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肩胛動作異常的過肩運動員在水中太極運動的肩胛肌肉活化探究

Effects of Ai Chi on scapular muscles activation in overhead athletes with scapular dyskinesis

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本研究希望能提供一個嶄新的復健視角，讓醫療人員對運動員的水中訓練有更加清晰的脈絡，也期許這篇文章能開啟世界上更多的水中運動科學研究。

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中文摘要

背景：肩胛區域肌群，包含上斜方肌、下斜方肌和前鋸肌，對於肩胛的穩定和肩膀的運動至關重要。然而，過肩運動員常常存在肩胛骨穩定肌群肌力較弱的問題，在功能性的肩胛穩定訓練運動，可能導致上斜方肌過度活化。因此，本研究旨在調查過肩運動員肩胛動作異常者在水中和陸地上進行水中太極運動時，肩胛區域肌肉的活化情形。**實驗方法：**本實驗有二十一名肩胛動作異常的過肩運動員，在水中與陸地進行水中太極運動，同時使用表面肌電圖測量上斜方肌、下斜方肌、前鋸肌和闊背肌的肌肉活化，並計算肩胛區域的肌肉平衡比值:上斜方肌/下斜方肌、上斜方肌/前鋸肌和下斜方肌/前鋸肌，以評估肩胛穩定的控制能力。**研究結果顯示**，在水中進行水中太極運動時，上斜方肌的收縮力全面衰退，平均降至1.6－3.0% 最大自主收縮（$p < .001$），而下斜方肌與前鋸肌略為減弱(下斜方肌：4.3－12.7% 最大自主收縮，前鋸肌：6.3－11.7% 最大自主收縮）。這導致上斜方肌/下斜方肌比值降為0.4至0.7（$p < .001$），上斜方肌/前鋸肌比值降為0.3至1.0（$p < .001$）。當水中太極的進程達到更高穩定需求的動作時，便增進了肩胛穩定肌群的活化效果，與陸上環境的肌肉活化效果無顯著差異，這些動作包含:1)下斜方肌在水中太極的展翅運動（水中vs.陸地：5.9±0.7 vs. 9.4±1.5，$p = .014$），2)下斜方肌在水中太極的內折運動（水中vs.陸地：9.4±1.4 vs. 12.2±1.8，$p = .033$），3)前鋸肌在水中太極的內折運動（水中vs.陸地：6.9±1.9 vs. 5.8±2.1，$p = .434$）。慢速的水中運動，通常會導致水中測得的肌肉活化較陸地更低，但由於不成比例的肌力下降，水中環境使肩胛區域呈現較陸地上更理想的發力表現，平日過度活化的上斜方肌於此時被抑制，下斜方肌與前鋸肌皆因水中運動的促進而接近陸上表現。並且水中太極的水中肌肉顯示較高的下斜方肌/前鋸肌比值（水中vs.陸地的展翅運動：2.3 ± 0.6 vs. 0.6 ± 0.1，$p < .001$ 和水中vs.陸地的匯集運動：2.2 ± 0.4 vs. 1.2 ± 0.2，$p = .009$），這代表下斜方肌與前鋸肌對肩胛作用的力偶旋轉軸往胸椎靠近，呈現肩胛內收的穩定姿勢，有助於肩胛胸椎關節的穩定性。**結論：**在水中進行的水中太極運動，有效抑制過肩運動員的上斜方肌活化，改善肩胛肌肉平衡比值，提升肩胛穩定控制力。本實驗結果指出，水中的水中太極運動在執行手臂運動時，能使肩胛肌群以適當的發力表現，控制肩胛處於較為內收的穩定位置，

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水中太極應為良好的肌肉再教育的運動形式，有助於提升肩胛動作異常的過肩運動員的肩胛區域健康。

