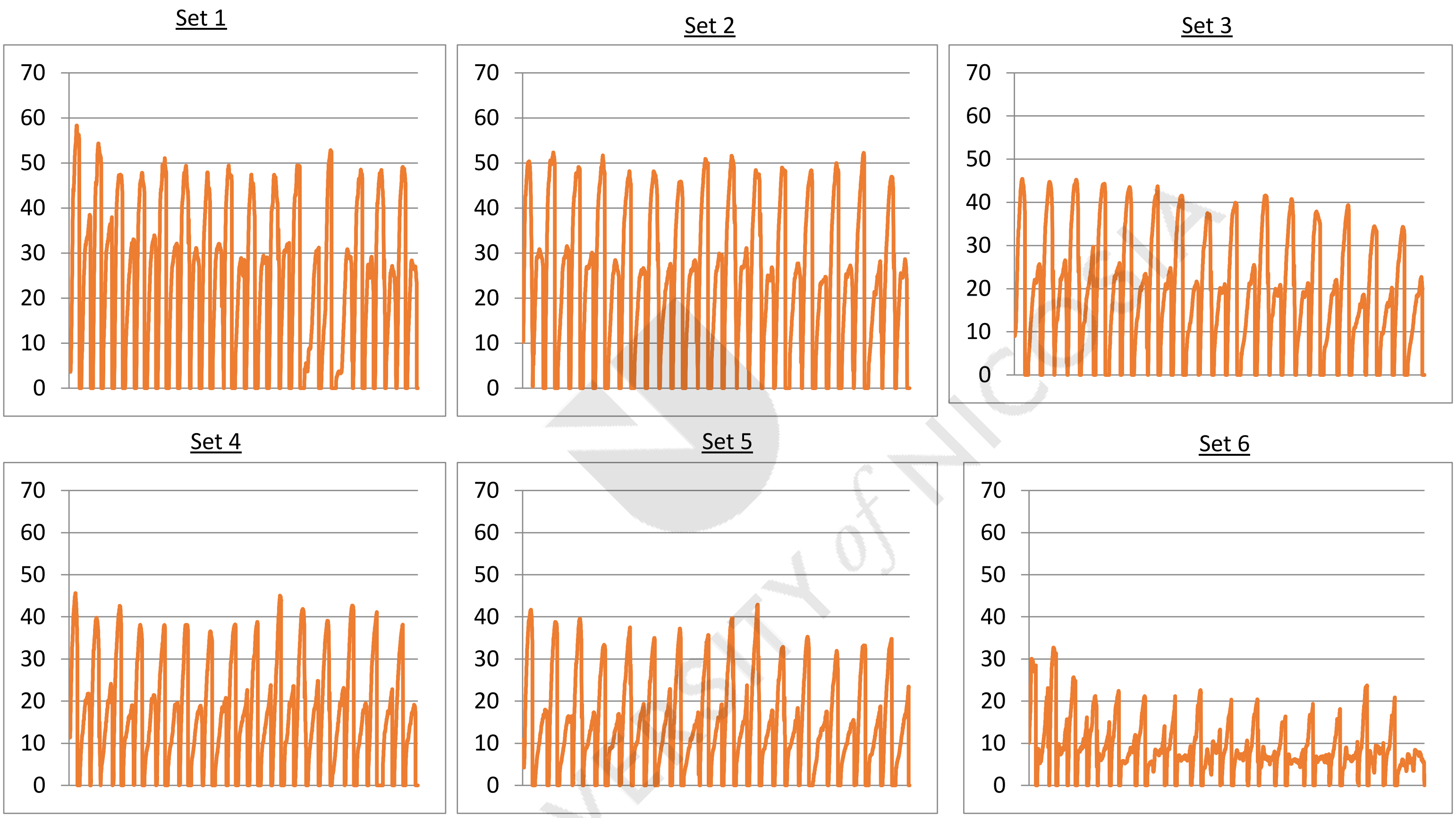
Following fatigue, the shoulder's internal rotation torque decreased by 66.53%, while the external rotation decreased by 68.85% (figure 6.1).

Figure 6.1. The torque of the shoulder's external rotation (ER) and internal rotation (IR) before and after the fatigue intervention



Every participant performed four to six sets, with each set consisting of fifteen repetitions (figure 6.2).

Figure 6.2. Illustration of muscle fatigue in a participant. The orange peaks in the diagram represent the torques exerted by the internal (high peaks) and external rotators (low peaks) throughout each repetition cycle. The subject completed a total of six sets, with each set consisting of 15 repetitions. The maximum torque was measured in each repetition. Confirmation of fatigue is apparent by comparing the highest points in the initial set to those in the last set.The scale of the y axis for all graphs is the same for quick visual comparison of the torque decline.



After fatigue, a significant increase ($p < 0.05$) in absolute angular error (table 6.2) was observed in five out of six target angles (ER15˚, ER30˚, ER45˚, IR15˚, and IR30˚). However there was no statistically significant difference in absolute angular error between pre and post fatigue intervention in the target angle IR45˚ ($p = 0.967$).

Table 6.2. AAE scores before and after fatigue intervention.

Variable	Target angles	Pre Fatigue	Post Fatigue	p value	Effect Size (95% CI)
AAE	$ER15^O$	1.95 ± 0.979	4.09 ± 1.801	< .001	-1.225 (-1.673, -0.7659)
AAE	$ER30^O$	2.78 ± 1.381	5.41 ± 2.261	< .001	-1.251 (-1.703, -0.7878)
AAE	$ER45^O$	2.53 ± 1.137	4.74 ± 2.142	< .001	-1.020 (-1.437, -0.5921)
AAE	$IR15^O$	2.22 ± 1.023	3.40 ± 1.724	0.001	-0.617 (-0.986, -2401)
AAE	$IR30^O$	3.08 ± 1.099	4.14 ± 2.356	0.017	-0.438 (-0.792, -0.0771)
AAE	$IR45^O$	2.69 ± 1.481	2.89 ± 1.747	0.967	-0.0108 (-0.833, 0.667)

AAE, absolute angular error; TTDPM, threshold to detection of passive movement; ER, external rotation; IR, internal rotation; ±, standard deviation; CI, confidence interval.

In addition, there was a significant increase in TTDPM (table 6.3) in internal rotation [mean (SD) pre = 5.18 (4.03), mean (SD) post = 6.70 (5.82), effect size = -1.50 (95% CI: -3.00, -0.500), p=0.011].

Table 6.3. TTDPM scores before and after fatigue intervention.

Variable	Pre Fatigue	Post Fatigue	p value	Effect Size (95% CI)
TTDPM	5.18 ± 4.03	6.70 ± 5.82	0.011	-1.50 (-3.00, -0.500)

Abbreviations: TTDPM, threshold to detection of passive movement; ±, standard deviation; CI, confidence interval.

YBT-UQ test (table 6.4) demonstated statististically significant differences in all reach directions to the right hand. However there were no statistically significantly differences in all reach directions to the left hand (p > 0.05). Furthermore, composite score (table 6.4) demonstrated a statistically significant difference only for the right hand (p < 0.001).

Table 6.4. YBT-UQ scores before and after fatigue intervention.

Variable	Pre Fatigue	Post Fatigue	p value	Effect Size (95% CI)
AM Right	90.6 ± 8.28	87.8 ± 8.80	0.005	0.519 (0.1514, 0.879)
IL Right	84.5 ± 11.55	78.5 ± 10.67	< .001	0.728 (0.3387, 1.108)
SL Right	64.9 ± 10.56	60.8 ± 12.02	< .001	0.779 (0.3838, 1.165)
AM Left	90.1 ± 7.43	89.3 ± 9.64	0.578	0.118 (-1.500, 3.00)
IL Left	83.0 ± 11.25	79.9 ± 10.49	0.071	0.415 (-5.27, 6.00)
SL Left	64.6 ± 11.40	62.3 ± 11.63	0.120	0.327 (-0.500, 4.00)
CS Right	86.2 ± 9.69	81.5 ± 9.93	< .001	4.28 (2.645, 6.54)
CS Left	85.4 ± 9.93	83.1 ± 9.63	0.231	1.15 (-0.585, 3.52)

AM, anteromedial; IL, inferolateral; SL, superolateral; CS, composite score; ±, standard deviation; CI, confidence interval

Moreover, following fatigue intervention, there was a significant reduction of the isometric strength in the ASH test mean scores (table 6.5) to all hand positions of the right side and at two positions of the left side ($p < 0.05$). There were no statistically significant differences ($p = 0.063$) to the “T” Left hand position.

Table 6.5. ASH test scores before and after fatigue intervention.

Variable	Pre Fatigue	Post Fatigue	p value	Effect Size (95% CI)
I Right	11.89 ± 3.05	10.52 ± 2.28	0.010	0.480 (0.1158, 0.837)
Y Right	10.72 ± 2.15	9.29 ± 2.00	< .001	0.924 (0.5100, 1.328)
T Right	9.81 ± 1.62	8.79 ± 1.74	< .001	0.841 (0.4377, 1.234)
I Left	11.48 ± 2.37	10.61 ± 2.31	0.002	0.573 (0.2009, 0.938)
Y Left	9.90 ± 2.18	9.08 ± 2.36	0.037	0.379 (0.0225, 0.729)
T Left	9.04 ± 1.65	8.58 ± 2.39	0.063	0.373 (-0.0400, 1.03)

I, Y and T, initial hand positions during the ASH test; ±, standard deviation; CI, confidence interval.

6.4 Discussion

The main objective of this study was to investigate the effects of eccentric exercise-induced fatigue of the shoulder rotator muscles on the proprioception, performance and motor control of male handball players. The null hypotheses were rejected. The current investigation substantiated the notion that eccentric exercise-induced fatigue has a significant adverse effect in upper limb proprioception (as measured by JRS and TTDPM) performance (ASH test) and motor control (as assessed by YBT-UQ).

The primary cause of shoulder disorders is attributed to rotator cuff muscle fatigue, which directly affects the kinematics of the humerus and scapula (Teyhen et al., 2008). Muscle fatigue, which arises from engaging in repetitive tasks, has a tendency to build up over time, leading to the development of musculoskeletal problems (Antony & Keir, 2010).

Exercise has the potential to disrupt proprioception, as seen by the heightened exertion experienced during periods of fatigue (Proske, 2019). Furthermore, there is data indicating that fatigue resulting from exercise can modify a person's perception of limb position. This is significant because the misalignment of limbs during physical activity and sports, caused by the impact of fatigue on the ability to perceive surroundings, might potentially lead to sports-related injuries (Proske, 2019).

6.4.1 Eccentric exercise-induced fatigue and Joint repositioning sense

The study's findings indicate that eccentric fatigue has a considerable negative impact on the shoulder joint repositioning sense in both external and internal rotation directions. After fatigue, the angular errors of the external rotation and internal rotation movements exhibited a mean percentage increase of 97.13% and 31.66% correspondingly. The higher percentage increase in angular errors during external rotation compared to internal rotation may be attributed to the longer fatigue resistance of internal rotator muscles in comparison to external rotator muscles (Ellenbecker and Roetert, 1999; Lee et al., 2003). The internal rotator muscle group is comprised of large muscles (e.g. latsissimus dorsi, pectoralis major). These muscles can produce greater forces than external rotator muscles resulting in greater fatigue resistance. The desensitization of the rotator cuff may have a greater impact on shoulder proprioception during external rotation compared to internal rotation. The observed disparity in active repositioning during external rotation between pre- and post-fatigue can be attributed to the heightened malfunctioning of mechanoreceptors in the external rotator muscle (Lee et al., 2003). The contribution of muscle spindles to the perception of joint position in various body segments is widely acknowledged (Proske, 2015). Nevertheless, it is plausible that the detrimental effects of eccentric exercise extend beyond the typical muscle fibers (Torres et al., 2010). The reduction in JPS can be conceptualized as a consequence of diminished muscle receptor input resulting from injury in the intrafusal fibers of spindle muscles (Proske & Allen, 2005). Brockett et al. (1997) found that both extrafusal and intrafusal fibers are affected by eccentric contractions, despite the fact that compliant connections may decrease intrafusal fiber strain (Brockett et al., 1997). In the event that the injured fibers undergo complete death or rupture, there would be a substantial decrease in spindle discharge levels.

However, conflicting results have been found in the study by Spargoli (2017). According to the researcher, neither eccentric nor concentric fatigue had a significant effect on shoulder proprioception. Furthermore, no significant differences were found between the 2 fatigue protocols. The non-significant finding may be attributed to the methodological disparities between the current study and Spargoli's investigation. The observed variations in methodology pertain to the sample size, the specific angles of repositioning, and the angular velocity. The study conducted by Spargoli encompassed both male and female individuals who were not athletes, whereas the current study exclusively focused on male handball athletes. Furthermore, the Spargoli study solely assessed a single specific angle of relocation, specifically 30 degrees of external rotation. In contrast, the current study assessed a total of six specific repositioning angles (15º, 30˚, and 45˚) in both internal and external rotation, with equal emphasis placed on each angle. In addition, Spargoli employed a 180° angular velocity to generate fatigue, whereas the current work utilized a 90˚ angular velocity which is more likely to induce fatigue.

6.4.2 Eccentric exercise-induced fatigue and threshold to detection of passive motion

The current study assessed the influence of muscle fatigue on shoulder kinesthesia using the TTDPM and determined that it had an adverse impact. One possible explanation is that muscular tiredness causes a reduction in the sensitivity of muscle receptors, which play a major role in providing kinesthetic information (Proske and Gandevia, 2012).

Thus far, there has been a lack of research examining the impact of eccentric exercise-induced fatigue on the TTDPM at the shoulder. The majority of research examining the impact of eccentric exercise-induced fatigue focused on other aspects of proprioception, such as the sensation of joint repositioning and the sense of force reproduction. Hence, additional investigation is required to confirm the findings of the current study.

6.4.3 Eccentric exercise-induced fatigue and Y balance upper quarter test

The present study provided confirmation of the diminished motor control of the upper limb resulting from eccentric exercise-induced fatigue of the rotator cuff muscles. The right limb had a more pronounced deficit in all directions (AM, AL, IL) and in the composite score when compared to the left limb. Afferent proprioceptive feedback from peripheral mechanoreceptors is a crucial component of neuromuscular regulation (Myers and Lephart, 2000). The information from the visual and vestibular systems is combined with afferent proprioceptive feedback at the CNSto generate spinal reflexes, cognitive programming, and balance (Lephart & Henry, 1996). These factors collectively influence muscle movement through efferent responses (Akay & Murray, 2021). The co-contraction response of the force-couple musculature is induced by the stimulation of the articular mechanoreceptors, which occurs as a result of the compression of the humeral head in the glenoid fossa with the closed kinetic chain posture (Wilk et al., 1993; Tippett, 1992). The fatigue experienced by the mechanoreceptors located in the force-couple musculature has a direct impact on the shoulder's capacity to retract in the closed kinetic chain position. Consequently, this fatigue has implications for the individual's ability to sustain the single arm push-up position (Myers et al., 1999).

So far there is limited research examining the impact of eccentric exercise-induced upper limb fatigue on YBT-UQ. Nevertheless, Singh et al (2023) conducted a study which aimed to investigated the immediate impact of eccentric knee exercises on dynamic balance in both athletes and nonathletes, utilizing the YBT-LQ test. The primary finding of this study indicated that there was no statistically significant reduction in CS following a brief period of physical activity among the participants. Moreover, no statistically significant disparity in CS was seen between athletes and non-athletes on the left side. However, a notable disparity was observed on the right side between athletes and non-athletes following a brief period of eccentric knee exercises. Athletes had a marginal decline in left CS and a marginal rise in right CS. In those who were not athletes, there was a marginal reduction in CS on both sides. The disparity in performance between nonathletes and athletes may be attributed to the fact that trained athletes had superior muscle strength, which perhaps mitigated the tiredness experienced by the athletic population. Given the scarcity of studies, additional research is required to ascertain the impact of eccentric fatigue of the rotator cuff on motor control in the current study.

6.4.4 Eccentric exercise-induced fatigue and ASH test

The results of this study demonstrate that eccentric exercise-induced fatigue can lead to a substantial decrease in isometric strength of the upper limb during the ASH test. The right limb (exercised limb) exhibited a higher average percentage decline (11.74%) in isometric strength compared to the left side (6.96%). Prior research has shown that strength is typically diminished immediately after eccentric exercise, followed by a gradual recovery over a period of hours (Journal et al., 1981; Newham et al., 1983), days (Byrne & Eston, 2002; Golden and Dudley, 1992; Hortoba et al., 1998), or even weeks (Clarkson et al., 1992; Cleak & Dpe, 1992) . Nevertheless, in the aforementioned studies, the decrease in strength can be attributed to eccentric exercise-induced muscle damage. In the current study, it seems plausible that the decrease in isometric strength can be attributed to muscle fiber injury due to eccentric exercise. However, confirmation is not possible as hematological markers of muscle injury have not been evaluated.

One feature of skeletal muscle fatigue is a decrease in isometric force output (Westerblad et al., 1998). During fatigue, the loss in force can be separated into two parts: an early decrease in the ability of cross-bridges to generate force, and a late decrease in the release of calcium ions from the sarcoplasmic reticulum (Westerblad et al., 1998). Lactic acid accumulation leading to acidification has been identified as a significant factor contributing to the decrease in cross-bridge force production (Cairns, 2006). The incapacity to produce an initial increase in force and strength is contingent upon factors that transpire at or beyond the neuro-muscular junction (peripheral fatigue) and a lack of voluntary muscle activation (central fatigue) (Westerblad et al., 1998).

6.4.5 Limitations

The impact of eccentric exercise induced-fatigue on females is uncertain as the current study only included male participants. Ultimately, the process of inducing tiredness was conducted using the isokinetic dynamometer. The muscle exhaustion experienced by handball players in real-life situations, such as repetitive throwing actions, sprinting, and jumping, is distinct from the tiredness reported in controlled laboratory environments.

6.5 Conclusions

Eccentric exercise-induced fatigue of the rotator cuff in the shoulder can result in a notable disruption in shoulder's joint position sense and kinesthesia. In addition, this fatigue can also lead to reduced stability and mobility of the upper limb, as well as a protracted decline in isometric strength. Further research is required to examine the impact of eccentric exercise-induced fatigue on the shoulder joint across all subcategories of proprioception, as well as the motor control of the upper limb.

Chapter 7.0: General discussion

Handball players due to the nature of the sport have a high incidence of shoulder injuries (Clarsen et al., 2014). A significant proportion of these injuries result in athletes being unable to participate in their sports activities, hence diminishing their sports performance (Asker et al., 2018). This thesis aims to contribute in the understanding of shoulder injuries in handball and specifically the influence on muscle fatigue on known risk factors for those injuries. Injury reduction strategies and preventive interventions require understanding of the various risk factors for shoulder injuries (Achenbach et al., 2020) in handball. So far, no systematic review summarizing the known risk factors for shoulder injuries in handball existed. As part of this thesis project, a systematic review was conducted to investigate risk factors for shoulder injury in handball athletes (Hadjisavvas et al., 2022). Various risk factors have been identified among which were the strength and ROM imbalances, inappropriate increase in training load, motor control of the scapula, player's position and level and altered joint position sense. Muscle fatigue is closely linked to several ,if not all, of these factors (Anderson et al., 2003; Piggott et al., 2009; Gabbett, 2016). Previous studies suggested that fatigue can cause disturbances in the neuromuscular system, increasing the risk of injury (Myers et al., 1999; Lee et al., 2003) and that most of the injuries happen towards the end of the game (Hiemstra et al., 2001; Steib et al., 2013) where fatigue is already induced.

The shoulder joint repositioning sense in handball athletes was significantly reduced by both concentric and eccentric exercise-induced fatigue, as evidenced by the increased repositioning errors after fatigue. Concentric exercise-induced fatigue had a more pronounced negative impact on joint position sense than eccentric exercise-induced fatigue as shown by the larger effect sizes of concentric fatigue on AAEs. Thus far, only a solitary study has compared the impact of eccentric and concentric exercise-induced fatigue on shoulder joint position sense (Spargoli, 2017). However, in Spargoli's study, shoulder joint position sense was not significantly affected in both fatigue protocols (Spargoli, 2017). The more repositioning examination angles (three versus one), the larger sample, and different sample (male handball athletes versus male and female healthy adults) may explain the statistically significant result found in the present thesis in contrast to Spargoli's (2017) study. Although inconclusive evidence was found regarding the effect of joint position sense on injury risk (Hadjisavvas et al., 2022), mainly due to the lack of sufficient number of investigations, the laboratory results of this thesis suggest that there is need for further prospective studies looking at the mediation of altered joint position sense in shoulder injuries in handball players.

A notable discovery in the current study was that the perception of shoulder repositioning at the desired angles was significantly influenced by the direction of rotation of the shoulder. Specifically, the average percentage increase of the inaccurate detection of joint angle was 115.14% in the external rotation direction and 58.3% in the internal rotation direction. The higher percentage increase in angular errors during external rotation compared to internal rotation may be attributed to the longer fatigue resistance of internal rotator muscles compared to external rotator muscles (Ellenbecher and Roetert, 1999) and/or to the heightened malfunctioning of mechanoreceptors in the external rotator muscles (Lee et al., 2003). When designing an exercise program to strengthen the rotator cuff, it is essential to note that the external rotator cuff exercises should be performed with a different volume and intensity than the internal rotator cuff exercises, especially in the novice stage. The increased tiredness in the external rotators will have a more significant negative impact on the shoulder's proprioception.