關鍵詞：動力鍊、肩胛動作異常、水療、水中太極、過肩運動員、肌電圖

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Abstract

The periscapular muscles, which include the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA), are crucial for scapular stabilization and shoulder movement. However, overhead athletes are known to have weak scapular stabilizers, and certain functional training exercises may primarily activate the UT muscles rather than the LT and SA. Therefore, this study aims to investigate the activation of periscapular muscles during Ai Chi exercises in water and on land for overhead athletes with scapular dyskinesis. Twenty-one overhead athletes with scapular dyskinesis performed Ai Chi exercises in water/on land while surface electromyography was used to measure muscle activation of the UT, LT, SA and latissimus dorsi (LD). The UT/LT, UT/SA, and LT/SA ratios were calculated to evaluate the scapular stability control. The findings revealed that during Ai Chi exercises in water, there was a significant decrease in UT activation (1.6-3.0% maximal voluntary isometric contraction, MVIC, $p < .001$). In contrast, the LT and SA showed a slight reduction in activation (LT: 4.3-12.7% of MVIC; SA:6.3-11.7% of MVIC), leading to a decreased UT/LT (0.4 to 0.7, $p < .001$) and UT/SA (0.3 to 1.0, $p < .001$). As the Ai Chi exercises progressed to movements with higher stability demands, the activation of the scapular stabilizing muscle group showed no significant difference between aquatic and land environments in the following: 1) LT during the Uplifting exercises (aquatic vs. land: 5.9 ± 0.7 vs 9.4 ± 1.5, $p = .014$), 2) LT during the Folding exercises (aquatic vs. land: 9.4 ± 1.4 vs 12.2 ± 1.8, $p = .033$), and 3) SA muscle during the Folding exercises (aquatic vs. land: 6.9 ± 1.9 vs 5.8 ± 2.1, $p =.434$). This can be attributed to the slow arm motions during Ai Chi exercises in water, leading to lower muscle activations compared to land-based exercises. However, as the exercises progressed and higher levels of stabilization were

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required, the activation of LT and SA increased, facilitating power transfer from the trunk to the arms in the water environment. The disproportionate decrease in periscapular muscle activations of UT, LT and SA in the aquatic environment led to better force performance compared to land exercises. Additionally, the aquatic Ai Chi exercises demonstrated higher LT/SA ratio (aquatic vs. land during the Uplifting exercises: 2.3 ± 0.6 vs. 0.6 ± 0.1, $p < .001$ and during the Gathering exercises: 2.2 ± 0.4 vs. 1.2 ± 0.2, $p = .009$), indicating improved thoracoscapular stabilization for the individuals with scapular dyskinesis. The aquatic Ai Chi exercises effectively inhibited the overactive UT and promoted appropriate muscle activation in the scapular region. These findings suggested that aquatic Ai Chi exercises may reeducate the periscapular muscles to stabilize the thoracoscapular joint and improve the scapular control in overhead athletes with scapular dyskinesis.

Keywords: Ai Chi, scapular dyskinesis, overhead athletes, kinetic chain, hydrotherapy, surface EMG

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Contents

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doi:10.6342/NTU202302157

doi:10.6342/NTU202302157

Chapter 1: Introduction

Background

Overhead athletes perform skilled arm movements with trunk rotation and bodyweight shifts, forming kinetic chains (KC) (Chu et al., 2016; Ellenbecker & Aoki, 2020; Sciascia et al., 2012). KC concept proposes the need for coordination among joints whereby movement at one joint affected adjacent joint motion in the kinetic link (Kibler, 1998; Saini et al., 2020). For sport-specific overhead activity, combination of the core, scapula and upper extremity constitutes a complex motor control. Moreover, the proper scapula function serves as an important linkage among joints for sport performance (Kibler et al., 2013; Saini et al., 2020; Sciascia et al., 2012; Voight & Thomson, 2000).

Control deficit in KC can overstress the scapula during sport-specific overhead activities. During a tennis serve, research indicates that 54% of power is generated from the hip and trunk, whereas 25% is from the upper limb (Kibler, 1994). A 20% loss in kinetic power from the hip and trunk when serving a ball would require a 34% increase in arm velocity to achieve the same force output (Kibler, 1995). An athlete with weak core strength may impede the power flow of KC and overstress the scapula when pitching or serving a ball (Ellenbecker & Aoki, 2020; Kibler, 2018). Kinetic power originates from the core, in particular, the latissimus dorsi (LD) attaches to the iliac crest, sacrum, thoracic and lumbar spine, thoracolumbar fascia and extends to the humerus. Performing overhead activities, the LD connects the shoulder and pelvic girdle to transmit the energy from the core to the upper extremity.