Shoulder kinesthesia was also reduced as evident from the delay to detect passive movement onset after muscle fatigue. Concentric and eccentric exercise-induced fatigue had a similar percentage increase in TTDPM, recording 25.04% and 29.34% increases, respectively. This result suggests that all forms of vigorous athletic activity that involve either eccentric or concentric contractions or a combination are capable of causing kinesthetic impairment.

Impaired shoulder joint proprioception and kinesthesia, along with concentric and eccentric fatigue, seem to result in reduced motor control of the upper limb, as evaluated by the Y balancing test upper quarter. Prior research examining the correlation between YBT-UQ performance and injury occurrence during the competitive season had demonstrated that if the Superolateral reach distance score is below 80.1% of the length of the upper limb, then there is an elevated risk of injury (Teyhen et al., 2014). In addition, if the composite score of the right upper limb falls between 77% to 88.9% of the limb's entire length, there is an elevated risk of injury (Cosio-Lima, 2016). However, these two studies (Teyhen et al., 2014; Cosio-Lima, 2016) pertain only to military and naval security response team members rather than handball players. Considering these reference values, in the present study, after applying concentric exercise-induced fatigue, the composite score in the right upper extremity was on average 91% of the total length of the upper extremity. On the contrary, after the application of eccentric exercise-induced fatigue, there was a more significant reduction in the composite score (87.6% of the total length of the upper limb). Furthermore, in the superolateral reach distance in the exercised hand, the results showed 66.83% and 65.51% scores of the total length of the upper limb after applying concentric and eccentric exercise-induced fatigue, respectively. The results suggest that fatigue can substantially decline YBT-UQ performance, heightening the likelihood of upper extremity injury. Nevertheless, conducting comparable research with a sample of throwing athletes is essential to accurately extrapolate reference values to such athletes. Based on the present findings, it is recommended that handball athletes assess the stability and mobility of their upper extremities before and after experiencing fatigue, whether in a controlled laboratory setting or during a real match. If a significant decline in performance is observed immediately after fatigue during the Y Balance Test-Upper Quarter (YBT-UQ), a tailored workout program that specifically targets the improvement of motor control in the upper extremities might be warranted to reduce risk of injury.

The findings of this study reveal that only eccentric exercise-induced fatigue in the shoulder rotator muscles can significantly reduce the isometric strength performance of the upper limb during the ASH test in handball athletes. Eccentric exercise-induced fatigue results in a more significant reduction in shoulder isometric strength than concentric exercise-induced fatigue due to the accompanied microtrauma within the contractile elements of the muscle, resulting in a more significant reduction in force production (Proske, 2019).

Another notable discovery from the current study was that concentric exercise-induced fatigue resulted in a more significant decrease in isometric strength in the non-fatigued left upper extremity. The lack of statistical significance in the right upper extremity, where fatigue was applied, may be attributed to the ASH test being the final test analyzed in the series following the fatigue protocol. Due to this time interval between the fatigue protocol and the ASH test, it is possible that there was a recovery of strength. Alternatively, the significant results of eccentric fatigue suggest that muscle damage and not fatigue might be the crucial factor in reducing performance. Chang et al. (2006) supported this idea, concluding that the restoration of shoulder muscular strength occurred faster than the recovery of shoulder joint position sense following fatigue. There was only one direction of the left non-exercised arm affected by concentric fatigue. This can be due to chance. Alternatively, the dominant arm (fatigued right arm) in handball athletes is likely to be more resistant to the ability to produce maximal isometric force even under fatigued conditions compared to the non-dominant arm due to neuromuscular adaptations (Escamilla et al., 2018). The reduction in the force production of the left, non-fatigued side might also be due to reduced stabilization from the opposite side (right) during the test post-fatigue. Although plausible, due to the way the test was performed this is unlikely, as the opposite hand was positioned behind the back to reduce the effect of stabilization. In addition, this is purely speculatively, as no studies exist to support this claim.

Upon comparing the mean effect of concentric fatigue across each testing location, there was an obvious decline from the first position (I) to the last position (T) in handball players. Multiple factors may have contributed to these disparities. The initial position, the "I" position, was the first to be measured and potentially the most prone to tiredness. The "I" position is an elevated position that offers the highest level of stability and involves the activation of significant muscles, specifically the latissimus dorsi, in comparison to the "Y" and "T" positions, which primarily engage the pectoral muscles. According to Donohue et al. (2017), the "Y" and "T" postures were used to imitate the participant's throwing technique. Interestingly, eccentric fatigue induced larger reductions in Y and T positions which suggest muscle damage might have different impact than fatigue in handball players.

Decreased shoulder isometric strength is considered a risk factor for shoulder injuries in throwing athletes (Hadjisavvas et al., 2022). This is a novel contribution to the field, if further research establishes a causal relationship between the decline in isometric strength shown in the ASH test and upper extremity injuries in handball. This new understanding can potentially revolutionize the way we approach injury prevention in throwing athletes.

The ASH test is quick, easy, and reliable; for this reason, it should be applied to throwing athletes during the pre-competition period to detect any imbalances in the maximal isometric strength capacity. If the athlete exhibits a notable decline in isometric strength in particular arm positions, it is advisable to implement strengthening workouts targeting the specific angle of the joint. This will rectify the imbalance and mitigate the risk of injuries resulting from diminished isometric strength.

The findings of this thesis indicate that non-athletes experience a more significant disruption in their ability to feel the location of their shoulder joint after exercise-induced fatigue compared to handball athletes. The non-athletes exhibited a 103.35% increase in the mean percentage value of the absolute angular inaccuracy of both ER and IR angles compared to handball players. Handball athletes showed an increase in absolute angular error of 64.44% and 94.91% after corresponding eccentric and concentric exercise-induced fatigue despite similar fatigue as demonstrated by fatigue index. The more extraordinary ability of athletes in the ability to detect the angle of repositioning compared to non-athletes was also demonstrated in previous studies (Shafipour & Shojaedin, 2014; Nodeghi-Moghadam et al., 2013; Morraveji et al., 2017; Niespodzinski et al., 2022). One potential reason for the reduced negative impact of fatigue on shoulder joint position sense in handball athletes, as opposed to non-athletes, could be attributed to the superior neuromuscular adaptations resulting from regular sport-specific training and the nature of the sport. Also, athletes can adapt better to fatigue than non-athletes. Another finding from this thesis is that exercise-induced fatigue in the rotator cuff of the shoulder can decrease the reflex reaction time of the external rotators following a rapid and unforeseen external disturbance in shoulder movement. After fatigue, although there was a significant percentage increase (47.34%) in the reflex reaction time, this increase was not statistically significant. The average timing of the overarm throw in team handball was estimated to be 0.174 sec during the cocking phase, 0.024 sec during the acceleration phase and 0.01 sec during the deceleration phase (Van den Tillar and Ettema, 2007). If during the cocking phase there is a delay in the activation of the internal rotator muscles then there will be a risk of injury to the anterior capsuloligamentous structures of the shoulder due to excessive accumulation of tensile loads and in later stages anterior instability (Meister, 2000). The capsuloligamentous structures will experience laxity as a result of the tensile loads. This laxity will result in a decrease in the sensitization of capsuloligamentous mechanoreceptors disrupting shoulder proprioception. Also, due to laxity there will be a delay in ligament-muscular reflexes creating a vicious cycle and the risk of shoulder injury. Furthermore, if the internal rotators are delayed, there will not be enough eccentric contraction to decelerate external rotation adequately. This will cause uncontrolled and excessive external rotation of the shoulder causing an accumulation of compressive loads on its posterior surface with the possibility of causing internal impingement syndrome (Wilk et al., 2009). However, if there is a delay in activating the external rotators during the deceleration phase, excessive tensile loads will be applied to these muscles. This is because there is not enough eccentric torque to decelerate the internal rotation of the shoulder, which can lead to tendinopathy in the external rotator muscles (Wilk et al., 2009). Although the results were not statistically significant, there is no way to judge if they are clinically significant as no reference value exists for the delay of muscle contaction in shoulder external rotators. No research has been conducted to investigate how rotator cuff muscle fatigue affects reflex reaction time. However, the present study revealed higher delay in MOL compared to previous studies (Granata et al., 2004; Chang et al., 2006; Behrens et al., 2013; Sun et al., 2021).

Due to this dysfunction of neuromuscular control because of fatigue, athletes should include various exercises in their training program to improve reflex neuromuscular control (Prentice, 2020). According to McComas (1994), strength training enhances the transmission of signals from the brain to the motor neurons and muscle spindles in skeletal muscles. This phenomenon is known as alpha-gamma coactivation. Enhancing both the level of muscular tension and the efferent drive to muscle spindles leads to an increased sensitivity to stretch, hence shortening the time it takes for reflexes to occur. Ihara and Nakayama (1986) substantially decreased the time it takes for muscles to react by subjecting patients to disturbances on unstable platforms over three weeks (Ihara and Nakayama, 1986). Subsequent researchers further validated this discovery by implementing rehabilitation programs to enhance reflex muscle activation; according to Beard et al. (1994) and Wojtys et al. (1996), agility-type training in the lower extremities results in more favorable muscle reaction times than strength training (Beard et al., 1994; Wojtys et al., 1996). In addition, Caraffa et al. (1995) effectively decreased knee injuries in soccer players who engaged in reactive-type training (Caraffa et al., 1995). Reactive neuromuscular training centers on activating the reflex circuits that connect the joints, tendons, and muscles. While preprogrammed muscle stiffness can improve the responsiveness of muscles by decreasing the time it takes for reflexes to occur, the goal is to create unexpected joint disturbances that promote reflex stability.

Consistent utilization of these reflex pathways can reduce the time it takes to respond and cultivate adaptive solutions for unforeseen joint perturpations.

According to Prentice (2020), to improve the neuromuscular reflex response of the upper limbs, the following exercises are recommended:

- Shoulder stabilization exercises utilizing unstable surfaces to enhance dynamic stability.
- Three closed-chain exercises that promote coactivation in the shoulder are push-ups, horizontal abduction on a slide board, and circular motions on a slide board using both the dominant and nondominant arms.
- Plyometric workouts that involve different ball weights and distances are highly effective for conditioning and activating muscles in preparation and response.
- Manually disturbing the upper extremity as the patient tries to maintain a stable position enhances reactive neuromuscular properties.

Based on the significant findings of this study, it is strongly recommended to incorporate reflex neuromuscular control training even when the athlete is fatigued. This training can increase the sensitivity of the receptors involved in reflex arc formation, thereby reducing the detrimental impact of fatigue on neuromuscular control. This is a crucial step in improving the athlete's performance and reducing the risk of injury.

7.1 Strengths and limitations

One of the strengths of this thesis was the innovation of the topic. Based on the literature assessment, there was a need for more research that specifically examines the impact of tiredness on shoulder proprioception. Therefore, the implementation of the current study became more imperative. In addition, in the present research, the effect of fatigue on the reflex reaction time of the shoulder was evaluated for the first time, as well as the stability/mobility of the shoulder through the YBT-UQ test. One unique aspect of the current research was using eccentric exercise to create fatigue in one of the three experimental investigations. The ASH test was also used to evaluate the upper limb's isometric strength. Currently, a limited amount of research has assessed the fatigue of the shoulder muscles during eccentric contractions, specifically in relation to the proprioception of the upper extremity. Finally, the participation of handball athletes in the study enhances the specificity of the results in a population with the high prevalence of shoulder injuries.

Only adult male handball athletes and male non-athletes were included in the three experimental investigations. In the sport of handball, both males and females participate extensively. Furthermore, adolescent athletes also exhibit significant involvement. Consequently, the findings of this thesis can only be applied to adult male handball players, which is a limitation. In addition, the induction of fatigue was carried out on the isokinetic dynamometer. While the isokinetic dynamometer is a reliable tool for measuring tiredness, the fatigue experienced by athletes in real settings may differ due to the excessive accumulation of training loads and the high number of ball throws. Furthermore, the reflex reaction time, a novel assessment method for this subject, was exclusively employed in the study involving the application of concentric fatigue to handball athletes. Currently, the impact of eccentric rotator cuff muscle exhaustion on reflex reaction time is still uncertain.

In the future, it is imperative to carry out research that possess the following methodological attributes:

- Prospective studies examining the correlation between risk variables and shoulder injuries in handball athletes.
- Studies examining the impact of a preventative intervention (designed to address risk factors) on decreasing the occurrence of shoulder injuries.
- Studies investigating the effect of concentric and eccentric fatigue in female handball players as well as adolescent handball players.
- Studies examining the correlation between proprioception/kinaesthesia of the upper extremities with motor control and performance.
- Studies examining the process by which the decline in proprioception, motor control, and performance occurs.

- Studies that will evaluate the effect of shoulder muscle fatigue on other subcategories of proprioception (e.g. sense of force reproduction).

References

1. Aaronson LS, Teel CS, Cassmeyer V, Neuberger GB, Pallikkathayil L, Pierce J, Press AN, Williams PD, Wingate A. Defining and measuring fatigue. Image J Nurs Sch. 1999;31(1):45-50.
2. Aasheim C, Stavenes H, Andersson SH, Engbretsen L, Clarsen B. Prevalence and burden of overuse injuries in elite junior handball. BMJ Open Sport Exerc Med. 2018;4(1):e000391.
3. Abd-Elfattah HM, Abdelazeim FH, Elshennawy S. Physical and cognitive consequences of fatigue: A review. Journal of Advanced Research. 2015;6:351–8.
4. Acharya, A. S., Prakash, A., Saxena, P., & Nigam, A. Sampling: Why and how of it. Indian Journal of Medical Specialties. 2013;4(2): 330-333.
5. Achenbach L, Laver L, Walter SS, Zeman F, Kuhr M, Krutsch W. Decreased external rotation strength is a risk factor for overuse shoulder injury in youth elite handball athletes. Knee Surg Sports Traumatol Arthrosc. 2020;28(4):1202-1211.
6. Achenbach L, Loose O, Laver L, Zeman F, Nerlich M, Angele P, Krutsch W. Beach handball is safer than indoor team handball: injury rates during the 2017 European Beach Handball Championships. Knee Surg Sports Traumatol Arthrosc. 2018;26(7):1909-1915.
7. Ager AL, Borms D, Deschepper L, Dhooghe R, Dijkhuis J, Roy JS, Cools A. Proprioception: How is it affected by shoulder pain? A systematic review. J Hand Ther. 2020;33(4):507-516.
8. Ahmad, S., Wasim, S., Irfan, S., Gogoi, S., Srivastava, A. and Farheen, Z. Qualitative v/s. quantitative research-a summarized review. Population. 2019;1(2):2828-2832.
9. Akay T, Murray AJ. Relative Contribution of Proprioceptive and Vestibular Sensory Systems to Locomotion: Opportunities for Discovery in the Age of Molecular Science. Int J Mol Sci. 2021;22(3):1467.
10. Albanese GA, Marini F, Morasso P, Campus C, Zenzeri J. μ-band desynchronization in the contralateral central and central-parietal areas predicts proprioceptive acuity. Front Hum Neurosci. 2023;17.
11. Allegrucci M, Whitney SL, Lephart SM, Irrgang JJ, Fu FH. Shoulder kinesthesia in healthy unilateral athletes participating in upper extremity sports. J Orthop Sports Phys Ther. 1995;21(4):220-6.
12. Allison GT, Fukushima S. Estimating three-dimensional spinal repositioning error: the impact of range, posture, and number of trials. Spine (Phila Pa 1976). 2003;28(22):2510-6.
13. Allman BL, Rice CL. Neuromuscular fatigue and aging: central and peripheral factors. Muscle Nerve. 2002;25(6):785-96.
14. Almeida GP, Silveira PF, Rosseto NP, Barbosa G, Ejnisman B, Cohen M. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. J Shoulder Elbow Surg. 2013;22(5):602-7.
15. Alvi MA manual for selecting sampling techniques in research. In Munich Personal. 2016

16. Ament W, Verkerke GJ. Exercise and fatigue. Sports Med. 2009;39(5):389-422.
17. Anderson L, Triplett-McBride T, Foster C, Doberstein S, Brice G. Impact of training patterns on incidence of illness and injury during a women's collegiate basketball season. J Strength Cond Res. 2003;17(4):734-8.
18. Anderson VB, Wee E. Impaired joint proprioception at higher shoulder elevations in chronic rotator cuff pathology. Arch Phys Med Rehabil. 2011;92(7):1146-51.
19. Andersson SH, Bahr R, Clarsen B, Myklebust G. Risk factors for overuse shoulder injuries in a mixed-sex cohort of 329 elite handball players: previous findings could not be confirmed. Br J Sports Med. 2018;52(18):1191-1198.
20. Andrade MDS, Fleury AM, de Lira CAB, Dubas JP, da Silva AC. Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. Journal of Sports Sciences. 2010;28:743–9.
21. Antony NT, Keir PJ. Effects of posture, movement and hand load on shoulder muscle activity. J Electromyogr Kinesiol. 2010;20(2):191-8.
22. Arzi H, Krasovsky T, Pritsch M, Liebermann DG. Movement control in patients with shoulder instability: a comparison between patients after open surgery and nonoperated patients. J Shoulder Elbow Surg. 2014;23(7):982-92.
23. Asembo JM, Wekesa M. Injury pattern during team handball competition in east Africa. East Afr Med J. 1998;75(2):113-6.
24. Ashworth B, Hogben P, Singh N, Tulloch L, Cohen DD. The Athletic Shoulder (ASH) test: Reliability of a novel upper body isometric strength test in elite rugby players. BMJ Open Sport Exerc Med. 2018;4.
25. Asker M, Brooke HL, Waldén M, Tranaeus U, Johansson F, Skillgate E, Holm LW. Risk factors for, and prevention of, shoulder injuries in overhead sports: a systematic review with best-evidence synthesis. Br J Sports Med. 2018;52(20):1312-1319.
26. Asker M, Holm LW, Källberg H, Waldén M, Skillgate E. Female adolescent elite handball players are more susceptible to shoulder problems than their male counterparts. Knee Surgery, Sports Traumatology, Arthroscopy. 2018;26:1892–900.
27. Asker M, Waldén M, Källberg H, Holm LW, Skillgate E. Preseason Clinical Shoulder Test Results and Shoulder Injury Rate in Adolescent Elite Handball Players: A Prospective Study. J Orthop Sports Phys Ther. 2020;50(2):67-74.
28. Bahr MA, Bahr R. Jump frequency may contribute to risk of jumper's knee: a study of interindividual and sex differences in a total of 11,943 jumps video recorded during training and matches in young elite volleyball players. Br J Sports Med. 2014;48:1322–6.
29. Bard C, Fleury M, Teasdale N, Paillard J, Nougier V. Contribution of proprioception for calibrating and updating the motor space. Can J Physiol Pharmacol. 1995;73(2):246-54.
30. Barden JM, Balyk R, Raso VJ, Moreau M, Bagnall K. Dynamic upper limb proprioception in multidirectional shoulder instability. Clin Orthop Relat Res. 2004;(420):181-9.
31. Barrack RL, Skinner HB, Cook SD. Proprioception of the knee joint. Paradoxical effect of training. Am J Phys Med. 1984;63(4):175-81.
32. Basmajian JV. Muscles alive. Their functions revealed by electromyography. Academic Medicine. 1962;37(8):802.

33. Bauer J, Hagen M, Weisz N, Muehlbauer T. The Influence of Fatigue on Throwing and YBT-UQ Performance in Male Adolescent Handball Players. Front Sports Act Living. 2020;2:81.
34. Bauer J, Schwiertz G, Muehlbauer T. Differences in Upper Quarter Y Balance Test Performance According to Playing Position in Youth Handball Players. 2020 (preprint).
35. Baxendale RH., Ferrell WR. Disturbances of proprioception at the human knee resulting from acute joint distension. J Physiol. 1987;392:60.
36. Bayios IA, Anastasopoulou EM, Sioudris DS, Boudolos KD. Relationship between isokinetic strength of the internal and external shoulder rotators and ball velocity in team handball. J Sports Med Phys Fitness. 2001;41(2):229-35.
37. Bayramoglu M, Toprak R, Sozay S. Effects of osteoarthritis and fatigue on proprioception of the knee joint. Arch Phys Med Rehabil. 2007;88(3):346-50.
38. Beard DJ, Kyberd PJ, O'Connor JJ, Fergusson CM, Dodd CA. Reflex hamstring contraction latency in anterior cruciate ligament deficiency. J Orthop Res. 1994;12(2):219-28.
39. Bedo BLS, Manechini JPV, Nunomura M, Menezes RP et al. Injury frequency in handball players: a descriptive study of injury pattern in São Paulo state regional teams. Motriz: Revista de Educação Física. 2019; 25:e101980.
40. Beelen A, Sargeant AJ. Effect of fatigue on maximal power output at different contraction velocities in humans. J Appl Physiol. 1991;71(6):2332-7.
41. Behrens M, Mau-Moeller A, Wassermann F, Bruhn S. Effect of Fatigue on Hamstring Reflex Responses and Posterior-Anterior Tibial Translation in Men and Women. PLoS One. 2013;8.
42. Bekker S, Clark AM. Bringing complexity to sports injury prevention research: From simplification to explanation. British Journal of Sports Medicine. 2016;50:1489–90.
43. Bellemare F, Bigland-Ritchie B. Central components of diaphragmatic fatigue assessed by phrenic nerve stimulation. J Appl Physiol. 1987;62(3):1307-16.
44. Benjaminse A, Sell TC, Abt JP, House AJ, Lephart SM. Reliability and precision of hip proprioception methods in healthy individuals. Clin J Sport Med. 2009;19(6):457-63.
45. Bere T, Alonso JM, Wangensteen A, Bakken A, Eirale C, Dijkstra HP, Ahmed H, Bahr R, Popovic N. Injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar. Br J Sports Med. 2015;49(17):1151-6.
46. Bigland-Ritchie B, Cafarelli E, Vøllestad NK. Fatigue of submaximal static contractions. Acta Physiol Scand Suppl. 1986;556:137-48.
47. Bigland-Ritchie B, Donovan EF, Roussos CS. Conduction velocity and EMG power spectrum changes in fatigue of sustained maximal efforts. J Appl Physiol Respir Environ Exerc Physiol. 1981;51(5):1300-5.
48. Bigland-Ritchie B, Johansson R, Lippold OC, Smith S, Woods JJ. Changes in motoneurone firing rates during sustained maximal voluntary contractions. J Physiol. 1983;340:335-46.

49. Bigland-Ritchie B, Jones DA, Woods JJ. Excitation frequency and muscle fatigue: electrical responses during human voluntary and stimulated contractions. Exp Neurol. 1979;64(2):414-27.
50. Bigland-Ritchie B, Woods JJ. Changes in muscle contractile properties and neural control during human muscular fatigue. Muscle Nerve. 1984;7(9):691-9.
51. Bigliani LU, Levine WN. Subacromial impingement syndrome. J Bone Joint Surg Am. 1997;79(12):1854-68.
52. Bittencourt NFN, Meeuwisse WH, Mendonça LD, Nettel-Aguirre A, Ocarino JM, Fonseca ST. Complex systems approach for sports injuries: Moving from risk factor identification to injury pattern recognition - Narrative review and new concept. British Journal of Sports Medicine. 2016;50:1309–14.
53. Björklund, M., Crenshaw, A. G., Djupsjöbacka, M., & Johansson, H. Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. European journal of applied physiology. 2000;81:361-367.
54. Blasier RB, Carpenter JE, Huston LJ. Shoulder proprioception. Effect of joint laxity, joint position, and direction of motion. Orthop Rev. 1994;23(1):45-50.
55. Boerboom AL, Huizinga MR, Kaan WA, Stewart RE, Hof AL, Bulstra SK, et al. Validation of a method to measure the proprioception of the knee. Gait Posture. 2008;28:610–4.
56. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. Sports Med. 2008;38(1):17-36.
57. Bosco G, Poppele RE. Proprioception from a spinocerebellar perspective. Physiol Rev. 2001;81(2):539-68.
58. Boyas S, Guével A. Neuromuscular fatigue in healthy muscle: underlying factors and adaptation mechanisms. Ann Phys Rehabil Med. 2011;54(2):88-108.
59. Boyas S, McGown C, Lajoie Y, Bilodeau M. Changes in posture associated with postural control impairment induced by ankle plantarflexor fatigue during unipedal quiet standing. Neuroscience Letters. 2013;547:48–52.
60. Braun S, Kokmeyer D, Millett PJ. Shoulder injuries in the throwing athlete. J Bone Joint Surg Am. 2009 Apr;91(4):966-78.
61. Brito J, Fontes I, Ribeiro F, Raposo A, Krustrup P, Rebelo A. Postural stability decreases in elite young soccer players after a competitive soccer match. Phys Ther Sport. 2012;13(3):175-9.
62. Brockett, C., Warren, N., Gregory, J. E., Morgan, D. L., Proske, U. A comparison of the effects of concentric versus eccentric exercise on force and position sense at the human elbow joint. In Brain Research. 1997;771.
63. Brumagne S, Cordo P, Lysens R, Verschueren S, Swinnen S. The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. Spine. 2000;25(8):989-94.
64. Burgess PR, Clark FJ. Characteristics of knee joint receptors in the cat. J Physiol. 1969;203(2):317-35.

65. Burgess PR, Wei JY, Clark FJ, Simon J. Signaling of kinesthetic information by peripheral sensory receptors. Annu Rev Neurosci. 1982;5:171-87.
66. Burke D, Gandevia SC, Macefield G. Responses to passive movement of receptors in joint, skin and muscle of the human hand. J Physiol. 1988;402:347-61.
67. Butt MT, Bradley A, Sills R. Nervous system. In Toxicologic Pathology. CRC Press. 2018;1093-1132.
68. Byrne C, Eston R. Maximal-intensity isometric and dynamic exercise performance after eccentric muscle actions. J Sports Sci. 2002;20(12):951-9.
69. Cairns SP. Lactic acid and exercise performance: culprit or friend? Sports Med. 2006;36(4):279-91.
70. Caron O. Effects of local fatigue of the lower limbs on postural control and postural stability in standing posture. Neurosci Lett. 2003;340:83–6.
71. Carpenter JE, Blasier RB, Pellizzon GG. The effects of muscle fatigue on shoulder joint position sense. Am J Sports Med. 1998;26(2):262-5.
72. Chambers L, Altchek DW. Microinstability and internal impingement in overhead athletes. Clin Sports Med. 2013;32(4):697-707.
73. Chang HY, et al. Recovery of joint position sense in the shoulder after muscle fatigue. Journal of Sport Rehabilitation, 2006;15(4): 312-325.
74. Chaudhuri A, Behan PO. Fatigue and basal ganglia. J Neurol Sci. 2000;179(S 1-2):34-42.
75. Cheetham ME, Boobis LH, Brooks S, Williams C. Human muscle metabolism during sprint running. J Appl Physiol. 1986;61(1):54-60.
76. Chiang JH., Wu G. The influence of foam surfaces on biomechanical variables contributing to postural control. Gait & Posture. 1997;5(3):239-245.
77. Cho YR, Hong BY, Lim SH, Kim HW, Ko YJ, Im SA, Lee JI. Effects of joint effusion on proprioception in patients with knee osteoarthritis: a single-blind, randomized controlled clinical trial. Osteoarthritis Cartilage. 2011;19(1):22-8.
78. Chycki J, Golas A, Halz M, Maszczyk A, Toborek M, Zajac A. Chronic Ingestion of Sodium and Potassium Bicarbonate, with Potassium, Magnesium and Calcium Citrate Improves Anaerobic Performance in Elite Soccer Players. Nutrients. 2018;10(11):1610.
79. Clark FJ, Burgess PR. Slowly adapting receptors in cat knee joint: can they signal joint angle? J Neurophysiol. 1975;38(6):1448-63.
80. Clark FJ, Horch KW, Bach SM, Larson GF. Contributions of cutaneous and joint receptors to static knee-position sense in man. J Neurophysiol. 1979;42(3):877-88.
81. Clark NC, Röijezon U, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 2: Clinical assessment and intervention. Man Ther. 2015;20(3):378-87.
82. Clarkson PM, N. K. B. B. Muscle function after exercise-induced muscle damage and rapid adaptation. Med Sci Sports Exerc. 1992;24(5):512–520.
83. Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. Br J Sports Med. 2014;48(17):1327-33.

84. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. Br J Sports Med. 2013;47(8):495-502.
85. Cleak MJ, Dpe RGE. Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. In Br J Sp Med. 1992;26 (4).
86. Clemente-Suárez VJ, Diaz-Manzano M. Evaluation of Central Fatigue by the Critical Flicker Fusion Threshold in Cyclists. J Med Syst. 2019;43(3):61.
87. Clemente-Suárez VJ. The Application of Cortical Arousal Assessment to Control Neuromuscular Fatigue During Strength Training. J Mot Behav. 2017;49(4):429-434.
88. Colby MJ, Dawson B, Peeling P, Heasman J, Rogalski B, Drew MK, et al. Multivariate modelling of subjective and objective monitoring data improve the detection of non-contact injury risk in elite Australian footballers. Journal of Science and Medicine in Sport. 2017;20:1068–74.
89. Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand J Med Sci Sports. 2007;17(1):25-33.
90. Cordeiro LMS, Rabelo PCR, Moraes MM, Teixeira-Coelho F, Coimbra CC, Wanner SP, Soares DD. Physical exercise-induced fatigue: the role of serotonergic and dopaminergic systems. Braz J Med Biol Res. 2017;50(12):e6432.
91. Costello JT, Donnelly AE. Cryotherapy and joint position sense in healthy participants: a systematic review. J Athl Train. 2010;45(3):306-16.
92. Coxon JP, Cash RFH, Hendrikse JJ, Rogasch NC, Stavrinos E, Suo C, Yücel M. GABA concentration in sensorimotor cortex following high-intensity exercise and relationship to lactate levels. J Physiol. 2018;596(4):691-702.
93. Criswell Eleanor, Cram JR. Cram's introduction to surface electromyography. Jones and Bartlett; 2011.
94. Cuomo F, Birdzell MG, Zuckerman JD. The effect of degenerative arthritis and prosthetic arthroplasty on shoulder proprioception. J Shoulder Elbow Surg. 2005;14:345–8.
95. Da Silva F, Monjo F, Gioda J, Blain GM, Piponnier E, Corcelle B, Colson SS. Knee position sense and knee flexor neuromuscular function are similarly altered after two submaximal eccentric bouts. Eur J Appl Physiol. 2023;123(2):311-323.
96. Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. The effects of comprehensive warm-up programs on proprioception, static and dynamic balance on male soccer players. PLoS One. 2012;7(12):e51568.
97. Davies CT, White MJ. Muscle weakness following eccentric work in man. Pflugers Arch. 1981;392(2):168-71.
98. Davis MP, Walsh D. Mechanisms of fatigue. J Support Oncol. 2010;8(4):164-74.
99. de Vasconcelos GS, Cini A, Sbruzzi G, Lima CS. Effects of proprioceptive training on the incidence of ankle sprain in athletes: systematic review and meta-analysis. Clin Rehabil. 2018;32(12):1581-1590.

100. del Grande F, Aro M, Jalali Farahani S, Cosgarea A, Wilckens J, Carrino JA. High-resolution 3-T magnetic resonance imaging of the shoulder in nonsymptomatic professional baseball pitcher draft picks. Journal of Computer Assisted Tomography. 2016;40:118–25.
101. Delahunt E, Remus A. Risk factors for lateral ankle sprains and chronic ankle instability. Journal of Athletic Training. 2019;54:611–6.
102. Delgado-Moreno R, Robles-Pérez JJ, Aznar S, Clemente-Suarez VJ. Inalambric Biofeedback Devices to Analyze Strength Manifestation in Military Population. J Med Syst. 2018;42(4):60.
103. Delp MD, Armstrong RB, Godfrey DA, Laughlin MH, Ross CD, Wilkerson MK. Exercise increases blood flow to locomotor, vestibular, cardiorespiratory and visual regions of the brain in miniature swine. J Physiol. 2001;533(Pt 3):849-59.
104. Dirx M, Bouter LM, de Geus GH. Aetiology of handball injuries: a case--control study. Br J Sports Med. 1992;26(3):121-4.
105. Djupsjöbacka M, Johansson H, Bergenheim M, Sjölander P. Influences on the gamma-muscle-spindle system from contralateral muscle afferents stimulated by KCl and lactic acid. Neurosci Res. 1995;21(4):301-9.
106. Douglas J, Pearson S, Ross A, McGuigan M. Chronic Adaptations to Eccentric Training: A Systematic Review. Sports Med. 2017;47(5):917-941.
107. Dover G, Powers ME. Reliability of Joint Position Sense and Force-Reproduction Measures During Internal and External Rotation of the Shoulder. J Athl Train. 2003;38(4):304-310.
108. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. Journal of Epidemiology and Community Health. 1998;52:377–84.
109. Doyscher R, Kraus K, Finke B, Scheibel M. Akutverletzungen und Überlastungsschäden der Schulter im Sport [Acute and overuse injuries of the shoulder in sports]. Orthopade. 2014;43(3):202-8.
110. Drayer RA, Mulsant BH, Lenze EJ, Rollman BL, Dew MA, Kelleher K, Karp JF, Begley A, Schulberg HC, Reynolds CF 3rd. Somatic symptoms of depression in elderly patients with medical comorbidities. Int J Geriatr Psychiatry. 2005;20(10):973-82.
111. Drew MK, Finch CF. The Relationship Between Training Load and Injury, Illness and Soreness: A Systematic and Literature Review. Sports Medicine. 2016;46:861–83.
112. Dugas JR, Andrews JR. Throwing injuries in the adult. DeLee and Drez's Orhopaedic Sports Medicine. Philadelphia, PA: Elsevier Science. 2003:1236-49.
113. Edouard P, Degache F, Oullion R, Plessis JY, Gleizes-Cervera S, Calmels P. Shoulder strength imbalances as injury risk in handball. International Journal of Sports Medicine. 2013;34:654–60.
114. Edouard P, Samozino P, Julia M, Cervera SG, Vanbiervliet W, Calmels P, et al. Reliability of isokinetic assessment of shoulder-rotator strength: A systematic review of the effect of position. Journal of Sport Rehabilitation. 2011;20:367–83.

115. Edwards RH, Hill DK, Jones DA, Merton PA. Fatigue of long duration in human skeletal muscle after exercise. J Physiol. 1977;272(3):769-78.
116. Edwards RH. Human muscle function and fatigue. Ciba Found Symp. 1981; 82: 1–18.
117. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011;39(6):1226-32.
118. Ellenbecker TS, Davies GJ. The application of isokinetics in testing and rehabilitation of the shoulder complex. J Athl Train. 2000;35(3):338-50.
119. Ellenbecker TS, Roetert EP. Testing isokinetic muscular fatigue of shoulder internal and external rotation in elite junior tennis players. J Orthop Sports Phys Ther. 1999;29(5):275-81.
120. Engebretsen L, Soligard T, Steffen K, Alonso JM, Aubry M, Budgett R, Dvorak J, Jegathesan M, Meeuwisse WH, Mountjoy M, Palmer-Green D, Vanhegan I, Renström PA. Sports injuries and illnesses during the London Summer Olympic Games 2012. Br J Sports Med. 2013;47(7):407-14.
121. Enoka RM, Baudry S, Rudroff T, Farina D, Klass M, Duchateau J. Unraveling the neurophysiology of muscle fatigue. J Electromyogr Kinesiol. 2011;21(2):208-19.
122. Enoka RM, Stuart DG. Neurobiology of muscle fatigue. J Appl Physiol. 1992;72(5):1631-48.
123. Ezzo J, Berman B, Hadhazy VA, Jadad AR, Lao L, Singh BB. Is acupuncture effective for the treatment of chronic pain? A systematic review. Pain. 2000;86(3):217-225.
124. Fabis J, Rzepka R, Fabis A, Zwierzchowski J, Kubiak G, Stanula A, Polguj M, Maciej R. Shoulder proprioception - lessons we learned from idiopathic frozen shoulder. BMC Musculoskelet Disord. 2016;17:123.
125. Falla D, Farina D. Neuromuscular adaptation in experimental and clinical neck pain. J Electromyogr Kinesiol. 2008;18(2):255-61.
126. Fallentin N, Jørgensen K, Simonsen EB. Motor unit recruitment during prolonged isometric contractions. Eur J Appl Physiol Occup Physiol. 1993;67(4):335-41.
127. Feijen S, Tate A, Kuppens K, Claes A, Struyf F. Swim-training volume and shoulder pain across the life span of the competitive swimmer: A systematic review. Journal of Athletic Training. 2020;55:32–41.
128. Ferrell WR, Gandevia SC, McCloskey DI. The role of joint receptors in human kinaesthesia when intramuscular receptors cannot contribute. J Physiol. 1987;386:63-71.
129. Fieseler G, Hermassi S, Hoffmeyer B, Schulze S, Irlenbusch L, Bartels T, Delank KS, Laudner KG, Schwesig R. Differences in anthropometric characteristics in relation to throwing velocity and competitive level in professional male team handball: a tool for talent profiling. J Sports Med Phys Fitness. 2017;57(7-8):985-992.
130. Fitch S, McComas A. Influence of human muscle length on fatigue. J Physiol. 1985;362:205-13.
131. Fitzpatrick P, Carello C, Turvey MT. Eigenvalues of the inertia tensor and exteroception by the “muscular sense”. Neuroscience. 1994;60(2):551-568.
132. Fleisig GS. Kinetics of Baseball Pitching with Implications About Injury Mechanisms. The American Journal of Sports Medicine. 1995;23:233-239.

133. Fong DTP, Leung WC, Mok KM, Yung PSH. Delayed ankle muscle reaction time in female amateur footballers after the first 15 min of a simulated prolonged football protocol. J Exp Orthop. 2020;7(1):54.
134. Forestier N, Teasdale N, Nougier V. Alteration of the position sense at the ankle induced by muscular fatigue in humans. Med Sci Sports Exerc. 2002;34:117–22.
135. Forthomme B, Dvir Z, Crielaard JM, Croisier JL. Isokinetic assessment of the shoulder rotators: A study of optimal test position. Clinical Physiology and Functional Imaging. 2011;31:227–32.
136. Fortier S, Basset FA, Billaut F, Behm D, Teasdale N. Which type of repetitive muscle contractions induces a greater acute impairment of position sense? J Electromyogr Kinesiol. 2010;20(2):298-304.
137. Franco PG, Santos KB, Rodacki AL. Joint positioning sense, perceived force level and two-point discrimination tests of young and active elderly adults. Braz J Phys Ther. 2015;19(4):304-10.
138. Freckleton G, Pizzari T. Risk factors for hamstring muscle strain injury in sport: A systematic review and meta-analysis. British Journal of Sports Medicine. 2013;47:351–8.
139. French AS., Torkkeli, PH. Mechanoreception: Touch, Sensillar Structure. In Encyclopedia of Insects. Academic Press. 2009;610-611.
140. Fritschi C, Quinn L. Fatigue in patients with diabetes: a review. J Psychosom Res. 2010;69(1):33-41.
141. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. J Appl Physiol. 1991;71(2):644-50.
142. Furmanek MP, Słomka KJ, Sobiesiak A, Rzepko M, Juras G. The Effects of Cryotherapy on Knee Joint Position Sense and Force Production Sense in Healthy Individuals. J Hum Kinet. 2018;61:39-51.
143. Fyhr C, Gustavsson L, Wassinger C, Sole G. The effects of shoulder injury on kinaesthesia: a systematic review and meta-analysis. Man Ther. 2015;20(1):28-37.
144. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? Br J Sports Med. 2016;50(5):273-80.
145. Gamet D, Maton B. The fatigability of two agonistic muscles in human isometric voluntary submaximal contraction: an EMG study. I. Assessment of muscular fatigue by means of surface EMG. Eur J Appl Physiol Occup Physiol. 1989;58(4):361-8
146. Gandevia SC, Enoka RM, McComas AJ, Stuart DG, Thomas CK. Neurobiology of muscle fatigue. Advances and issues. Adv Exp Med Biol. 1995;384:515-25.
147. Gandevia SC. Kinesthesia: role for afferent signals and motor commands.: Vol. Section 12 (Rowell L.B & Shephert J.B, Eds.). Oxford University Press. 1996.
148. Gandevia SC. Spinal and supraspinal factors in human muscle fatigue. Physiol Rev. 2001;81(4):1725-89.
149. Garsden LR, Bullock-Saxton JE. Joint reposition sense in subjects with unilateral osteoarthritis of the knee. Clin Rehabil. 1999;13(2):148-55.
150. Gilman S. Joint position sense and vibration sense: anatomical organisation and assessment. J Neurol Neurosurg Psychiatry. 2002;73(5):473-7.

151. Giroto N, Hespanhol Junior LC, Gomes MR, Lopes AD. Incidence and risk factors of injuries in Brazilian elite handball players: A prospective cohort study. Scand J Med Sci Sports. 2017;27(2):195-202.
152. Givoni NJ, Pham T, Allen TJ, Proske U. The effect of quadriceps muscle fatigue on position matching at the knee. J Physiol. 2007;584(Pt 1):111-9.
153. Goble DJ, Coxon JP, Van Impe A, Geurts M, Doumas M, Wenderoth N, Swinnen SP. Brain activity during ankle proprioceptive stimulation predicts balance performance in young and older adults. J Neurosci. 2011;31(45):16344-52.
154. Goble DJ, Coxon JP, Van Impe A, Geurts M, Van Hecke W, Sunaert S, Wenderoth N, Swinnen SP. The neural basis of central proprioceptive processing in older versus younger adults: an important sensory role for right putamen. Hum Brain Mapp. 2012;33(4):895-908.
155. Goble DJ, Coxon JP, Wenderoth N, Van Impe A, Swinnen SP. Proprioceptive sensibility in the elderly: degeneration, functional consequences and plastic-adaptive processes. Neurosci Biobehav Rev. 2009;33(3):271-8.
156. Golden CL, Dudley GA. Strength after bouts of eccentric or concentric actions. Med Sci Sports Exerc. 1992;24(8), 926–933.
157. Gomoll AH, George FH, Peter JM. Injuries In. Sports Medicine. 2006; 200.
158. Goodwin GM, McCloskey DI, Matthews PBC. The contribution of muscle afferents to keslesthesia shown by vibration induced illusionsof movement and by the effects of paralysing joint afferents. Brain. 1972; 95(4):705-748.
159. Gorman PP, Butler RJ, Plisky PJ, Kiesel KB. Upper quarter y balance test: Reliability and performance comparison between genders in active adults. J Strength Cond Res. 2012;26:3043–8.
160. Granata KP, Slota GP, Wilson SE. Influence of fatigue in neuromuscular control of spinal stability. Hum Factors. 2004;46:81–91.
161. Green B, Bourne MN, van Dyk N, Pizzari T. Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-Analysis of risk factors for index and recurrent hamstring strain injury in sport. British Journal of Sports Medicine. 2020;54:1081–8.
162. Greenfield BH, Donatelli R, Wooden MJ, Wilkes J. Isokinetic evaluation of shoulder rotational strength between the plane of scapula and the frontal plane. Am J Sports Med. 1990;18(2):124-8.
163. Gregory JE, Brockett CL, Morgan DL, Whitehead NP, Proske U. Effect of eccentric muscle contractions on Golgi tendon organ responses to passive and active tension in the cat. J Physiol. 2002;538(Pt 1):209-18.
164. Gregory JE, Morgan DL, Proske U. Responses of muscle spindles following a series of eccentric contractions. Exp Brain Res. 2004;157(2):234-40.
165. Grigg P, Finerman GA, Riley LH. Joint-position sense after total hip replacement. J Bone Joint Surg Am. 1973;55:1016–25.
166. Grigg P. Peripheral Neural Mechanisms in Proprioception. Journal of sport rehabilitation. 1994;3(1).