In addition to affect power transmission along KC, poor coordination of the periscapular muscle can change the scapula/shoulder biomechanics. The scapular

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stabilizers, serratus anterior (SA) and lower trapezius (LT), control the scapular motion when raising or lowering of the arm (Miyakoshi et al., 2019; Paine & Voight, 1993). Researchers indicate that a pitcher tends to have more anterior and forward scapular position and displays a decreased SA and LT activities during baseball pitching (Sciascia et al., 2012). Besides, low SA and LT activation accompanied by overactive upper trapezius (UT) is related to the inferior/ medial boarder prominence of the scapula, the most common scapula dyskinesis (SD) in overhead athletes, (Huang et al., 2017; Huang, Ou, et al., 2015). Athletes with SD have a 43% increased risk of a shoulder pain in the following 2 years than those without SD (Hickey et al., 2018). For sport-specific overhead activity, role of the scapula has been described as a funnel for force transmission and a fulcrum for stability throughout the rapid arm sequence (Saini et al., 2020). The aims of scapular dyskinesis rehabilitation should involve a protocol of low load with high repetitions (Osteras et al., 2010).

Aquatic rehabilitation has been extensively studied and documented for athletes with shoulder injuries, including conditions like rotator cuff injuries and shoulder impingement. It is widely recognized that aquatic exercises, which leverage the properties of buoyancy and water resistance, are beneficial for individuals with shoulder disorders (Brady et al., 2008; Burmaster et al., 2016; Thein & Brody, 1998, 2000). Hydrostatic pressure during aquatic exercises results in forceful inspiration, reduces residual air volume in the lungs, and increases the venous returns to the central cavity, potentially enhancing sports recovery (Geigle & Brody, 2000; Wilcock et al., 2006). The buoyancy of water can be utilized to provide an assistance, resistance or support during exercises, enhancing stretching and strengthening effects for various motions (Thein & Brody, 2000). The buoyancy of water induces instability, requiring individuals

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to constantly engage their core muscles for stability before initiating movements.

"Ai Chi" is a widely practiced water exercise developed by Jun Konno in the 1990s, and it is commonly utilized by physiotherapists worldwide. Ai Chi exercises involve performing movements in functional postures, such as squats, lunges, and one-leg stands, making it a type of kinetic chain (KC) training. The fundamental principle of Ai Chi's movement patterns is characterized by "heavy feet and light body" (Konno, 1999), aligning with the KC concept of "anticipatory postural adjustments (APAs)." This APAs’s concept emphasizes the importance of stabilizing the body before initiating movement (Sciascia, Thigpen et al., 2012). Research has shown that functional KC training effectively activates the scapular muscles (De Mey, Danneels et al., 2013).

Furthermore, the slow speed of water exercises leads to lower activation of shoulder muscles and reduced mechanical load on the shoulder joint (Kelly et al., 2000; Lauer et al., 2018). The deliberate pace of Ai Chi exercises, following the rhythm of diaphragmatic breathing, facilitates deep and controlled breathing activities, promoting greater mobility in the rib cage and that may increase flexibility of the attached muscles and fascia between the spine, ribs, and scapula.

Statement of the problems

Scapular dyskinesis (SD) is a prevalent issue among overhead athletes, negatively impacting their performance and increasing the risk of shoulder injuries. Previous research has highlighted the importance of addressing SD rehabilitation goals, particularly in reducing UT activation while promoting SA and LT muscle activities (Cools et al., 2007; Schory et al., 2016).

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Understanding the significance of the force couple in the scapular region, researchers have emphasized the assessment of UT/LT, UT/SA, and LT/SA muscle balance ratios, with an ideal ratio below 1.0 indicating greater activation of LT and SA relative to UT during arm motions (Cools et al., 2007). Additionally, Michener et al. (2016) observed lower LT/SA ratios in individuals experiencing subacromial pain during arm raising and lowering motions. Sciascia and Cromwell (2012) reported that arm elevation between 60-120 degrees in an upright training position activates the UT. To address excessive UT activation, certain literature suggests incorporating non-functional positions, such as side-lying, quadrant, plank, or prone positions, during training, although it is important to note that these positions may potentially discourage activation of the kinetic chain (KC).

This study utilized the KC-based Ai Chi exercise, a water-based exercise that involves performing movements in functional positions, facilitating effective power transfer from the core to the limbs. The water environment reduces the impact of gravity on the body, resulting in reduced global muscle activation (Psycharakis et al., 2019), including decreased activation of the UT muscle (Schory, Bidinger et al., 2016). The buoyancy experienced during water exercises can be utilized to provide an assistance or resistance, challenging arm movements and potentially reinforcing scapula stabilization, thus enhancing the power linkage from the kinetic chain. Lauer et al. (2018) recommended maintaining arm motion speed below 30 degrees per second for shoulder stabilization exercises. Furthermore, Castillo-Lozano et al. (2013) suggested a specific sequence to challenge arm stability, starting with shoulder flexion followed by shoulder abduction, which aligns with the Ai Chi exercises of Floating and Uplifting, respectively.