167. Gumina S, Camerota F, Celletti C, Venditto T, Candela V. The effects of rotator cuff tear on shoulder proprioception. Int Orthop. 2019;43:229–35.
168. Habets B, Staal JB, Tijssen M, van Cingel R. Intrarater reliability of the Humac NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles. BMC Res Notes. 2018;11(1):15.
169. Hadjisavvas S, Efstathiou MA, Malliou V, Giannaki CD, Stefanakis M. Risk factors for shoulder injuries in handball: systematic review. BMC Sports Sci Med Rehabil. 2022;14.
170. Hadjisavvas S, Efstathiou MA, Themistocleous I-C, Daskalaki K, Malliou P, Lewis J, et al. Can resistance training improve throwing performance in handball players? A Systematic review and meta-analysis. BMC Sports Sci Med Rehabil. 2024;16:85.
171. Hall MC, Mockett SP, Doherty M. Relative impact of radiographic osteoarthritis and pain on quadriceps strength, proprioception, static postural sway and lower limb function. Ann Rheum Dis. 2006;65(7):865-70.
172. Harvie DS, Broecker M, Smith RT, Meulders A, Madden VJ, Moseley GL. Bogus visual feedback alters onset of movement-evoked pain in people with neck pain. Psychol Sci. 2015;26(4):385-92.
173. Hasan Z, Stuart DG. Animal solutions to problems of movement control: the role of proprioceptors. Annu Rev Neurosci. 1988;11:199-223.
174. Hassan BS, Mockett S, Doherty M. Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. Ann Rheum Dis. 2001;60(6):612-8.
175. Hatzimanouil D, Oxizoglou N, Sikaras E, Hatzimanouil A, Koronas K, Tsigilis N, Abatzides G. Factors related to the incidence and severity of injuries in team handball. Journal of Human Movement Studies. 2005;48(5):335-352.
176. Hewitt BA, Refshauge KM, Kilbreath SL. Kinesthesia at the knee: the effect of osteoarthritis and bandage application. Arthritis Rheum. 2002;47(5):479-83.
177. Hickey D, Solvig V, Cavalheri V, Harrold M, Mckenna L. Scapular dyskinesis increases the risk of future shoulder pain by 43% in asymptomatic athletes: a systematic review and meta-analysis. Br J Sports Med. 2018;52(2):102-110.
178. Hiemstra LA. Effect of fatigue on knee proprioception: implications for dynamic stabilization. J Orthop Sports Phys Ther. 2001;31:598–605.
179. Hirschauer N, Grüner S, Mußhoff O, Becker C, Jantsch A. Can p-values be meaningfully interpreted without random sampling? Statistics Surveys. 2020;14:71-91.
180. Hodges PW. Pain and motor control: From the laboratory to rehabilitation. J Electromyogr Kinesiol. 2011;21(2):220-8.
181. Hogan C, Corbett JA, Ashton S, Perraton L, Frame R, Dakic J. Scapular Dyskinesis Is Not an Isolated Risk Factor for Shoulder Injury in Athletes: A Systematic Review and Meta-analysis. American Journal of Sports Medicine. 2021;49:2843–53.
182. Hootman JM, Driban JB, Sitler MR, Harris KP, Cattano NM. Reliability and validity of three quality rating instruments for systematic reviews of observational studies. Research Synthesis Methods. 2011;2:110–8.

183. Hopper DM, Creagh MJ, Formby PA, Goh SC, Boyle JJ, Strauss GR. Functional measurement of knee joint position sense after anterior cruciate ligament reconstruction. Arch Phys Med Rehabil. 2003;84:868–72.
184. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing. 2006;35 Suppl 2:ii7-ii11.
185. Hortobágyi T, Houmard J, Fraser D, Dudek R, Lambert J, Tracy J. Normal forces and myofibrillar disruption after repeated eccentric exercise. Journal of Applied Physiology. 1998;84(2):492-8.
186. Hortobágyi T, Garry J, Holbert D, Devita P. Aberrations in the control of quadriceps muscle force in patients with knee osteoarthritis. Arthritis Rheum. 2004;51(4):562-9.
187. Howell JN, Chleboun G, Conatser R. Muscle stiffness, strength loss, swelling and soreness following exercise-induced injury in humans. J Physiol. 1993;464:183-96.
188. Hübscher M, Zech A, Pfeifer K, Hänsel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. Med Sci Sports Exerc. 2010;42(3):413-21.
189. Hunter SK, Pereira HM, Keenan KG. The aging neuromuscular system and motor performance. J Appl Physiol. 2016;121(4):982-995.
190. Hurley MV, Scott DL, Rees J, Newham DJ. Sensorimotor changes and functional performance in patients with knee osteoarthritis. Ann Rheum Dis. 1997;56(11):641-8.
191. Hutchinson MR, McCormack B. Predicting recurrent shoulder instability. British Journal of Sports Medicine. 2015;49:911–2.
192. Hwang S, Agada P, Kiemel T, Jeka JJ. Dynamic reweighting of three modalities for sensor fusion. PLoS One. 2014;9(1):e88132.
193. Iida N, Kaneko F, Aoki N, Shibata E. The effect of fatigued internal rotator and external rotator muscles of the shoulder on the shoulder position sense. J Electromyogr Kinesiol. 2014;24(1):72-7.
194. Ingram HA, Van Donkelaar P, Cole J, Vercher JL, Gauthier GM, Miall RC. The role of proprioception and attention in a visuomotor adaptation task. Exp Brain Res. 2000;132:114–26.
195. International Handball Federation. IX Rules of the Game a) Indoor Handball. Edition:1March2022) Retrieved from: https://www.ihf.info/sites/default/files/2022-03/09A%20-%20Rules%20of%20the%20Game_Indoor%20Handball_E.pdf.
196. Irving DB, Cook JL, Menz HB. Factors associated with chronic plantar heel pain: a systematic review. J Sci Med Sport. 2006;9(1-2):11-22; discussion 23-4.
197. Itoi E, Tabata S. Incomplete rotator cuff tears. Results of operative treatment. Clin Orthop Relat Res. 1992;(284):128-35.
198. Iwasa, K., Miyamoto, K., & Shimizu, K. Effects of erector spinae muscle fatigue on trunk repositioning accuracy in forward and lateral flexion. Journal of Back and Musculoskeletal Rehabilitation. 2005;18(3-4):61-66.
199. Jahjah A, Seidenspinner D, Schüttler K, Klasan A, Heyse TJ, Malcherczyk D, et al. The effect of ankle tape on joint position sense after local muscle fatigue: A randomized controlled trial. BMC Musculoskelet Disord. 2018;19.

200. Janwantanakul P, Magarey ME, Jones MA, Dansie BR. Variation in shoulder position sense at mid and extreme range of motion. Arch Phys Med Rehabil. 2001;82(6):840-4.
201. Jerosch J, Wüstner P. Effekt eines sensomotorischen Trainingsprogramms bei Patienten mit subakromialem Schmerzsyndrom [Effect of a sensorimotor training program on patients with subacromial pain syndrome]. Unfallchirurg. 2002;105(1):36-43.
202. Jha P, Ahamad I, Khurana S, Ali K, Verma S, Kumar T. Proprioception: an evidence based narrative review. Res. Inves. Sport Med. 2017;1:1-5.
203. Johanson E, Brumagne S, Janssens L, Pijnenburg M, Claeys K, Pääsuke M. The effect of acute back muscle fatigue on postural control strategy in people with and without recurrent low back pain. Eur Spine J. 2011;20(12):2152-9.
204. Johansson H, Arendt Nielsen L, Bergenheim M, Blair S, Van Dieen J, Djupsjbacka M, Zukowska Z. Epilogue: an integrated model for chronic work-related myalgia "Brussel Model". In Chronic Work-Related Myalgia, Neuromuscular Mechanisms behind Work-Related Chronic Muscle Pain Syndromes. Gavle University Press. 2003; 291-300
205. Johnson JE, Fullmer JA, Nielsen CM, Johnson JK, Moorman CT. Glenohumeral Internal Rotation Deficit and Injuries: A Systematic Review and Meta-analysis. Orthopaedic Journal of Sports Medicine. 2018;6.
206. Johnston W, Dolan K, Reid N, Coughlan GF, Caulfield B. Investigating the effects of maximal anaerobic fatigue on dynamic postural control using the Y-Balance Test. J Sci Med Sport. 2018;21:103–8.
207. Jones DA, Bigland-Ritchie B, Edwards RH. Excitation frequency and muscle fatigue: mechanical responses during voluntary and stimulated contractions. Exp Neurol. 1979;64(2):401-13.
208. Jones DA. High-and low-frequency fatigue revisited. Acta Physiol Scand. 1996;156(3):265-70.
209. Junge A, Engebretsen L, Mountjoy ML, Alonso JM, Renström PA, Aubry MJ, Dvorak J. Sports injuries during the Summer Olympic Games 2008. Am J Sports Med. 2009;37(11):2165-72.
210. Junge A, Langevoort G, Pipe A, Peytavin A, Wong F, Mountjoy M, Beltrami G, Terrell R, Holzgraefe M, Charles R, Dvorak J. Injuries in team sport tournaments during the 2004 Olympic Games. Am J Sports Med. 2006;34(4):565-76.
211. Kablan N, Ertan H, Ünver F, Kirazci S, Korkusuz F. Factors affecting the shoulder proprioceptive sense among male volleyball players. Isokinet Exerc Sci. 2004;12:193–8.
212. Kablan N. Effect of Different Joint Positions, Rotator Cuff Muscle Fatigue and Experience on Shoulder Proprioceptive Sense Among Male Volleyball Players (Doctoral dissertation, METU). 2004
213. Kaplan FS, Nixon JE, Reitz M, Rindfleish L, Tucker J. Age-related changes in proprioception and sensation of joint position. Acta Orthop Scand. 1985;56(1):72-4.
214. Karcher C, Buchheit M. On-court demands of elite handball, with special reference to playing positions. Sports Med. 2014;44(6):797-814.

215. Keener JD, Wei AS, Kim HM, Steger-May K, Yamaguchi K. Proximal humeral migration in shoulders with symptomatic and asymptomatic rotator cuff tears. Journal of Bone and Joint Surgery - Series A. 2009;91:1405–13.
216. Keeton R, Benjamin A, Stuart A. Binder-Macleod. "Low-frequency fatigue." Physical therapy. 2006; 86(8):1146-1150.
217. Keller RA, de Giacomo AF, Neumann JA, Limpisvasti O, Tibone JE. Glenohumeral Internal Rotation Deficit and Risk of Upper Extremity Injury in Overhead Athletes: A Meta-Analysis and Systematic Review. Sports Health. 2018;10:125–32.
218. Kelly CM, Burnett AF, Newton MJ. The effect of strength training on three-kilometer performance in recreational women endurance runners. J Strength Cond Res. 2008;22(2):396-403.
219. Kerr GK, Worringham CJ. Velocity perception and proprioception. Adv Exp Med Biol. 2002;508:79-86.
220. Kiers H, Brumagne S, van Dieën J, van der Wees P, Vanhees L. Ankle proprioception is not targeted by exercises on an unstable surface. Eur J Appl Physiol. 2012;112(4):1577-85.
221. Kim GH, Suzuki S, Kanda K. Age-related physiological and morphological changes of muscle spindles in rats. J Physiol. 2007;582(Pt 2):525-38.
222. Klass M, Baudry S, Duchateau J. Modulation of reflex responses in activated ankle dorsiflexors differs in healthy young and elderly subjects. European journal of applied physiology. 2011;111:1909-1916.
223. Knoop J, Steultjens MP, van der Leeden M, van der Esch M, Thorstensson CA, Roorda LD, Lems WF, Dekker J. Proprioception in knee osteoarthritis: a narrative review. Osteoarthritis Cartilage. 2011;19(4):381-8.
224. Knox JJ, Beilstein DJ, Charles SD, Aarseth GA, Rayar S, Treleaven J, Hodges PW. Changes in head and neck position have a greater effect on elbow joint position sense in people with whiplash-associated disorders. Clin J Pain. 2006;22(6):512-8.
225. Koerber A., McMichael L. Qualitative sampling methods: A primer for technical communicators. Journal of business and technical communication. 2008;22(4): 454-473.
226. Konishi Y, Fukubayashi T, Takeshita D. Possible mechanism of quadriceps femoris weakness in patients with ruptured anterior cruciate ligament. Med Sci Sports Exerc. 2002;34(9):1414-8.
227. Kraan RBJ, Nobel D, Eygendaal D, Daams JG, Kuijer PPFM, Maas M. Incidence, prevalence, and risk factors for elbow and shoulder overuse injuries in youth athletes: A systematic review. Translational Sports Medicine. 2019;2:186–95.
228. Kristjansson E, Oddsdottir GL. "The Fly": a new clinical assessment and treatment method for deficits of movement control in the cervical spine: reliability and validity. Spine (Phila Pa 1976). 2010;35(23):E1298-305.
229. Krogh-Lund C, Jørgensen K. Modification of myo-electric power spectrum in fatigue from 15% maximal voluntary contraction of human elbow flexor muscles, to limit of endurance: reflection of conduction velocity variation and/or centrally mediated mechanisms? Eur J Appl Physiol Occup Physiol. 1992;64(4):359-70.

230. Kuhn JE, Huston LJ, Soslowsky LJ, Shyr Y, Blasier RB. External rotation of the glenohumeral joint: ligament restraints and muscle effects in the neutral and abducted positions. J Shoulder Elbow Surg. 2005;14(1 Suppl S):39S-48S.
231. Kuijpers T, van der Windt DAWM, van der Heijden GJMG, Bouter LM. Systematic review of prognostic cohort studies on shoulder disorders. Pain. 2004;109(3):420-431.
232. Landgren S SH. Projection to cerebral cortex of group I muscle afferents from the cat's hind limb. J Physiol. 1969;2:353–72.
233. Langevoort G, Myklebust G, Dvorak J, Junge A. Handball injuries during major international tournaments. Scand J Med Sci Sports. 2007;17(4):400-7.
234. LaSorda KR, Gmelin T, Kuipers AL, Boudreau RM, Santanasto AJ, Christensen K, Renner SW, Wojczynski MK, Andersen SL, Cosentino S, Glynn NW. Epidemiology of Perceived Physical Fatigability in Older Adults: The Long Life Family Study. J Gerontol A Biol Sci Med Sci. 2020;75(9):e81-e88.
235. Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. American Journal of Sports Medicine. 2010;38:2106–12.
236. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. Journal of Orthopaedic and Sports Physical Therapy. 2006;36:485–94.
237. Laver L, Landreau P, Seil R, Popovic N, editors. Handball Sports Medicine: Basic science, injury management and return to sport. springer; 2018 May 10.
238. Lavidor M, Weller A, Babkoff H. Multidimensional fatigue, somatic symptoms and depression. Br J Health Psychol. 2002;7(Pt 1):67-75.
239. Leavitt VM, DeLuca J. Central fatigue: issues related to cognition, mood and behavior, and psychiatric diagnoses. PM R. 2010;2(5):332-7.
240. Lee HM, Liau JJ, Cheng CK, Tan CM, Shih JT. Evaluation of shoulder proprioception following muscle fatigue. Clin Biomech (Bristol, Avon). 2003;18(9):843-7.
241. Lee S, Lee JW, Yeom JS, Kim KJ, Kim HJ, Chung SK, Kang HS. A practical MRI grading system for lumbar foraminal stenosis. AJR Am J Roentgenol. 2010;194(4):1095-8.
242. Leong HT, Tsui SSM, Ng GY fat, Fu SN. Reduction of the subacromial space in athletes with and without rotator cuff tendinopathy and its association with the strength of scapular muscles. Journal of Science and Medicine in Sport. 2016;19:970–4.
243. Lephart SM, Giraldo JL, Borsa PA, Fu FH, Fn FH. Knee joint proprioception: a comparison between female intercollegiate gymnasts and controls. Springer-Verlag; 1996.
244. Lephart SM, Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. Sports Med. 1998;25(3):149-55.
245. Lephart SM, Warner JJ, Borsa PA, Fu FH. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. J Shoulder Elbow Surg. 1994;3(6):371-80.
246. Lephart SM, Henry TJ. The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. Journal of Sport Rehabilitation. 1996;5(1):71-87.

247. Levine DN. Sherrington's "The Integrative action of the nervous system": a centennial appraisal. J Neurol Sci. 2007;253(1-2):1-6.
248. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6(7):e1000100.
249. Lin HT, Ko HT, Lee KC, Chen YC, Wang DC. The changes in shoulder rotation strength ratio for various shoulder positions and speeds in the scapular plane between baseball players and non-players. J Phys Ther Sci. 2015;27(5):1559-63.
250. Lindstedt SL. When active muscles lengthen: properties and consequences of eccentric contractions. News Physiol Sci. 2001;16:256–261.
251. Lisberger SG, Thach WT. Chapter 42: The Cerebellum. In The Principles of Neural Science, eds. E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum & A. J. Hudspeth. McGraw Hill. 2013;960-981
252. Liu JX, Eriksson PO, Thornell LE, Pedrosa-Domellöf F. Fiber content and myosin heavy chain composition of muscle spindles in aged human biceps brachii. J Histochem Cytochem. 2005;53(4):445-54.
253. Lock AM, Bonetti DL, Campbell ADK. The psychological and physiological health effects of fatigue. Occup Med (Lond). 2018;68(8):502-511.
254. Lopes M, Lopes S, Patinha T, Araújo F, Rodrigues M, Costa R, Oliveira J, Ribeiro F. Balance and proprioception responses to FIFA 11+ in amateur futsal players: Short and long-term effects. J Sports Sci. 2019;37(20):2300-2308.
255. Loring SH, Hershenson MB. Effects of series compliance on twitches superimposed on voluntary contractions. J Appl Physiol. 1992;73(2):516-21.
256. Lubiatowski P, Kaczmarek P, Cisowski P, Breborowicz E, Grygorowicz M, Dzianach M, et al. Rotational glenohumeral adaptations are associated with shoulder pathology in professional male handball players. Knee Surgery, Sports Traumatology, Arthroscopy. 2018;26:67–75.
257. Lubiatowski P, Ogrodowicz P, Wojtaszek M, Romanowski L. Bilateral shoulder proprioception deficit in unilateral anterior shoulder instability. J Shoulder Elbow Surg. 2019;28(3):561-569.
258. Lucas J, van Doorn P, Hegedus E, Lewis J, van der Windt D. A systematic review of the global prevalence and incidence of shoulder pain. BMC Musculoskelet Disord. 2022;23(1):1073.
259. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. Journal of Orthopaedic and Sports Physical Therapy. 2009;39:90–104.
260. Luig P, Bloch H, Burkhardt K, Klein C, Kühn N. VBG-Sportreport 2017—Analyse des Unfallgeschehens in den zwei höchsten Ligen der Männer: Basketball, Eishockey, Fußball und Handball. Hamburg: VBG; 2017.
261. Luig P, Krutsch W, Nerlich M, Henke T, Klein C, Bloch H, Platen P, Achenbach L. Increased injury rates after the restructure of Germany's national second league of team handball. Knee Surg Sports Traumatol Arthrosc. 2018;26(7):1884-1891.

262. Luime JJ, Koes BW, Hendriksen IJM, Burdorf A, Verhagen AP, Miedema HS, et al. Prevalence and incidence of shoulder pain in the general population; a systematic review. Scandinavian Journal of Rheumatology. 2004;33:73–81.
263. Lund H, Juul-Kristensen B, Hansen K, Christensen R, Christensen H, Danneskiold-Samsoe B, Bliddal H. Movement detection impaired in patients with knee osteoarthritis compared to healthy controls: a cross-sectional case-control study. J Musculoskelet Neuronal Interact. 2008;8(4):391-400.
264. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. Am J Sports Med. 2002;30(4):463-8.
265. Macefield G, Gandevia SC, Burke D. Perceptual responses to microstimulation of single afferents innervating joints, muscles and skin of the human hand. J Physiol. 1990;429:113-29.
266. Macefield VG, Fuglevand AJ, Howell JN, Bigland-Ritchie B. Discharge behaviour of single motor units during maximal voluntary contractions of a human toe extensor. J Physiol. 2000;528 Pt 1(Pt 1):227-34.
267. Machner A, Merk H, Becker R, Rohkohl K, Wissel H, Pap G. Kinesthetic sense of the shoulder in patients with impingement syndrome. Acta Orthop Scand. 2003;74:85–8.
268. Maddock RJ, Casazza GA, Buonocore MH, Tanase C. Vigorous exercise increases brain lactate and Glx (glutamate+glutamine): a dynamic 1H-MRS study. Neuroimage. 2011;57(4):1324-30.
269. Madsen K, Ertbjerg P, Djurhuus MS, Pedersen PK. Calcium content and respiratory control index of skeletal muscle mitochondria during exercise and recovery. Am J Physiol. 1996;271(6 Pt 1):E1044-50.
270. Magee DJ. Orthopedic Physical Asssessment. 6th edition. Canada: Saunders; 2014.
271. Maher AC, Fu MH, Isfort RJ, Varbanov AR, Qu XA, Tarnopolsky MA. Sex differences in global mRNA content of human skeletal muscle. PLoS One. 2009;4(7):e6335.
272. Maier, MD S, Rudisill, BS S, Wright, MD C, Daniell, MD H, Lydston, MLS M, O'Donnell, MD E. Sex Differences in Shoulder Anatomy and Biomechanics: A Systematic Review and Meta-Analysis. Journal of Women's Sports Medicine. 2022;2:5–17.
273. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Gerontol. 1994;49(2):M72-84.
274. Malmström EM, Westergren H, Fransson PA, Karlberg M, Magnusson M. Experimentally induced deep cervical muscle pain distorts head on trunk orientation. Eur J Appl Physiol. 2013;113(10):2487-99.
275. Manske R, Wilk KE, Davies G, Ellenbecker T, Reinold M. Glenohumeral motion deficits: friend or foe? Int J Sports Phys Ther. 2013;8(5):537-53.
276. Manske RC., Magee DJ. Orthopedic physical assessment-E-Book. Elsevier Health Sciences. 2020.

277. Maor MB, Ronin T, Kalichman L. Scapular dyskinesis among competitive swimmers. Journal of Bodywork and Movement Therapies. 2017;21:633–6.
278. Marks R, Quinney HA, Wessel J. Proprioceptive sensibility in women with normal and osteoarthritic knee joints. Clin Rheumatol. 1993;12(2):170-5.
279. Marks R, Quinney HA. Effect of fatiguing maximal isokinetic quadriceps contractions on ability to estimate knee-position. Percept Mot Skills. 1993;77(3 Pt 2):1195-202.
280. Martin V, Millet GY, Martin A, Deley G, Lattier G. Assessment of low-frequency fatigue with two methods of electrical stimulation. J Appl Physiol. 2004;97(5):1923-9.
281. Matthews PB. Long-latency stretch reflexes of two intrinsic muscles of the human hand analysed by cooling the arm. J Physiol. 1989;419:519-38.
282. McCartney N, Heigenhauser GJ, Sargeant AJ, Jones NL. A constant-velocity cycle ergometer for the study of dynamic muscle function. J Appl Physiol Respir Environ Exerc Physiol. 1983;55(1 Pt 1):212-7.
283. McKenna MJ, Hargreaves M. Resolving fatigue mechanisms determining exercise performance: Integrative physiology at its finest! Journal of Applied Physiology. 2008;104:286–7.
284. McKenzie A, Larequi SA, Hams A, Headrick J, Whiteley R, Duhig S. Shoulder pain and injury risk factors in competitive swimmers: A systematic review. Scand J Med Sci Sports. 2023;33(12):2396-2412.
285. McKenzie DK, Gandevia SC. Recovery from fatigue of human diaphragm and limb muscles. Respir Physiol. 1991;84(1):49-60.
286. Melnyk M, Gollhofer A. Submaximal fatigue of the hamstrings impairs specific reflex components and knee stability. Knee Surgery, Sports Traumatology, Arthroscopy. 2007;15:525–32.
287. Mengshoel AM, Saugen E, Forre O, Vøllestad NK. Muscle fatigue in early fibromyalgia. J Rheumatol. 1995;22(1):143-50.
288. Merton PA. Voluntary strength and fatigue. J Physiol. 1954 Mar 29;123(3):553-64.
289. Michael-Titus AT, Shortland P. The Nervous System: The Nervous System, E-Book. Elsevier Health Sciences. 2020.
290. Michalsik LB, Aagaard P. Physical demands in elite team handball: comparisons between male and female players. J Sports Med Phys Fitness. 2015;55(9):878-91.
291. Michalsik LB, Madsen K, Aagaard P. Technical match characteristics and influence of body anthropometry on playing performance in male elite team handball. J Strength Cond Res. 2015;29(2):416-28.
292. Miura K, Ishibashi Y, Tsuda E, Okamura Y, Otsuka H, Toh S. The Effect of Local and General Fatigue on Knee Proprioception. Arthroscopy - Journal of Arthroscopic and Related Surgery. 2004;20:414–8.
293. Miwa T, Miwa Y, Kanda K. Dynamic and static sensitivities of muscle spindle primary endings in aged rats to ramp stretch. Neurosci Lett. 1995;201(2):179-82.
294. Mohapatra S, Kukkar KK, Aruin AS. Support surface related changes in feedforward and feedback control of standing posture. J Electromyogr Kinesiol. 2014;24(1):144-52.

295. Mohseni-Bandpei MA, Keshavarz R, Minoonejhad H, Mohsenifar H, Shakeri H. Shoulder pain in Iranian elite athletes: the prevalence and risk factors. J Manipulative Physiol Ther. 2012;35(7):541-8.
296. Moller M, Attermann J, Myklebust G, Wedderkopp N. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. British Journal of Sports Medicine. 2012;46:531–7.
297. Møller M, Nielsen RO, Attermann J, Wedderkopp N, Lind M, Sørensen H, Myklebust G. Handball load and shoulder injury rate: a 31-week cohort study of 679 elite youth handball players. British journal of sports medicine. 2017;51(4):231-237.
298. Moore JC. The Golgi tendon organ: a review and update. Am J Occup Ther. 1984;38(4):227-36.
299. Moritani T, Muro M, Nagata A. Intramuscular and surface electromyogram changes during muscle fatigue. J Appl Physiol. 1986;60(4):1179-85.
300. Morton S, Barton CJ, Rice S, Morrissey D. Risk factors and successful interventions for cricket-related low back pain: A systematic review. British Journal of Sports Medicine. 2014;48:685–91.
301. Moseley GL, Flor H. Targeting cortical representations in the treatment of chronic pain: a review. Neurorehabil Neural Repair. 2012;26(6):646-52.
302. Mouthon A, Ruffieux J, Mouthon M, Hoogewoud HM, Annoni JM, Taube W. Age-Related Differences in Cortical and Subcortical Activities during Observation and Motor Imagery of Dynamic Postural Tasks: An fMRI Study. Neural Plast. 2018;2018:1598178.
303. Moxham J, Edwards RH, Aubier M, De Troyer A, Farkas G, Macklem PT, Roussos C. Changes in EMG power spectrum (high-to-low ratio) with force fatigue in humans. J Appl Physiol Respir Environ Exerc Physiol. 1982 Nov;53(5):1094-9.
304. Myers JB, Guskiewicz KM, Schneider RA, Prentice WE. Proprioception and neuromuscular control of the shoulder after muscle fatigue. J Athl Train. 1999;34(4):362-7.
305. Myers JB, Guskiewicz KM, Schneider RA, Prentice WE. Proprioception and neuromuscular control of the shoulder after muscle fatigue. J Athl Train. 1999;34(4):362-7.
306. Myers JB, Lephart SM. Sensorimotor deficits contributing to glenohumeral instability. Clin Orthop Relat Res. 2002;(400):98-104.
307. Myers JB, Lephart SM. The role of the sensorimotor system in the athletic shoulder. J Athl Train. 2000;35(3):351-63.
308. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: A prospective study. Journal of Shoulder and Elbow Surgery. 2013;22:1154–9.
309. Myers JB, Oyama S. Sensorimotor factors affecting outcome following shoulder injury. Clin Sports Med. 2008;27(3):481-90, x.
310. Myers JB, Wassinger CA, Lephart SM. Sensorimotor contribution to shoulder stability: effect of injury and rehabilitation. Man Ther. 2006;11(3):197-201.

311. Myklebust G, Hasslan L, Bahr R, Steffen K. High prevalence of shoulder pain among elite Norwegian female handball players. Scand J Med Sci Sports. 2013;23(3):288-94.
312. Myklebust G, Maehlum s, Engebretsen L, Strand T, Solheim E. Registration of cruciate ligament injuries in Norwegian top level team handball. A prospective study covering two seasons. Scand J Med Sci Sports. 1997;7:289-292.
313. Nagai T, Sell TC, Abt JP, Lephart SM. Reliability, precision, and gender differences in knee internal/external rotation proprioception measurements. Phys Ther Sport. 2012;13(4):233-7.
314. Navarro-Ledesma S, Struyf F, Labajos-Manzanares MT, Fernandez-Sanchez M, Morales-Asencio JM, Luque-Suarez A. Does the acromiohumeral distance matter in chronic rotator cuff related shoulder pain? Musculoskeletal Science and Practice. 2017;29:38–42.
315. Newham DJ, McCarthy T, Turner J. Voluntary activation of human quadriceps during and after isokinetic exercise. J Appl Physiol. 1991;71(6):2122-6.
316. Newham DJ, McPhail G, Mills KR, Edwards RH. Ultrastructural changes after concentric and eccentric contractions of human muscle. J Neurol Sci. 1983;61(1):109-22.
317. Noffal GJ. Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. Am J Sports Med. 2003;31(4):537-41.
318. O’connell C, Stokes EK. Chapter 62-Fatigue A2-Kauffman, Timothy L. A comprehensive guide to geriatric rehabilitation. 2014;453-457.
319. O’Connor KL, Baker MM, Dalton SL, Dompier TP, Broglio SP, Kerr ZY. Epidemiology of sport-related concussions in high school athletes: National athletic treatment, injury and outcomes network (NATION), 2011-2012 through 2013-2014. Journal of Athletic Training. 2017;52:175–85.
320. O'Leary SP, Vicenzino BT, Jull GA. A new method of isometric dynamometry for the craniocervical flexor muscles. Phys Ther. 2005;85(6):556-64.
321. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury pattern in youth team handball: a comparison of two prospective registration methods. Scand J Med Sci Sports. 2006;16(6):426-32.
322. Orchard JW, Blanch P, Paoloni J, Kountouris A, Sims K, Orchard JJ, Brukner P. Cricket fast bowling workload patterns as risk factors for tendon, muscle, bone and joint injuries. Br J Sports Med. 2015;49(16):1064-8.
323. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. Am J Sports Med. 2002;30(3):347-53.
324. Matthews PBC. A Critique of the Hypothesis that the Spindle Secondary Endings Contribute Excitation to the Stretch Reflex (R. B. Stein, K. G. Pearson, R. S. Smith, & J. B. Redford, Eds.; Springer, Vol. 7). Springer. 1973.
325. Pai YC, Rymer WZ, Chang RW, Sharma L. Effect of age and osteoarthritis on knee proprioception. Arthritis Rheum. 1997 Dec;40(12):2260-5.
326. Pap G, Eberhardt R, Stürmer I, Machner A, Schwarzberg H, Roessner A, Neumann W. Development of osteoarthritis in the knee joints of Wistar rats after strenuous running exercise in a running wheel by intracranial self-stimulation. Pathol Res Pract. 1998;194(1):41-7.

327. Papadonikolakis A, McKenna M, Warme W, Martin BI, Matsen FA. Published evidence relevant to the diagnosis of impingement syndrome of the shoulder. Journal of Bone and Joint Surgery - Series A. 2011;93:1827–32.
328. Pearson KA. Spinal reflexes. Principles of neural science. 2000.
329. Pedersen J, Lönn J, Hellström F, Djupsjöbacka M, Johansson H. Localized muscle fatigue decreases the acuity of the movement sense in the human shoulder. Med Sci Sports Exerc. 1999;31(7):1047-52.
330. Pedersen J, Sjölander P, Wenngren BI, Johansson H. Increased intramuscular concentration of bradykinin increases the static fusimotor drive to muscle spindles in neck muscles of the cat. Pain. 1997;70(1):83-91.
331. Perrine JJ, Edgerton VR. Muscle force-velocity and power-velocity relationships under isokinetic loading. Med Sci Sports. 1978;10(3):159-66.
332. Peters EJ, Fuglevand AJ. Cessation of human motor unit discharge during sustained maximal voluntary contraction. Neurosci Lett. 1999;274(1):66-70.
333. Phillips RO. A review of definitions of fatigue–And a step towards a whole definition. Transportation research part F: traffic psychology and behavior. 2015;29:48-56.
334. Pickard CM, Sullivan PE, Allison GT, Singer KP. Is There a Difference in Hip Joint Position Sense Between Young and Older Groups? 2003.
335. Pieper HG. Humeral torsion in the throwing arm of handball players. Am J Sports Med. 1998;26(2):247-53.
336. Pieper HG, Muschol M. The throwing and overhead athlete's shoulder. Sports Orthopaedics and Traumatology. 2014.
337. Piggott B. The relationship between training load and incidence of injury and illness over a pre-season at an Australian Football League club. 2008.
338. Piper BF, Lindsey AM., Dodd MJ., Ferketich, S., Paul, SM., Weller S. The development of an instrument to measure the subjective dimension of fatigue. In Management of pain, fatigue and nausea. Macmillan Education UK. 1989:199-208
339. Piry H, Fallahi A, Kordi R, Rajabi R, Rahimi M, Yosefi M. Handball injuries in elite Asian players. World Applied Sciences Journal. 2011;14(10):1559-1564.
340. Place N, Yamada T, Bruton JD, Westerblad H. Muscle fatigue: from observations in humans to underlying mechanisms studied in intact single muscle fibres. Eur J Appl Physiol. 2010;110(1):1-15.
341. Plummer HA, Oliver GD. The effects of localised fatigue on upper extremity jump shot kinematics and kinetics in team handball. J Sports Sci. 2017;35(2):182-188.
342. Porter MM, Stuart S, Boij M, Lexell J. Capillary supply of the tibialis anterior muscle in young, healthy, and moderately active men and women. J Appl Physiol. 2002;92(4):1451-7.
343. Postle K, Pak D, Smith TO. Effectiveness of proprioceptive exercises for ankle ligament injury in adults: a systematic literature and meta-analysis. Man Ther. 2012;17(4):285-91.

344. Póvoas SC, Ascensão AA, Magalhães J, Seabra AF, Krustrup P, Soares JM, Rebelo AN. Analysis of fatigue development during elite male handball matches. J Strength Cond Res. 2014;28(9):2640-8.
345. Póvoas SCA, Castagna C, Resende C, Coelho EF, Silva P, Santos R, Seabra A, Tamames J, Lopes M, Randers MB, Krustrup P. Physical and Physiological Demands of Recreational Team Handball for Adult Untrained Men. Biomed Res Int. 2017;2017:6204603.
346. Pozzi F, Plummer HA, Shanley E, Thigpen CA, Bauer C, Wilson ML, et al. Preseason shoulder range of motion screening and in-season risk of shoulder and elbow injuries in overhead athletes: Systematic review and meta-analysis. British Journal of Sports Medicine. 2020;54:1019–27.
347. Prochazka A. Proprioception: clinical relevance and neurophysiology. In Current Opinion in Physiology. Elsevier Ltd. 2021; 23
348. Proschinger S, Freese J. Neuroimmunological and neuroenergetic aspects in exercise-induced fatigue. Exerc Immunol Rev. 2019;25:8-19.
349. Proske U, Allen TJ. Damage to skeletal muscle from eccentric exercise. Exerc Sport Sci Rev. 2005;33(2):98-104.
350. Proske U, Gandevia SC. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. Physiol Rev. 2012 Oct;92(4):1651-97.
351. Proske U, Morgan DL, Gregory JE. Thixotropy in skeletal muscle and in muscle spindles: a review. Prog Neurobiol. 1993;41(6):705-21.
352. Proske U. The role of muscle proprioceptors in human limb position sense: a hypothesis. J Anat. 2015;227(2):178-83.
353. Proske U. Exercise, fatigue and proprioception: a retrospective. In Experimental Brain Research. Springer Verlag. 2019; 237(10):2447-2459.
354. Pfaff DW, Volkow ND, Rubenstein JL, editors. Neuroscience in the 21st century: from basic to clinical. Springer Nature; 2022:Oct 17.
355. Radebold A, Cholewicki J, Polzhofer GK, Greene HS. Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. Spine (Phila Pa 1976). 2001;26(7):724-30.
356. Rafnsson ET, Valdimarsson Ö, Sveinsson T, Árnason Á. Injury Pattern in Icelandic Elite Male Handball Players. Clin J Sport Med. 2019;29(3):232-237.
357. Rahi S. Research design and methods: A systematic review of research paradigms, sampling issues and instruments development. International Journal of Economics & Management Sciences. 2017;6(2):1-5.
358. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. Am J Sports Med. 2002;30(3):354-60.
359. Ream E, Richardson A. Fatigue in patients with cancer and chronic obstructive airways disease: a phenomenological enquiry. Int J Nurs Stud. 1997;34(1):44-53.
360. Relph N, Herrington L, Tyson S. The effects of ACL injury on knee proprioception: a meta-analysis. Physiotherapy. 2014;100(3):187-95.

361. Ribeiro F, Oliveira J. Aging effects on joint proprioception: The role of physical activity in proprioception preservation. European Review of Aging and Physical Activity. 2007;4:71–6.
362. Riemann BL Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. J Athl Train. 2002;37:71–9.
363. Riemann BL, Lephart SM. The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. J Athl Train. 2002;37(1):80–84.
364. Roepstorff C, Steffensen CH, Madsen M, Stallknecht B, Kanstrup IL, Richter EA, Kiens B. Gender differences in substrate utilization during submaximal exercise in endurance-trained subjects. Am J Physiol Endocrinol Metab. 2002;282(2):E435-47.
365. Röijezon U, Björklund M, Djupsjöbacka M. The slow and fast components of postural sway in chronic neck pain. Man Ther. 2011;16(3):273-8.
366. Röijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. Man Ther. 2015;20(3):368-77.
367. Rokito AS, Birdzell MG, Cuomo F, Di Paola MJ, Zuckerman JD. Recovery of shoulder strength and proprioception after open surgery for recurrent anterior instability: A comparison of two surgical techniques. J Shoulder Elbow Surg. 2010;19:564–9.
368. Romero LM. Fight or Flight Responses; Elsevier: Amsterdam, The Netherlands. 2019
369. Romero-Franco N, Jiménez-Reyes P. Unipedal Postural Balance and Countermovement Jumps After a Warm-up and Plyometric Training Session: A Randomized Controlled Trial. J Strength Cond Res. 2015;29(11):3216-22.
370. Rondelli RR, Dal Corso S, Simões A, Malaguti C. Methods for the assessment of peripheral muscle fatigue and its energy and metabolic determinants in COPD. J Bras Pneumol. 2009;35(11):1125-35.
371. Rothwell J, Rothwell J. Proprioceptors in muscles, joints and skin. Control of Human voluntary movement. 1994:86-126.
372. Sabick MB, Kim YK, Torry MR, Keirns MA, Hawkins RJ. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. Am J Sports Med. 2005;33(11):1716-22.
373. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJP. Shoulder proprioception in baseball pitchers. J Shoulder Elbow Surg. 2001;10:438–44.
374. Sahin E, Dilek B, Baydar M, Gundogdu M, Ergin B, Manisali M, Akalin E, Gulbahar S. Shoulder proprioception in patients with subacromial impingement syndrome. J Back Musculoskelet Rehabil. 2017;30(4):857-862.
375. Sainburg RL, Ghilardi MF, Poizner H, Ghez C. Control of limb dynamics in normal subjects and patients without proprioception. J Neurophysiol. 1995;73(2):820-35.
376. Saini SS, Shah SS, Curtis AS. Scapular Dyskinesis and the Kinetic Chain: Recognizing Dysfunction and Treating Injury in the Tennis Athlete. Current Reviews in Musculoskeletal Medicine. 2020;13:748–56.