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Considering these benefits, Ai Chi may be a suitable exercise option for overhead athletes with SD. However, to date, there has been no study investigating the effects of aquatic exercises on scapular stabilizers, particularly in relation to the KC-based approach, in overhead athletes with SD. Therefore, a research gap exists in understanding the impact of KC-based aquatic exercises on scapular muscles specifically in this population.

Purpose of the study

The purpose of this study was to investigate muscle activations of the UT, LT, SA, LD, and muscle balance ratios of UT/LT, UT/SA and LT/SA in overhead athletes with SD via KC-based exercise in water and on land. KC-based exercises including the movement patterns of Ai Chi: Floating, Uplifting, Folding, Gathering, which consist of shoulder flexion/extension, abduction/adduction, horizontal abduction/adduction, internal and external rotation, scapular protraction/retraction combined with spinal rotation. Moreover, the progression of Ai Chi exercises, in accordance with the challenge for body balance, follows a sequence from Floating, Uplifting, Folding, to Gathering. The analysis of periscapular muscle activation during water exercises was also conducted.

Hypothesis

The first null hypothesis stated that there was no significant difference in periscapular muscle activities, including the UT, LT, SA, LD, and balance ratios of UT/LT, UT/SA and LT/SA, between aquatic Ai Chi and land Ai Chi exercises in overhead athletes with SD. Conversely, the first alternative hypothesis stated that

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aquatic Ai Chi exercises resulted in a significant decrease in UT activation, UT/LT and UT/SA, as well as a significant increase in LT, SA and LD muscle activities and LT/SA ratio compared to land Ai Chi exercises in overhead athletes with SD. The second null hypothesis stated that there was no significant difference in UT, LT, SA and LD activations among aquatic Ai Chi exercises in overhead athletes with SD. Conversely, the second alternative hypothesis stated that was a significant difference in UT, LT, SA and LD activation between aquatic Ai Chi exercises in overhead athletes with SD.

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Chapter 2: Literature review

Scapular dyskinesis (SD) and kinetic chain (KC) deficits in overhead athletes

Scapular dyskinesis (SD) refers to abnormal scapular movement control. The excessive internal rotation, anterior tilt, or decreased upward rotation of the scapula causes the scapular to tip, wing, or snap during arm motions (Kibler, Ludewig et al. 2009, Ludewig and Reynolds 2009, Kibler, Sciascia et al. 2012, Kibler, Ludewig et al. 2013, Kibler and Sciascia 2019). SD is a common condition among overhead athletes (Sciascia, Thigpen et al. 2012, Burn, McCulloch et al. 2016, Chu, Jayabalan et al. 2016, Saini, Shah et al. 2020); the prevalence of SD among overhead athletes was 61% compared to 33% among non-overhead athletes. (n=1257, 144, $p < .0001$) (Burn, McCulloch et al. 2016). It has been demonstrated that 35% of athletes with SD will be diagnosed with shoulder pathologies within 2 years, while 25% of athletes without SD will have shoulder pathologies; SD increases the likelihood of future shoulder pain in asymptomatic athletes by 43% (Hickey, Solvig et al. 2018).

According to the SD classification proposed by Kibler WB, there are four types of scapular dyskinesis while arm moving, Type 1: inferior angle prominence; anterior tipping; Type 2: medial border prominence; excessive internal rotation; Type 3: superior border prominence; excessive or adequate scapular elevation, upward rotation; and Type 4: normal, symmetric scapula motion (Kibler, Uhl et al. 2002). Mixed type of Type 1 and Type 2 was shown to be the most prevalent among overhead athletes, according to research (Huang, Lin et al. 2017).

Various kinds of SD are characterized by distinct changes in scapular muscle activation. UT hyperactivity is one of the characteristics of Type 2 SD, which internal

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rotates the scapula and causes medial border prominence; whereas, Mixed type of SD is characterized by low activation of LT and serratus anterior (SA) (Huang, Ou et al. 2015). SD alters the biomechanics of the periscapular muscles and is detrimental to the transmission of force along the KC (Kibler, Ludewig et al. 2013). The objective of SD rehabilitation is to balance the force couples between the periscapular muscles (Huang, Ou et al. 2015).