377. Salahzadeh Z, Maroufi N, Salavati M, Aslezaker F, Morteza N, Rezaei Hachesu, P. Proprioception in subjects with patellofemoral pain syndrome: using the sense of force accuracy. Journal of Musculoskeletal Pain. 2013;21(4):341-349.
378. Salamh P, Jones E, Bashore M, Liu X, Hegedus EJ. Injuries and associated risk factors of the shoulder and elbow among adolescent baseball pitchers: A systematic review and meta-analysis. Physical Therapy in Sport. 2020;43:108–19.
379. Salo TD, Chaconas E. The Effect of Fatigue on Upper Quarter Y-Balance Test Scores in Recreational Weightlifters: A Randomized Controlled Trial. Int J Sports Phys Ther. 2017;12(2):199-205.
380. Sánchez-Zuriaga D, Adams MA, Dolan P. Is activation of the back muscles impaired by creep or muscle fatigue? Spine (Phila Pa 1976). 2010;35:517–25.
381. Sargeant AJ, Hoinville E, Young A. Maximum leg force and power output during short-term dynamic exercise. J Appl Physiol Respir Environ Exerc Physiol. 1981;51(5):1175-82.
382. Sayers SP, Clarkson PM. Force recovery after eccentric exercise in males and females. European journal of applied physiology. 2001;84:122-6.
383. Scanlan AT, Fox JL, Borges NR, Delextrat A, Spiteri T, Dalbo VJ, et al. Decrements in knee extensor and flexor strength are associated with performance fatigue during simulated basketball game-play in adolescent, male players. J Sports Sci. 2018;36:852–60.
384. Schiftan GS, Ross LA, Hahne AJ. The effectiveness of proprioceptive training in preventing ankle sprains in sporting populations: a systematic review and meta-analysis. J Sci Med Sport. 2015;18(3):238-44.
385. Schmidt RA, Lee TD, Winstein C, Wulf G, Zelaznik HN. Motor control and learning: A behavioral emphasis. Human kinetics. 2018;30.
386. Sciascia A, Kibler W ben. Current concepts: Scapular dyskinesis. British Journal of Sports Medicine. 2010;44:300–5.
387. Segal NA, Glass NA, Torner J, Yang M, Felson DT, Sharma L, Nevitt M, Lewis CE. Quadriceps weakness predicts risk for knee joint space narrowing in women in the MOST cohort. Osteoarthritis Cartilage. 2010;18(6):769-75.
388. Seidler RD, Bernard JA, Burutolu TB, Fling BW, Gordon MT, Gwin JT, Kwak Y, Lipps DB. Motor control and aging: links to age-related brain structural, functional, and biochemical effects. Neurosci Biobehav Rev. 2010;34(5):721-33.
389. Seil R, Laver L, Landreau P, Myklebust G, Waldén M. ESSKA helps making a change: the example of handball medicine. Knee Surgery, Sports Traumatology, Arthroscopy. 2018;26:1881–3.
390. Semmler JG, Tucker KJ, Allen TJ, Proske U. Eccentric exercise increases EMG amplitude and force fluctuations during submaximal contractions of elbow flexor muscles. J Appl Physiol. 2007;103(3):979-89.
391. Serrien B, Clijsen R, Blondeel J, Goossens M, Baeyens JP. Differences in ball speed and three-dimensional kinematics between male and female handball players during a standing throw with run-up. BMC Sports Sci Med Rehabil. 2015;7:27.

392. Shaffer SW, Harrison AL. Aging of the somatosensory system: a translational perspective. Phys Ther. 2007;87(2):193-207.
393. Shanley E, Kissenberth MJ, Thigpen CA, Bailey LB, Hawkins RJ, Michener LA, et al. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. Journal of Shoulder and Elbow Surgery. 2015;24:1005–13.
394. Sharma L, Cahue S, Song J, Hayes K, Pai YC, Dunlop D. Physical functioning over three years in knee osteoarthritis: role of psychosocial, local mechanical, and neuromuscular factors. Arthritis Rheum. 2003;48(12):3359-70.
395. Sharma L, Pai YC, Holtkamp K, Rymer WZ. Is knee joint proprioception worse in the arthritic knee versus the unaffected knee in unilateral knee osteoarthritis? Arthritis Rheum. 1997;40(8):1518-25.
396. Shokri, P., Eslamian, F., Kazem Shakouri, S., Ohanian, S., & Jahanjoo, F. Sense of Force and Senses of Position among Young Normal Adults-A Controlled Single-Blinded Study. Journal of Research in Medical and Dental Science. 2018;6(3):258–267.
397. Singh, A., Tandel, B., Shenoy, S., & Sandhu, J. S. Acute effect of eccentric knee exercises on dynamic balance among athletes and non-athletes. Medical Journal of Dr. D.Y. Patil Vidyapeeth. 2023;16(1):42–46.
398. Sjölander P, Michaelson P, Jaric S, Djupsjöbacka M. Sensorimotor disturbances in chronic neck pain--range of motion, peak velocity, smoothness of movement, and repositioning acuity. Man Ther. 2008;13(2):122-31.
399. Skinner HB, Barrack RL, Cook SD. Age-related decline in proprioception. Clin Orthop Relat Res. 1984;(184):208-11.
400. Skinner HB, Wyatt " M P, Hodgdon JAW, Conard $ R, Barrack L. Effect of Fatigue on Joint Position Sense of the Knee. Orthopaedic Research Society; 1986.
401. Skurvydas A, Jascaninas J, Zachovajevas P. Changes in height of jump, maximal voluntary contraction force and low-frequency fatigue after 100 intermittent or continuous jumps with maximal intensity. Acta Physiol Scand. 2000;169(1):55-62.
402. Smith RL, Brunolli J. Shoulder kinesthesia after anterior glenohumeral joint dislocation. Phys Ther. 1989;69(2):106-12.
403. Sole G, Osborne H, Wassinger C. The effect of experimentally-induced subacromial pain on proprioception. Man Ther. 2015;20(1):166-70.
404. Soltys JS, Wilson SE. Directional sensitivity of velocity sense in the lumbar spine. J Appl Biomech. 2008;24(3):244-51.
405. Spargoli G. The acute effects of concentric versus eccentric muscle fatigue on shoulder active repositioning sense. Int J Sports Phys Ther. 2017;12(2):219–226.
406. Steensberg A, van Hall G, Osada T, Sacchetti M, Saltin B, Klarlund Pedersen B. Production of interleukin-6 in contracting human skeletal muscles can account for the exercise-induced increase in plasma interleukin-6. J Physiol. 2000;529 Pt 1(Pt 1):237-42.
407. Steib S, Zech A, Hentschke C, Pfeifer K. Fatigue-induced alterations of static and dynamic postural control in athletes with a history of ankle sprain. J Athl Train. 2013;48:203–8.
408. Sterner RL, Pincivero DM, Lephart SM. The effects of muscular fatigue on shoulder proprioception. Clin J Sport Med. 1998;8(2):96-101.

409. Struyf F, Nijs J, Meeus M, Roussel NA, Mottram S, Truijen S, Meeusen R. Does scapular positioning predict shoulder pain in recreational overhead athletes? Int J Sports Med. 2014;35(1):75-82.
410. Subasi SS, Gelecek N, Aksakoglu G. Effects of different warm-up periods on knee proprioception and balance in healthy young individuals. J Sport Rehabil. 2008;17(2):186-205.
411. Sun W Chan EC, Fong DT. Delayed peroneal muscle reaction time in male amateur footballers during a simulated prolonged football protocol. Res Sports Med. 2021;29:364–72.
412. Suprak DN, Osternig LR, van Donkelaar P, Karduna AR. Shoulder joint position sense improves with elevation angle in a novel, unconstrained task. J Orthop Res. 2006;24(3):559-68.
413. Suprak DN, Osternig LR, van Donkelaar P, Karduna AR. Shoulder joint position sense improves with external load. J Mot Behav. 2007;39(6):517-25.
414. Swait G, Rushton AB, Miall RC, Newell D. Evaluation of cervical proprioceptive function: optimizing protocols and comparison between tests in normal subjects. Spine (Phila Pa 1976). 2007;32(24):E692-701.
415. Swanik CB, Lephart SM, Rubash HE. Proprioception, kinesthesia, and balance after total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses. J Bone Joint Surg Am. 2004;86(2):328-34.
416. Swanik KA, Lephart SM, Swanik CB, Lephart SP, Stone DA, Fu FH. The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics. J Shoulder Elbow Surg. 2002;11(6):579-86.
417. Tabben M, Landreau P, Chamari K, Juin G, Ahmed H, Farooq A, et al. Age, player position and 2 min suspensions were associated with match injuries during the 2017 Men's Handball World Championship (France). British Journal of Sports Medicine. 2019;53:436–41.
418. Takenaga T, Sugimoto K, Goto H, Nozaki M, Fukuyoshi M, Tsuchiya A, et al. Posterior shoulder capsules are thicker and stiffer in the throwing shoulders of healthy college baseball players. American Journal of Sports Medicine. 2015;43:2935–42.
419. Tate AR, McClure P, Kareha S, Irwin D, Barbe MF. A clinical method for identifying scapular dyskinesis, part 2: validity. J Athl Train. 2009;44(2):165-73.
420. Taylor JL Butler JE, Gandevia SC. Changes in muscle afferents, motoneurons and motor drive during muscle fatigue. Eur J Appl Physiol. 2000;83:106–15.
421. Teyhen DS, Miller JM, Middag TR, Kane EJ. Rotator cuff fatigue and glenohumeral kinematics in participants without shoulder dysfunction. J Athl Train. 2008;43(4):352-8.
422. Thomas SJ, Swanik CB, Higginson JS, Kaminski TW, Swanik KA, Bartolozzi AR, et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. Journal of Shoulder and Elbow Surgery. 2011;20:708–16.
423. Thunberg J, Hellström F, Sjölander P, Bergenheim M, Wenngren B, Johansson H. Influences on the fusimotor-muscle spindle system from chemosensitive nerve endings in

cervical facet joints in the cat: possible implications for whiplash induced disorders. Pain. 2001;91(1-2):15-22.
424. Tippett SR. Closed chain exercise. Orthop Phys Ther Clinic N Am.. 1992;1:253–267.
425. Tomporowski PD. Effects of acute bouts of exercise on cognition. Acta Psychol (Amst). 2003;112(3):297-324.
426. Tonak H, Kaya Kara ÖZ, Şahin S. Investigation of Activity, Participation and Quality of Life in Elderly Living in Ankara and Antalya Provinces. Bezmialem Science. 2020;8(3).
427. Tooth C, Forthomme B, Croisier JL, Gofflot A, Bornheim S, Schwartz C. The Modified-Athletic Shoulder Test: Reliability and validity of a new on-field assessment tool. Phys Ther Sport. 2022;58:8-15.
428. Tooth C, Gofflot A, Schwartz C, Croisier JL, Beaudart C, Bruyère O, Forthomme B. Risk Factors of Overuse Shoulder Injuries in Overhead Athletes: A Systematic Review. Sports Health. 2020;12(5):478-487.
429. Tornero-Aguilera JF, Jimenez-Morcillo J, Rubio-Zarapuz A, Clemente-Suárez VJ. Central and Peripheral Fatigue in Physical Exercise Explained: A Narrative Review. Int J Environ Res Public Health. 2022;19(7):3909.
430. Torres R, Silva F, Pedrosa V, Ferreira J, Lopes A. The Acute Effect of Cryotherapy on Muscle Strength and Shoulder Proprioception. J Sport Rehabil. 2017;26(6):497-506.
431. Torres R, Vasques J, Duarte JA, Cabri JM. Knee proprioception after exercise-induced muscle damage. Int J Sports Med. 2010;31(6):410-5.
432. Treleaven J, Clamaron-Cheers C, Jull G. Does the region of pain influence the presence of sensorimotor disturbances in neck pain disorders? Man Ther. 2011;16(6):636-40.
433. Treleaven J, Jull G, Sterling M. Dizziness and unsteadiness following whiplash injury: characteristic features and relationship with cervical joint position error. J Rehabil Med. 2003;35(1):36-43.
434. Trinh B, Peletier M, Simonsen C, Plomgaard P, Karstoft K, Klarlund Pedersen B, van Hall G, Ellingsgaard H. Blocking endogenous IL-6 impairs mobilization of free fatty acids during rest and exercise in lean and obese men. Cell Rep Med. 2021;2(9):100396.
435. Tsay A, Allen TJ, Leung M, Proske U. The fall in force after exercise disturbs position sense at the human forearm. Exp Brain Res. 2012;222(4):415-25.
436. Uhl TL, Kibler W ben, Gecewich B, Tripp BL. Evaluation of Clinical Assessment Methods for Scapular Dyskinesis. Arthroscopy - Journal of Arthroscopic and Related Surgery. 2009;25:1240–8.
437. Urwin M, Symmons D, Allison T, Brammah T, Busby H, Roxby M, Simmons A, Williams G. Estimating the burden of musculoskeletal disorders in the community: the comparative prevalence of symptoms at different anatomical sites, and the relation to social deprivation. Ann Rheum Dis. 1998;57(11):649-55.
438. uul-Kristensen B, Lund H, Hansen K, Christensen H, Danneskiold-Samsøe B, Bliddal H. Poorer elbow proprioception in patients with lateral epicondylitis than in healthy controls: a cross-sectional study. J Shoulder Elbow Surg. 2008;17(1 Suppl):72S-81S.

439. Van Beijsterveldt AM, van de Port IG, Vereijken AJ, Backx FJ. Risk factors for hamstring injuries in male soccer players: a systematic review of prospective studies. Scandinavian journal of medicine & science in sports. 2013;23(3):253-62.
440. Van Den Tillaar R, Cabri JM. Gender differences in the kinematics and ball velocity of overarm throwing in elite team handball players. J Sports Sci. 2012;30(8):807-13.
441. van den Tillaar R, Cabri JMH. Sex differences in the kinematics and ball velocity of overarm throwing in elite team handball players. Journal of Sports Sciences. 2012;30:807–13.
442. van den Tillaar R, Ettema G. A comparison between novices and experts of the velocity-accuracy trade-off in overarm throwing. Percept Mot Skills. 2006;103(2):503-14.
443. van den Tillaar R, Ettema G. A comparison of kinematics between overarm throwing with 20% underweight, regular, and 20% overweight balls. J Appl Biomech. 2011;27(3):252-7.
444. van den Tillaar R, Ettema G. A three-dimensional analysis of overarm throwing in experienced handball players. J Appl Biomech. 2007;23(1):12-9.
445. van den Tillaar R, Ettema G. Effect of body size and gender in overarm throwing performance. Eur J Appl Physiol. 2004;91(4):413-8.
446. van den Tillaar R, Ettema G. Is there a proximal-to-distal sequence in overarm throwing in team handball? J Sports Sci. 2009;27(9):949-55.
447. van den Tillaar R, Zondag A, Cabri J. Comparing performance and kinematics of throwing with a circular and whip-like wind up by experienced handball players. Scand J Med Sci Sports. 2013;23(6):e373-80.
448. van den Tillaar R. Comparison of range of motion tests with throwing kinematics in elite team handball players. J Sports Sci. 2016;34(20):1976-82.
449. van Mechelen W, Twisk J, Molendijk A, Blom B, Snel J, Kemper HCG. Subject-related risk factors for sports injuries: A 1-yr prospective study in young adults. Medicine and Science in Sports and Exercise. 1996;28:1171–9.
450. Van Tulder M, Furlan A, Bombardier C, Bouter L. Updated method guidelines for systematic reviews in Cochrane collaboration back review group. SPINE. 2003;28:1290-1299.
451. Van Tulder M, Willem J.J, Koes W, Bouter M. Method guidelines for systematic reviews in the Cochrane collaboration back review group for spinal disorders. SPINE. 1997;22:2323-2330.
452. van Tunen JAC, Dell'Isola A, Juhl C, Dekker J, Steultjens M, Thorlund JB, Lund H. Association of malalignment, muscular dysfunction, proprioception, laxity and abnormal joint loading with tibiofemoral knee osteoarthritis - a systematic review and meta-analysis. BMC Musculoskelet Disord. 2018;19(1):273.
453. Vila-Chã C, Riis S, Lund D, Møller A, Farina D, Falla D. Effect of unaccustomed eccentric exercise on proprioception of the knee in weight and non-weight bearing tasks. Journal of Electromyography and Kinesiology. 2011;21(1):141–147.
454. Vogt M, Hoppeler HH. Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. J Appl Physiol. 2014;116(11):1446-54.

455. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. J Orthop Sports Phys Ther. 1996;23(6):348-52.
456. Vøllestad NK, Sejersted OM, Bahr R, Woods JJ, Bigland-Ritchie B. Motor drive and metabolic responses during repeated submaximal contractions in humans. J Appl Physiol. 1988;64(4):1421-7.
457. Vøllestad NK. Changes in Activation, Contractile Speed, and Electrolyte Balance During Fatigue of Sustained and Repeated Contractions. Lung Biology in Health and Disease. 1995;85:235-235.
458. Vuillerme N, Pinsault N, Bouvier B. Cervical joint position sense is impaired in older adults. Aging Clin Exp Res. 2008;20(4):355-8.
459. Waddington G, Adams R, Jones A. Wobble board (ankle disc) training effects on the discrimination of inversion movements. Aust J Physiother. 1999;45(2):95-101.
460. Waddington G, Seward H, Wrigley T, Lacey N, Adams R. Comparing wobble board and jump-landing training effects on knee and ankle movement discrimination. J Sci Med Sport. 2000;3(4):449-59.
461. Wagner H, Buchecker M, von Duvillard SP, Müller E. Kinematic comparison of team handball throwing with two different arm positions. Int J Sports Physiol Perform. 2010;5(4):469-83.
462. Wagner H, Pfusterschmied J, von Duvillard SP, Müller E. Performance and kinematics of various throwing techniques in team-handball. J Sports Sci Med. 2011;10(1):73-80.
463. Wagner H, Pfusterschmied J, Von Duvillard SP, Müller E. Skill-dependent proximal-to-distal sequence in team-handball throwing. J Sports Sci. 2012;30(1):21-9.
464. Wagner H, Kainrath S, Müller E. Coordinative and tactical parameters of team-handball throw. The correlation of level of performance, throwing quality and selected technique-tactical parameters. Leistungssport. 2008;38(5):35-41.
465. Waldén M, Hägglund M, Magnusson H, Ekstrand J. Anterior cruciate ligament injury in elite football: A prospective three-cohort study. Knee Surgery, Sports Traumatology, Arthroscopy. 2011;19:11–9.
466. Walecka J, Lubiatowski P, Consigliere P, Atoun E, Levy O. Shoulder proprioception following reverse total shoulder arthroplasty. Int Orthop. 2020;44(12):2691-2699.
467. Walsh LD, Moseley GL, Taylor JL, Gandevia SC. Proprioceptive signals contribute to the sense of body ownership. J Physiol. 2011;589(Pt 12):3009-21.
468. Walsh LD, Hesse CW, Morgan DL, Proske U. Human forearm position sense after fatigue of elbow flexor muscles. Journal of Physiology. 2004;558(2):705–715.
469. Wan JJ, Qin Z, Wang PY, Sun Y, Liu X. Muscle fatigue: general understanding and treatment. Exp Mol Med. 2017;49(10):e384.
470. Wang D, Wang X. GLT-1 mediates exercise-induced fatigue through modulation of glutamate and lactate in rats. Neuropathology. 2018;38(3):237-246.
471. Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. J Sports Med Phys Fitness. 2001;41(3):403-10..

472. Weber SC. Arthroscopic debridement and acromioplasty versus mini-open repair in the management of significant partial-thickness tears of the rotator cuff. Orthop Clin N Am. 1997;28:79–82.
473. Webster CA, Nussbaum MA, Madigan ML. Stiffness and proprioceptive contributions of ankle braces and the influence of localized muscle fatigue. Journal of Electromyography and Kinesiology. 2017;34:37–43.
474. Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K, Wedderkopp N. Injuries in young female players in European team handball. Scand J Med Sci Sports. 1997;7:342–7.
475. Weerakkody N, Allen T. The effects of fast bowling fatigue and adhesive taping on shoulder joint position sense in amateur cricket players in Victoria, Australia. J Sports Sci. 2017;35(19):1954-1962.
476. Weerakkody N, Percival P, Morgan DL, Gregory JE, Proske U. Matching different levels of isometric torque in elbow flexor muscles after eccentric exercise. Exp Brain Res. 2003;149(2):141-50.
477. Westerblad, H., Allen, D. G., Bruton, J. D., Andrade, F. H., & Lännergren, J. Mechanisms underlying the reduction of isometric force in skeletal muscle fatigue. Acta Physiologica Scandinavica. 1998;162(3):253–260.
478. Westrick RB, Miller HM, Carow SD, Gerper JP. Exploration of the y-balance test for assessment of upper quarter closed kinetic chain performance. Int J Sports Phys Ther. 2012;7:139–47.
479. Whiteley R, Ginn K, Nicholson L, Adams R. Indirect ultrasound measurement of humeral torsion in adolescent baseball players and non-athletic adults: reliability and significance. J Sci Med Sport. 2006;9(4):310-8.
480. Whittaker JL, Small C, Maffey L, Emery CA. Risk factors for groin injury in sport: An updated systematic review. British Journal of Sports Medicine. 2015;49:803–9.
481. Whitten JHD, Hodgson DD, Drinkwater EJ, Prieske O, Aboodarda SJ, Behm DG. Unilateral Quadriceps Fatigue Induces Greater Impairments of Ipsilateral versus Contralateral Elbow Flexors and Plantar Flexors Performance in Physically Active Young Adults. J Sports Sci Med. 2021;20(2):300-309.
482. Wilk KE, Arrigo C. Current concepts in the rehabilitation of the athletic shoulder. J Orthop Sports Phys Ther. 1993;18(1):365-78.
483. Wilk KE, MacRina LC, Fleisig GS, Porterfield R, Simpson CD, Harker P, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. American Journal of Sports Medicine. 2011;39:329–35.
484. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. Am J Sports Med. 2002;30(1):136-51.
485. Wilk KE, Obma P, Simpson CD, Cain EL, Dugas JR, Andrews JR. Shoulder injuries in the overhead athlete. J Orthop Sports Phys Ther. 2009;39(2):38-54.
486. Williamson EM, Marshall PH. Effect of osteoarthritis on accuracy of continuous tracking leg movement. Percept Mot Skills. 2014;118(1):162-82.

487. Williamson JW, McColl R, Mathews D, Ginsburg M, Mitchell JH. Activation of the insular cortex is affected by the intensity of exercise. J Appl Physiol. 1999;87(3):1213-9.
488. Winkelmann MT, Walter SS, Laver L, Zeman F, Fehske K, Achenbach L. Increased posterior shoulder capsule thickness in youth elite handball players: a sonographic investigation. Journal of Shoulder and Elbow Surgery. 2021;30:194–9.
489. Woledge RC, Curtin NA, Homsher E. Energetic aspects of muscle contraction. Monogr Physiol Soc. 1985;41:1-357.
490. Woodward M, Debold EP. Acidosis and Phosphate Directly Reduce Myosin's Force-Generating Capacity Through Distinct Molecular Mechanisms. Front Physiol. 2018;9:862.
491. Wright AA, Ness BM, Donaldson M, Hegedus EJ, Salamh P, Cleland JA. Effectiveness of shoulder injury prevention programs in an overhead athletic population: A systematic review. Phys Ther Sport. 2021;52:189-193.
492. Wright CJ, Arnold BL. Fatigue’s effect on eversion force sense in individuals with and without functional ankle instability. J Sport Rehabil. 2012;21:127–36.
493. Xu D, Hong Y, Li J, Chan K. Effect of tai chi exercise on proprioception of ankle and knee joints in old people. Br J Sports Med. 2004;38(1):50-4.
494. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am. 2006 Aug;88(8):1699-704.
495. Yamamoto N, Muraki T, Sperling JW, Steinmann SP, Itoi E, Cofield RH, et al. Contact between the coracoacromial arch and the rotator cuff tendons in nonpathologic situations: A cadaveric study. Journal of Shoulder and Elbow Surgery. 2010;19:681–7.
496. Yang JL, Jan MH, Hung CJ, Yang PL, Lin JJ. Reduced scapular muscle control and impaired shoulder joint position sense in subjects with chronic shoulder stiffness. J Electromyogr Kinesiol. 2010;20(2):206-11.
497. Yeh TH, Hwang HM, Chen JJ, Wu T, Li AH, Wang HL. Glutamate transporter function of rat hippocampal astrocytes is impaired following the global ischemia. Neurobiol Dis. 2005;18(3):476-83.
498. Yeh TH, Hwang HM, Chen JJ, Wu T, Li AH, Wang HL. Glutamate transporter function of rat hippocampal astrocytes is impaired following the global ischemia. Neurobiol Dis. 2005;18(3):476-83.
499. Yoon, J., Bae, M., Kang, H., & Kim, T. Descriptive epidemiology of sports injury and illness during the Rio 2016 Olympic Games: A prospective cohort study for Korean team. International Journal of Sports Science & Coaching. 2018;13(6):939-946.
500. Yu LJ, Stokell R, Treleaven J. The effect of neck torsion on postural stability in subjects with persistent whiplash. Man Ther. 2011;16(4):339-43.
501. Zając A, Chalimoniuk M, Gołaš A, Lngfort J, Maszczyk A. Central and peripheral fatigue during resistance exercise - A critical review. Journal of Human Kinetics. 2015;49:159–69.

502. Zanca GG, Mattiello SM, Karduna AR. Kinesio taping of the deltoid does not reduce fatigue induced deficits in shoulder joint position sense. Clinical Biomechanics. 2015;30:903–7.
503. Zapartidis I, Gouvali M, Bayios I, Boudolos K. Throwing effectiveness and rotational strength of the shoulder in team handball. J Sports Med Phys Fitness. 2007;47(2):169-78.
504. Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Neuromuscular training for rehabilitation of sports injuries: a systematic review. Med Sci Sports Exerc. 2009;41(10):1831-41.
505. Zech A, Steib S, Hentschke C, Eckhardt H, Pfeifer K. Effects of localized and general fatigue on static and dynamic postural control in male team handball athletes. J Strength Cond Res. 2012;26(4):1162-8.
506. Zuckerman JD, Gallagher MA, Cuomo F, Rokito A. The effect of instability and subsequent anterior shoulder repair on proprioceptive ability. J Shoulder Elbow Surg. 2003;12(2):105-9.
507. Zwergal A, Linn J, Xiong G, Brandt T, Strupp M, Jahn K. Aging of human supraspinal locomotor and postural control in fMRI. Neurobiol Aging. 2012;33(6):1073-84.

APPENDICES

Appendix A – Approval by National (Cyprus) Bioethics Committee

ΚΥΠΡΙΑΚΗ ΔΗΜΟΚΡΑΤΙΑ

ΕΘΝΙΚΗ ΕΠΙΤΡΟΠΗ ΒΙΟΗΘΙΚΗΣ ΚΥΠΡΟΥ

Αρ. Φακ.: ΕΕΒΚ/ΕΠ /2020/40
Αρ. Τηλ.: 22809038 / 22809039
Αρ. Φαξ: 22353878

24 Σεπτεμβρίου, 2020

Δρ Μάνος Στεφανάκης
Επίκουρος Καθηγητής Φυσικοθεραπείας
Πανεπιστήμιο Λευκωσίας
Ζανέτου 3
1100 Άγιος Ανδρέας
Λευκωσία

Αγαπητέ Δρ Στεφανάκη,

Ερευνητική πρόταση με τίτλο:
«Η επίδραση της συγκέντρωσης και έκκεντρης μυϊκής κόπωσης στην ιδιοδεκτικότητα του ώμου σε αθλητές χάντμπολ»

Η Επιτροπή Βιοηθικής Αξιολόγησης Βιοϊατρικής και Κλινικής Έρευνας Β', ενεργώντας με βάση την εκχωρηθείσα σ΄ αυτήν αρμοδιότητα από την Εθνική Επιτροπή Βιοηθικής Κύπρου, να αξιολογεί βιοηθικά ερευνητικές προτάσεις που αφορούν την βιοϊατρική και κλινική έρευνα στον άνθρωπο, έχει πραγματοποιήσει την βιοηθική αξιολόγηση της πιο πάνω ερευνητικής σας πρότασης, η οποία σας αποστέλλεται συνημμένα.

Με εκτίμηση,

Δρ Σίμων Μαλάς
Πρόεδρος
Επιτροπής Βιοηθικής Αξιολόγησης
Βιοϊατρικής και Κλινικής Έρευνας Β'

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ΕΕΒΚ/ΕΠ/2020/40

ΕΜΠΙΣΤΕΥΤΙΚΟ

ΑΠΟΦΑΣΗ ΕΠΙΤΡΟΠΗΣ ΒΙΟΗΘΙΚΗΣ ΓΙΑ ΕΓΚΡΙΣΗ Ή ΑΠΟΡΡΙΨΗ ΠΡΟΓΡΑΜΜΑΤΟΣ

Η απόφαση της Επιτροπής Βιοηθικής Αξιολόγησης (ΕΒΑ) θα πρέπει να κοινοποιηθεί προς την Εθνική Επιτροπή Βιοηθικής Κύπρου μαζί με όλα τα υπόλοιπα έντυπα που αφορούν το πρόγραμμα για το οποίο λήφθηκε σχετική απόφαση.

<u>Συμπληρώνεται από την Επιτροπή Βιοηθικής</u>

Τίτλος Προγράμματος για το οποίο γίνεται η αίτηση
Η επίδραση της συγκέντρωσης και έκκεντρης μυϊκής κόπωσης στην ιδιοδεκτικότητα του ώμου σε αθλητές χάντμπολ
Επιστημονικός Υπεύθυνος του Προγράμματος
Δρ Μάνος Στεφανάκης (διδακτορικός φοιτητής ο Στέλιος Χατζησάββας)

Όνομα Επιτροπής Βιοηθικής	
Επιτροπή Βιοηθικής Αξιολόγησης Βιοϊατρικής και Κλινικής Έρευνας Β'	
Μέλη της Επιτροπής Βιοηθικής	
Όνομα	Επίθετο
κα Αντώνια	Σοφιανού
Δρ Αφροδίτη	Ελισσαίου
Δρ Βασιλική	Γκρέτση
κα Έλενα	Κκολού
κα Ελένη	Αθανασούλια
κος Κυριάκος	Ανδρέου
Δρ Μαρία	Ζένιου
Δρ Σίμων	Μαλάς
Δρ Στέλλα	Νικολάου

Σχόλια από την Επιτροπή Βιοηθικής Αξιολόγησης με βάση τα οποία λήφθηκε η απόφαση για την αίτηση που υποβλήθηκε

Η Επιτροπή κατά τη σημερινή συνεδρίασή της ημερομηνίας 24/09/2020, πραγματοποίησε τη βιοηθική αξιολόγηση των πρόσθετων ή/και αναθεωρημένων εγγράφων που κατατέθηκαν στις 02/09/2020, σε συνέχεια απόφασης της Επιτροπής ημερομηνίας 23/07/2020.

Τα σχόλια της Επιτροπής κατά τη σημερινή συνεδρίαση παρουσιάζονται με έντονα μαύρα γράμματα.

<u>Σχόλιο ημερομηνίας 23/07/2020:</u>

<u>Η Επιτροπή κατά τη σημερινή συνεδρίαση της ημερομηνίας 23/07/2020, πραγματοποίησε τη βιοηθική αξιολόγηση της ερευνητικής πρότασης που καταχωρήθηκε στις 03/07/2020 και αποφάσισε ομόφωνα όπως εγκρίνει την ερευνητική πρόταση υπό τον όρο ότι θα κατατεθεί επικαιροποιημένο έντυπο συγκατάθεσης ΕΕΒΚ 03 στο οποίο θα επεξηγείται ο όρος της «ιδιοδεκτικότητας» σε απλή και κατανοητή γλώσσα έτσι ώστε να είναι πλήρως κατανοητός στους εθελοντές που θα συμμετέχουν και δεν είναι γνώστες της σχετικής ορολογίας.</u> **Απαντήθηκε**

<u>Σημειώνεται ότι, τα διορθωμένα / επικαιροποιημένα έντυπα θα πρέπει να αποσταλούν το συντομότερο δυνατό και όχι αργότερα από την Παρασκευή 04 Σεπτεμβρίου 2020 ώστε να διασφαλιστεί η ισχύς της εξασφαλισθείσας έγκρισης.</u> **Απαντήθηκε**

Συμπληρώνεται από την Επιτροπή Βιοηθικής Αξιολόγησης

Στοιχεία	ΝΑΙ	ΟΧΙ
Βιογραφικά Στοιχεία ΟΛΩΝ των ερευνητών και των συνεργατών τους	√	
Δήλωση μη συγκρουόμενων συμφερόντων	√	
Περιγραφή του είδους του Προγράμματος	√	
Περιγραφή του πληθυσμού που θα μελετηθεί	√	
Ο τρόπος με τον οποίο θα στρατολογηθούν άτομα για το Πρόγραμμα	√	
Μελετήθηκαν προσεκτικά τα έντυπα συγκατάθεσης (ΕΕΒΚ03);	Σχόλια	
Τα έντυπα που θα χρησιμοποιηθούν για την στρατολόγηση ατόμων	√	
Ολόκληρο το πρωτόκολλο του Προγράμματος	√	
Δικαιολόγηση για την χρήση εικονικής φαρμακευτικής αγωγής		ΔΙ
Υπεύθυνη δήλωση από όλους τους ερευνητές και συνεργάτες τους ότι τα έντυπα πληροφόρησης και συναίνεσης τους δεσμεύουν	√	
Διασφάλιση της προστασίας των δεδομένων που αφορούν τα άτομα που θα λάβουν μέρος στο Πρόγραμμα	√	
Λεπτομέρειες για την χρηματοδότηση του Προγράμματος	√	
Έχουν εκδοθεί ειδικά συμβόλαια σε σχέση με αμοιβές ;	√	
Θα δίδονται αμοιβές στα άτομα που θα συμμετάσχουν στο Πρόγραμμα ;		√
Θα υπάρξουν οποιεσδήποτε οικονομικές επιβαρύνσεις για τα άτομα που θα συμμετάσχουν στο Πρόγραμμα ;		√
Οι ερευνητές ή/και συνεργάτες τους θα παίρνουν αμοιβές ;		√
Έχουν περιγραφεί τα αναμενόμενα οφέλη του Προγράμματος ;	√	
Έχει διαφανεί ότι προκύπτουν οποιαδήποτε οφέλη προς τον χρηματοδότη, τους ερευνητές και τους συνεργάτες τους από το Πρόγραμμα ;		
Εάν πιο πάνω είναι ΝΑΙ, να εξηγηθεί: Δημοσιεύσεις		
Έχουν τεκμηριωθεί όλες οι διευθετήσεις που έγιναν σε σχέση με τις υπηρεσίες που τυχόν θα παρασχεθούν για το Πρόγραμμα ;	√	
Θα υπάρχει συνεχής ενημέρωση για την ασφάλεια των ατόμων που θα λαμβάνουν μέρος στο Πρόγραμμα ;	√	
Υπάρχουν διαδικασίες για την υποβολή παραπόνων/καταγγελιών;	√	
Διασφαλίζονται επαρκώς τα δικαιώματα των ερευνητών για τις δημοσιεύσεις των αποτελεσμάτων ;	√	
Έχει δεσμευθεί ο/η Επιστημονικός Υπεύθυνος ότι δεν θα γίνουν οποιεσδήποτε αλλαγές στο Πρόγραμμα από την ημέρα που θα εγκριθεί από την Επιτροπή Βιοηθικής ;	√	

***Αποτελεί ευθύνη της Επιτροπής Βιοηθικής Αξιολόγησης να σταθμίσει όλα τα στοιχεία που έχουν δοθεί, να δώσει την απαραίτητη βαρύτητα εκεί που χρειάζεται και να λάβει απόφαση ως προς το κατά πόσον έχουν δοθεί ικανοποιητικές επεξηγήσεις σε σχέση με το προτεινόμενο Πρόγραμμα.**

Δήλωση για «μη συγκρουόμενα συμφέροντα» από την Επιτροπή Βιοηθικής Αξιολόγησης		
Εμείς τα μέλη της Επιτροπής Βιοηθικής Αξιολόγησης που λάβαμε μέρος στις συνεδρίες σε σχέση με την παρούσα αίτηση, υπογράφοντας πιο κάτω δηλώνουμε υπεύθυνα ότι δεν έχουμε οποιαδήποτε άμεσα ή έμμεσα συγκρουόμενα συμφέροντα σε σχέση με το Πρόγραμμα που μελετήσαμε και εκδώσαμε σχετική απόφαση.		
Ονοματεπώνυμο	**Υπογραφή**	**Ημερομηνία**
κα Αντώνια Σοφιανού		24/09/2020
Δρ Αφροδίτη Ελισσαίου		24/09/2020
Δρ Βασιλική Γκρέτση		24/09/2020
κα Έλενα Κκολού		24/09/2020
κα Ελένη Αθανασούλια		24/09/2020
κος Κυριάκος Ανδρέου		24/09/2020
Δρ Μαρία Ζένιου	ΑΠΟΥΣΑ	24/09/2020
Δρ Σίμων Μαλάς		24/09/2020
Δρ Στέλλα Νικολάου		24/09/2020

Τίτλος Προγράμματος

Η επίδραση της συγκέντρωσης και έκκεντρης μυϊκής κόπωσης στην ιδιοδεκτικότητα του ώμου σε αθλητές χάντμπολ

Αριθμός Πρωτοκόλλου Εθνικής Επιτροπής Βιοηθικής Κύπρου

ΕΕΒΚ/ΕΠ/2020/40

Απόφαση της Επιτροπής Βιοηθικής Αξιολόγησης
(Εγκρίνεται ή Ζητούνται επιπρόσθετα στοιχεία ή Απορρίπτεται)

Εγκρίνεται

1. Νοείται ότι την νομική ευθύνη της επιστημονικής εγκυρότητας, αναγκαιότητας, πληρότητας και της συνολικής επιστημονικής αξίας της προτεινομένης έρευνας έχουν οι επιστημονικοί υπεύθυνοι της έρευνας και ο Φορέας του επιστημονικού υπεύθυνου. Όλοι οι πιο πάνω έχουν επίσης την νομική ευθύνη της διεξαγωγής της έρευνας με τη δέουσα επιστημονική επιμέλεια και φροντίδα.

2.Από 01/08/2012 η Εθνική Επιτροπή Βιοηθικής Κύπρου διενεργεί δειγματοληπτικό έλεγχο σε ερευνητικές προτάσεις που λαμβάνουν έγκριση. Περισσότερες λεπτομέρειες είναι διαθέσιμες στην ιστοσελίδα της Επιτροπής σε σχετική ανακοίνωση.

3.Το παρόν έντυπο απόφασης κοινοποιείται και στον χρηματοδότη της ερευνητικής πρότασης.

4. Οι ερευνητές υποχρεούνται να υποβάλλουν προς την Επιτροπή ανά εξάμηνο από σήμερα έκθεση για την εξέλιξη της έρευνας μέσα του εντύπου ΕΕΒΚ05.

5. Με το πέρας της έρευνας, οι ερευνητές υποχρεούνται όπως υποβάλουν στην Επιτροπή αναφορά μέσω του Εντύπου ΕΕΒΚ06.

6. Τονίζεται στους ερευνητές η υποχρέωσή τους να τηρούν τις εκάστοτε υποχρεώσεις τους με βάση την κείμενη νομοθεσία και κανονισμούς και ιδιαιτέρως η υποχρέωσή τους να ενημερώνουν άμεσα την Επιτροπή για οποιοδήποτε έκτακτο συμβάν ή οποιαδήποτε τροποποίηση στην πρόταση ως εγκρίθηκε, με την υποβολή των προνοουμένων εντύπων.

Μέλη που ήταν παρόντα στη λήψη απόφασης/Αποτέλεσμα Ψηφοφορίας

Ως αναφέρεται στη σελίδα 4 ανωτέρω και η απόφαση ήταν ομόφωνη.

Ημερομηνία έκδοσης απόφασης ΕΒΑ:

Ημερομηνία: ……24…… Μήνας: ……Σεπτεμβρίου…… Έτος: ……2020……

Υπογράφει ο Πρόεδρος και ο Αντιπρόεδρος της Επιτροπής Βιοηθικής Αξιολόγησης

Αξίωμα	Όνομα	Επίθετο	Υπογραφή
Πρόεδρος	Σίμων	Μαλάς	
Αντιπρόεδρος	Κυριάκος	Ανδρέου	

Appendix B – Consent form

ΕΝΤΥΠΑ ΣΥΓΚΑΤΑΘΕΣΗΣ
για συμμετοχή σε ερευνητικό πρόγραμμα

(Τα έντυπα αποτελούνται συνολικά από …….. σελίδες)

Τίτλος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε

Η επίδραση της σύγκεντρης κόπωσης στην ιδιοδεκτικότητα και κινητικό έλεγχο του άνω άκρου σε υγιείς συμμετέχοντες.

Στο έντυπο αυτό δίνονται εξηγήσεις σε απλή και κατανοητή γλώσσα σχετικά με το τι ζητείται από εσάς ή/και τι θα συμβεί σε εσάς, εάν συμφωνήσετε να συμμετάσχετε στο πρόγραμμα:

1. Περιγράφονται οποιοιδήποτε κίνδυνοι μπορεί να υπάρξουν ή ταλαιπωρία που τυχόν θα υποστείτε από την συμμετοχή σας στο πρόγραμμα.
2. Επεξηγείται με κάθε λεπτομέρεια ποιος ή ποιοι θα έχουν πρόσβαση στα δεδομένα που σας αφορούν και θα προκύψουν από το πρόγραμμα που θα συμμετάσχετε ή/και άλλο υλικό/δεδομένα που εθελοντικά θα δώσετε για το πρόγραμμα.
3. Δίνεται η χρονική περίοδος για την οποία οι υπεύθυνοι του προγράμματος θα έχουν πρόσβαση στις πληροφορίες ή/και υλικό σας αφορά.
4. Επεξηγείται το τί ευελπιστούν να μάθουν οι υπεύθυνοι του προγράμματος σαν αποτέλεσμα και της δικής σας συμμετοχής.
5. Δίνεται μία εκτίμηση για το όφελος που μπορεί να υπάρξει για τους ερευνητές ή/και χρηματοδότες αυτού του προγράμματος.
6. **Δεν πρέπει να συμμετάσχετε, εάν δεν επιθυμείτε ή εάν έχετε οποιουσδήποτε ενδοιασμούς που αφορούν τη συμμετοχή σας στο πρόγραμμα.**
7. Εάν αποφασίσετε να συμμετάσχετε, πρέπει να αναφέρετε εάν είχατε συμμετάσχει σε οποιοδήποτε άλλο πρόγραμμα έρευνας μέσα στους τελευταίους 12 μήνες.
8. Εάν αποφασίσετε να μην συμμετάσχετε και είστε ασθενής, η θεραπεία σας δεν θα επηρεαστεί από την απόφασή σας.
9. **Είστε ελεύθεροι να αποσύρετε οποιαδήποτε στιγμή εσείς επιθυμείτε τη συγκατάθεση για την συμμετοχή σας στο πρόγραμμα.**
10. Εάν είστε ασθενής, η απόφασή σας να αποσύρετε την συγκατάθεση σας, δεν θα έχει οποιεσδήποτε επιπτώσεις στη θεραπεία σας.
11. Πρέπει όλες οι σελίδες των εντύπων συγκατάθεσης να φέρουν το ονοματεπώνυμο και την υπογραφή σας.

Επιστημονικός υπεύθυνος του Προγράμματος στο οποίο καλείστε να συμμετάσχετε
Στέλιος Χατζησάββας

ΕΝΤΥΠΑ ΣΥΓΚΑΤΑΘΕΣΗΣ
για συμμετοχή σε ερευνητικό πρόγραμμα
(Τα έντυπα αποτελούνται συνολικά από …….. σελίδες)

Η επίδραση της σύγκεντρης κόπωσης στην ιδιοδεκτικότητα και κινητικό έλεγχο του άνω άκρου σε υγιείς συμμετέχοντες.

1 χρόνος

Δίδετε συγκατάθεση για τον εαυτό σας ή για κάποιο άλλο άτομο;	
Εάν πιο πάνω απαντήσατε για κάποιον άλλο, τότε δώσετε λεπτομέρειες και το όνομα του.	

Ερώτηση	ΝΑΙ ή ΟΧΙ
Συμπληρώσατε τα έντυπα συγκατάθεσης εσείς προσωπικά;	
Τους τελευταίους 12 μήνες έχετε συμμετάσχει σε οποιοδήποτε άλλο ερευνητικό πρόγραμμα;	
Διαβάσατε και καταλάβατε τις πληροφορίες για ασθενείς ή/και εθελοντές;	
Είχατε την ευκαιρία να ρωτήσετε ερωτήσεις και να συζητήσετε το Πρόγραμμα;	
Δόθηκαν ικανοποιητικές απαντήσεις και εξηγήσεις στα τυχόν ερωτήματά σας;	
Καταλαβαίνετε ότι μπορείτε να αποσυρθείτε από το πρόγραμμα, όποτε θέλετε;	
Καταλαβαίνετε ότι, εάν αποσυρθείτε, δεν είναι αναγκαίο να δώσετε οποιεσδήποτε εξηγήσεις για την απόφαση που πήρατε;	
(Για ασθενείς) καταλαβαίνετε ότι, εάν αποσυρθείτε, δεν θα υπάρξουν επιπτώσεις στην τυχόν θεραπεία που παίρνετε ή που μπορεί να πάρετε μελλοντικά;	
Συμφωνείτε να συμμετάσχετε στο πρόγραμμα;	
Με ποιόν υπεύθυνο μιλήσατε;	

Σύντομη περιγραφή του προγράμματος (διαδικασίες και σκοπός).
Σας καλούμε να λάβετε μέρος στην έρευνα που πραγματοποιείται από τον υποψήφιο διδάκτορα του Προγράμματος Φυσικοθεραπείας του Πανεπιστημίου Λευκωσίας Στέλιος Χατζησάββας. Το παρόν έγγραφο αποτελεί μια πρώτη ενημέρωση για την έρευνα, ώστε να έχετε πλήρη επίγνωση των ερευνητικών διαδικασιών που θα ακολουθηθούν, για ποιο λόγο πραγματοποιείται η έρευνα και τι προσπαθούμε να βρούμε. Εάν επιθυμείτε μπορείτε να συμβουλευτείτε και να συζητήσετε με άλλους και μετά να μας απαντήσετε εάν επιθυμείτε να συμμετάσχετε ή όχι στην έρευνα. Για οποιαδήποτε απορία ή διευκρίνιση είμαστε στην διάθεση σας για να σας δώσουμε περισσότερες πληροφορίες. Η έρευνα έχει σαν σκοπό να διερευνήσει την επίδραση που έχει η σύγκεντρη μυϊκή κόπωση των στροφέων μυών του στροφικού πετάλου του ώμου στην ιδιοδεκτικότητα του ώμου σε υγιή άτομα. Συγκεκριμένα θα διερευνηθεί η επίδραση της σύγκεντρης μυϊκής κόπωσης των στροφέων μυών του ώμου στην αίσθηση επανατοποθέτησης, στην ικανότητα του κατωφλιού ανίχνευσης της παθητικής κίνησης και στον κινητικό έλεγχο του άνω άκρου.

Λεπτομέρειες του τι θα ζητηθεί ή/και τι θα συμβεί στους συμμετέχοντες στο πρόγραμμα
Εάν τελικά αποφασίσετε να συμμετέχετε στην έρευνα, θα σας ζητηθεί να προσέλθετε σε ένα εργαστηριακό χώρο του Πανεπιστημίου Λευκωσίας. Αρχικά όταν προσέλθετε θα καταγραφούν οι σωματομετρικές σας μετρήσεις (ύψος, βάρος, δείκτης μάζας σώματος). Ακολούθως θα σας δοθεί να συμπληρώσετε ένα ειδικό ερωτηματολόγιο το οποίο θα αξιολογεί την ποιοτική και ποσοτική έκφραση μυοσκελετικού πόνου ή άλλων συμπτωμάτων στα άνω άκρα. Αφού συμπληρώσετε το ερωτηματολόγιο θα ακολουθήσει προσυμπτωματικός έλεγχος από τον ερευνητή που είναι ειδικός Αθλητικός και Μυοσκελετικός φυσικοθεραπευτής. Σε αυτόν τον έλεγχο θα αξιολογηθούν σε εσάς όλες οι κινήσεις του ώμου (με και χωρίς αντίσταση) ώστε να βεβαιωθεί ότι η άρθρωση είναι α-συμπτωματική και το εύρος της κίνησης σε φυσιολογικά όρια. Επιπλέον θα εξεταστείτε με ειδικές ορθοπεδικές κλινικές δοκιμασίες στον ώμο για να διαφανεί εάν ο ώμος παρουσιάζει κάποιο πόνο. Εάν σας παρουσιαστεί πόνος σε περισσότερες από 2 ορθοπεδικές κλινικές δοκιμασίες τότε δεν μπορείτε να συμμετάσχετε στην έρευνα και θα συμβουλεύεστε να επισκεφτείτε ένα γιατρό για επίσημη μυοσκελετική διάγνωση. Μετά από αυτό θα σας ζητηθεί να καθίσετε σε ένα ειδικό μηχάνημα που ονομάζεται ισοκινητικό δυναμόμετρο όπου θα εκτελέσετε κινήσεις στον ώμο σας και το δυναμόμετρο θα καταγράφει κάποιες γωνίες στο εύρος κίνησης. Ακολούθως, θα μετρηθεί η ιδιοδεκτικότητα των άνω άκρων σας πάνω στο ισοκινητικό δυναμετρο. Στο ισοκινητικό δυναμόμετρο αφού πρώτα μετρηθεί το εύρος κίνησης του ώμου μετά θα αξιολογηθείτε ως προς την ικανότητα σας να αντιλαμβάνεστε με κλειστά μάτια μία συγκεκριμένη γωνία τοποθέτησης της άρθρωσης του ώμου, την

ικανότητα σας στο πόσο γρήγορα αισθάνεστε την έναρξη μίας παθητικής κίνησης του ώμου και στο πόσο γρήγορα αντιδρούν και ενεργοποιούνται οι μύες του ώμου σας για να φρενάρουν μία συγκεκριμένη κίνηση που θα είναι αποτέλεσμα παθητικής κίνησης από το ισοκινητικό δυναμόμετρο. Αυτές οι μετρήσεις θα πραγματοποιηθούν σε εσάς δύο φορές. Οι πρώτες μετρήσεις θα πραγματοποιηθούν εφόσον είσαστε ξεκούραστος και οι δεύτερες μετρήσεις αμέσως μετά από μία άσκηση που θα κάνετε στο ισοκινητικό δυναμόμετρο που θα έχει ως στόχο να προκαλέσει κόπωση σε επιλεγμένους μύες του ώμου. Ο λόγος που γίνεται αυτό είναι για να μελετηθεί κατά πόσο η κόπωση επιλεγμένων μυών του ώμου μπορεί να επηρεάσει την ιδιοδεκτικότητα του ώμου. Η άσκηση που θα εκτελέσετε στο ισοκινητικό δυναμόμετρο θα πραγματοποιηθεί στο μη επικρατές άνω άκρο λόγω ευκολότερης πρόκλησης μυϊκής κόπωσης. Αρχικά θα σας δοθούν οδηγίες να εκτελέσετε για 10 λεπτά προθέρμανση (push ups και δυναμικές διατάσεις του άνω ακρου) με σκοπό την πρόληψη οποιουδήποτε τραυματισμού κατά τη διάρκεια της παρέμβασης. Μετά από την προθέρμανση θα καθίσετε ξανά στο ισοκινητικό δυναμόμετρο θα σας δοθούν οδηγίες σχετικά με την ορθότερη εκτέλεση της άσκησης.

Λεπτομέρειες της χρηματοδότησης του ερευνητικού προγράμματος
Το παρόν ερευνητικό πρόγραμμα δεν χρηματοδοτείται.

Λεπτομέρειες οποιονδήποτε κινδύνων που πιθανόν να υπάρξουν ή ταλαιπωρία που τυχόν θα υποστούν οι συμμετέχοντες στο πρόγραμμα.
Κατά την διάρκεια των μετρήσεων δεν θα υπάρξει κάποια ταλαιπωρία για εσάς. Λόγω της άσκησης που θα κληθείτε να εκτελέσετε στο ισοκινητικό υπάρχει μία μικρή πιθανότητα μετά να νιώσετε μυϊκό πόνο αμέσως μετά ή μετά από λίγες ώρες ο οποίος είναι φυσιολογικό επακόλουθο λόγω της άσκησης και είναι μικρής διάρκειας και εξαφανίζεται μετά από λίγο χωρίς να δημιουργεί ιδιαίτερη ενόχληση στον ασκούμενο. Επίσης υπάρχει πιθανότητα να νιώσετε ένα άλλο είδος μυϊκού πόνου που ονομάζεται καθυστερημένος μυϊκός πόνος ο οποίος χαρακτηρίζεται από πόνο και πιάσιμο των ασκούμενων μυών μετά από 24 – 72 ώρες μετά το τέλος της άσκησης. Επειδή όμως θα υπάρχει ένα περιθώριο 2 εβδομάδων μέχρι να έρθετε ξανά να μετρηθείτε αυτός ο μυϊκός πόνος αναμένεται να εξαφανιστεί μετά από 5-7

ημέρες.

Λεπτομέρειες για το ποιες πληροφορίες ή/και τι υλικό θα συλλεγεί στα πλαίσια του προγράμματος, ποιος/ποιοι θα έχουν πρόσβαση σε αυτά και για πόσο χρονικό διάστημα.
Οι πληροφορίες που θα συλλέξουμε μετά από την συγκατάθεσή σας θα αφορούν το φύλο, βάρος, ύψος σας, η λειτουργικότητα του ώμου μέσω ειδικού ερωτηματολογίου και τα αποτελέσματα των διαφόρων μετρήσεων που θα αφορούν τις γωνίες κίνησης του ώμου, την ιδιοδεκτικότητα του ώμου και την άσκηση που θα εκτελέσετε που θα έχει ως στόχο την πρόκληση της μυϊκής κόπωσης Όλες αυτές οι πληροφορίες θα είναι γνωστές μόνο σε εσάς και τους 4 υπεύθυνους. ερευνητές της συγκεκριμένης έρευνας. Οι πληροφορίες αυτές θα κρατηθούν για ένα χρονικό διάστημα τριών χρόνων για σκοπούς ανάλυσης των δεδομένων και μετά θα καταστρέφονται.

ΟΠΟΥ ΙΣΧΥΕΙ, ΜΕΛΛΟΝΤΙΚΗ ΑΠΟΘΗΚΕΥΣΗ ΚΑΙ ΧΡΗΣΗ ΒΙΟΛΟΓΙΚΩΝ ΔΕΙΓΜΑΤΩΝ ΚΑΙ ΠΡΟΣΩΠΙΚΩΝ ΔΕΔΟΜΕΝΩΝ: Παρακαλούμε σημειώστε και υπογράψτε είτε αριστερά είτε δεξιά	
Εκτός από τους σκοπούς του παρόντος προγράμματος που θα διαρκέσει .... χρόνια **Αποδέχομαι** ☐ όπως: Υπογραφή:	Εκτός από τους σκοπούς της παρούσας μελέτης που θα διαρκέσει .... χρόνια **Δεν αποδέχομαι** ☐ όπως: Υπογραφή:
τα βιολογικά μου δείγματα (παρειακά επιχρίσματα ή σάλιο ή DNA) και γενετικά δεδομένα μου που θα φυλάσσονται στο .... **να μπορούν να κρατηθούν πέραν των .... χρόνων και να χρησιμοποιηθούν σε μελλοντικές μελέτες** αφού πρώτα εγκριθεί κάτι τέτοιο από την Εθνική Επιτροπή Βιοηθικής Κύπρου (ΕΕΒΚ) μετά από σχετικό αίτημα ανανέωσης προς την ΕΕΒΚ από τον υπεύθυνο ερευνητή του παρόντος προγράμματος. Καταλαβαίνω ότι θέματα εμπιστευτικότητας θα ισχύουν πάντοτε.	

Σε περίπτωση που ανακαλυφθούν νέες πληροφορίες που επηρεάζουν άμεσα την υγεία σας θα θέλατε να πληροφορηθείτε;		
ΝΑΙ ☐	ΟΧΙ ☐	ΔΕΝ ΜΠΟΡΩ ΝΑ ΑΠΟΦΑΣΙΣΩ ΤΩΡΑ, ΝΑ ΕΡΩΤΗΘΩ ΕΚ ΝΕΟΥ ΕΦΟΣΟΝ ΥΠΑΡΞΕΙ ΑΝΑΓΚΗ ☐

Λεπτομέρειες για το ποια δεδομένα θα προκύψουν για σας στα πλαίσια του προγράμματος και ποιος/ποιοι θα έχουν πρόσβαση σε αυτά και για πόσο χρονικό διάστημα.
Τα δεδομένα που θα προκύψουν από την συγκεκριμένη έρευνα θα είναι κατά πόσο η πρόκληση κόπωσης στον ώμο επηρεάζει την ιδιοδεκτικότητα του ώμου. Μόνο εσείς και οι 4 υπεύθυνοι ερευνητές θα έχουν πρόσβαση στα αποτελέσματα των μετρήσεων για μία περίοδο τριών χρόνων όπου μετά από αυτό το χρονικό διάστημα θα καταστρέφονται.

Αναμενόμενο όφελος για τους συμμετέχοντες
Με την ολοκλήρωση των μετρήσεων ο υπεύθυνος ερευνητής Στέλιος Χατζησάββας θα σας ενημερώσει για τη σημαντικότητα της ιδιοδεκτικότητας και πως σχετίζεται αυτή με την πρόκληση αθλητικών τραυματισμών. Επιπλέον θα σας δείξει διάφορες ασκήσεις στον ώμο που στοχεύουν στην ενίσχυση της ιδιοδεκτικότητας. Επίσης θα σας ενημερώσει σχετικά με την μυϊκή κόπωση και πως αυτή σχετίζεται με την πρόκληση αθλητικών τραυματισμών. Όσον αφορά τη μυϊκή κόπωση ο υπεύθυνος ερευνητής θα σας δώσει συμβουλές για τρόπους αντιμετώπισης της κόπωσης για να αποφύγετε μελλοντικούς αθλητικούς τραυματισμούς.

Αναμενόμενο όφελος για ερευνητές ή/και χρηματοδότες
Η συγκεκριμένη έρευνα έχει ιδιαίτερη κλινική σημασία αφού θα διαφανεί εάν η πρόκληση μυϊκής κόπωσης στον ώμο επηρεάζει την ιδιοδεκτικότητα του ώμου. Τα αποτελέσματα θα μπορούν να βοηθήσουν στο σωστότερο σχεδιασμό προληπτικών προγραμμάτων άσκησης (π.χ περισσότερες ασκήσεις οι οποίες θα ενισχύουν την ιδιοδεκτικότητα) και στον τακτικότερο έλεγχο των αθλητών όσον αφορά την πρόκληση μυϊκής κόπωσης. Επίσης, θα κατανοηθεί καλύτερα η επίπτωση που έχει η μυϊκή κόπωση στη λειτουργία μίας άρθρωσης.

Λεπτομέρειες συνθηκών τερματισμού ή πρόωρης διακοπής του ερευνητικού προγράμματος.

Χώρος και χρονική διάρκεια φύλαξης δεδομένων ή/και βιολογικών δειγμάτων που θα ληφθούν στο πλαίσιο του προγράμματος

Επίθετο:	....	Όνομα:	....
Υπογραφή:		Ημερομηνία:	

Appendix C – Assessment form

ΦΑΣΗ 1

Κάρτα συμμετέχοντα

Ονοματεπώνυμο: ……………………………………………………………………………………………

Κωδικός:…………………

Ηλικία:………………………………

Φύλο:……………………

Σωματικό Βάρος:…………………………..

Ύψος:……………………..

ΔΜΣ:…………….

Κυρίαρχο χέρι:………………………..

Ειδικές ερωτήσεις

Ερώτηση	**ΝΑΙ/ΟΧΙ**
Είχατε κάποιο τραυματισμό στον ώμο τους τελευταίους 6 μήνες;	
Κάνατε κάποιο χειρουργείο στον ώμο;	
Λαμβάνετε αυτό το διάστημα οποιαδήποτε αναλγητική αγωγή;	
Παρουσιάζετε πόνο στον ώμο;	
Έχετε κάποιο νευρολογικό πρόβλημα;	
Έχετε κάποιο καρδιοαναπνευστικό πρόβλημα;	
Είχατε πάθει στο παρελθόν εξάρθρημα ώμου/κάταγμα ώμου/ρήξη στροφικού πετάλου/ρήξη επιχείλιου χόνδρου;	
Έχετε κάποιο πρόβλημα στον αυχένα (π.χ αυχενική ριζοπάθεια);	

Pre-Fatigue tests

1)Upper Quarter Y balance test

Μήκος άνω άκρου (cm): ....

	Left			Right			Difference
Medial							
Inferolateral							
Superolateral							
Absolute reach distance (cm)							
Relative reach distance (%)							
Composite reach distance (%)							

Absolute reach distance = (reach 1 + reach 2 + reach 3) / 3

Relative reach distance = Absolute reach distance / limb length * 100

Composite reach distance = Sum of the 3 reach directions / 3 times the limb length * 100

2) Athletic Shoulder performance test

ASH test						
	Right			Left		
I Position (N)						
Y Position (N)						
T Position (N)						

Ρύθμιση Ισοκινητικού Δυναμόμετρου

Scale or Position	Setting	Right	Left
Chair rotation scale			
Chair-Back angle			
Chair-Seat position			
Dyna Tilt Scale	70°		
Dyna Height Scale		Black	Teal
Dyna Rotation Scale	30°		

Βήματα στο ισοκινητικό δυναμόμετρο:

1) Patient, new και καταχωρώ στοιχεία
2) Test: Shoulder standing IR:ER
3) Single set: Σημειώνω Dyna tilt, Dyna rotation και Dyna Height και μετά πατάω οκ
4) Ρυθμίζω το ανατομικό μηδέν
5) Μετράω ROM
6) Set ROM
7) Mechanical stops
8) Lock για weight limb

Assessment of Range of Motion

Movement	Total ROM	25%	50%	75%
Internal Rotation				
External Rotation				

3) Joint Position Sense

Movement	25%			50%			75%		
Έσω στροφή									
Έξω στροφή									

4) movement detection threshold

Κίνηση	Παθητικά		
Έσω στροφή			
Έξω στροφή			

5) Αντανακλαστικός χρόνος αντίδρασης των έξω στροφέων

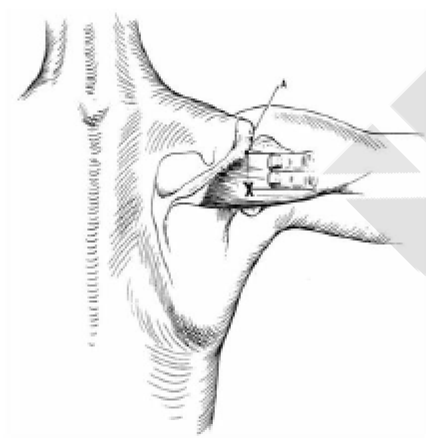
<u>Τοποθέτηση EMG</u>

EMG 1 - Οπίσθιος δελτοειδής: Πρηνής θέση, 90° απαγωγή ώμου με κάμψη αγκώνα. 2 δάκτυλα κάτω από την οπίσθια γωνία του ακρωμίου

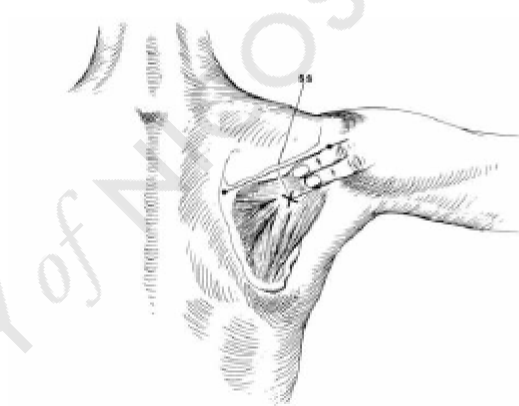
EMG 2 - Υπακάνθιος: 2 δάκτυλα κάτω από την ωμοπλατιαία άκανθα

EMG 3 – Στο βραχίονα του ισοκινητικού δυναμόμετρου

DELTOID, POSTERIOR



INFRASPINATUS



- **Test**
- **Shoulder mode standing**
- **Ok**
- **Right or Left**
- **Single set**
- **Ok**
- **Anatomical Zero and lock**
- **Mechanical stops**
- **Weight limb**
- **Resistance band**
- **Πατάω οκ και φεύγει βραχίονας**

Post Fatigue tests

Εκτέλεση 10 επαναλήψεων συγκεντρης συστολής με μέγιστη προσπάθεια

Κίνηση	Max Torque	40% of max torque
Έσω στροφή		
Έξω στροφή		

Post Fatigue tests

	Left	Right	Difference
Medial			
Inferolateral			
Superolateral			
Absolute reach distance (cm)			
Relative reach distance (%)			
Composite reach distance (%)			

Athletic shoulder test						
	Right			Left		
I Position (N)						
Y Position (N)						
T Position (N)						

Joint position sense

Movement	25%			50%			75%		
Έσω στροφή									
Έξω στροφή									

Threshold to Detection of Passive Movement

Κίνηση	Παθητικά		
Έσω στροφή			