Proper kinetic chain (KC) sequences, often known as "nodes", are crucial for athletic performance (Sciascia, Thigpen et al. 2012). If the nodes are not met, excessive loads are placed on the upper extremities, leading to shoulder pain and injury (Sciascia, Thigpen et al. 2012). Shoulder pathologies associated with SD include shoulder instability, impingement, labral lesion, rotator cuff injury, acromioclavicular (AC) joint dysfunction, and cervical issues (Kibler, Sciascia et al. 2012, Kibler, Ludewig et al. 2013, Kibler and Sciascia 2019).

Kinetic chain deficiency is detrimental to scapular motion and is caused by a lack of flexibility and poor muscle function in the lower body (Kibler, Ludewig et al. 2013). Importantly, the trunk and Legs contribute more than 50% of the force when throwing or serving the ball (Ellenbecker and Aoki 2020); tight but weak muscles, such as quadriceps, hip abductors, hip rotators, and lower back musculature, limit energy transmission through KC and increase joint loads of distal limbs (McMullen and Uhl 2000, Sciascia and Cromwell 2012). Reduced knee flexion reduces force transmission to the hip and trunk in tennis players, while increasing shoulder horizontal adduction and elbow valgus loads by 23 and 27 percent, respectively (Elliott, Fleisig et al. 2003). Forty-nine percent of athletes with labral tears are accompanied by a lack of hip rotator and hip abductor flexibility and muscular strength (Burkhart, Morgan et al. 2000).

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Inadequate KC function changes the force generation and transfer, which increases the risk for shoulder or elbow injuries (Kibler, Press et al. 2006, Sciascia, Thigpen et al. 2012, Kibler, Ludewig et al. 2013). There is an increasing understanding of the significance of incorporating KC principles into SD rehabilitation regimens for overhead athletes (McMullen and Uhl 2000, Sciascia and Cromwell 2012, Kibler, Ludewig et al. 2013, Yamauchi, Hasegawa et al. 2015, Miyakoshi, Umehara et al. 2019).

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Anatomy of periscapular muscles and its function

The muscles that connect the scapula to the thorax are the serratus anterior (SA), trapezius, rhomboids, levator scapulae, and pectoralis minor. The stabilizers of the scapula, the serratus anterior (SA) and lower trapezius (LT), maintain the correct trajectory of scapular motions when the arm is raised and lowered (Johnson, Bogduk et al. 1994, Nasu, Yamaguchi et al. 2012). Particularly, the lower portion of the SA collaborates with the LT as force couples to the scapula during forward flexion (Paine and Voight 1993).

Ludewig, Cook et al. (1996) reported that as the arm is elevated from 0 to 140 degrees, the scapula reduces its internal rotation, increases its posterior tilt and upward rotation, and activates the UT, LT and SA. For LT activation, there was a considerable recruitment from 0 to 90 degrees and consistently upward rotates the scapula; above 90 degrees that LT has reduced activation, conversely. For SA activation, Januario, Machado Cid et al. (2022) reported that SA has the most activation between 90 and 125 degrees of shoulder elevation, as similar as the previous study of Ludewig et al (1996).

In individuals with SD, research has revealed that UT is overactive, whereas SA and LT are underactive. Pathologic shoulder problems, such as shoulder impingement or subacromial pain, have been associated with hyperactive UT (Cricchio and Frazer 2011, Mintken, McDevitt et al. 2016, Karabay, Emuk et al. 2020). Moreover, Umehara, Kusano et al. (2018) indicated that fatigue SA resulted in increased UT activation. Cricchio and Frazer (2011) found that early UT activation occurs during arm elevation in people with shoulder impingement, whereas arm lowering results in early SA deactivation. Michener, Sharma et al. (2016) discovered altered muscle balance ratios of increased UT/LT and decreased LT/SA in individuals with subacromial pain during

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active arm raising. This study concluded that the LT is the key muscle, and that the coordination of the LT and its associated synergists, the SA and UT, should be emphasized for normal, pain-free shoulder function.

Transferring KC energy is dependent on the function of the core muscles. From an anatomical standpoint, the thoracolumbar fascia fuses with the aponeurosis of the latissimus dorsi (the lower back to the arm), connecting with the LT; delivers force from the core to distal portions of the upper extremities (Kibler, Press et al. 2006, Sciascia, Thigpen et al. 2012, De Mey, Danneels et al. 2013). The aim behind KC for SD rehabilitation is to achieve proximal stabilization of the core and upper quarter as necessary for fluid motions of the distal limbs (McMullen and Uhl 2000).

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Kinetic chain (KC) exercises for periscapular muscle activation

When prescribing scapular stabilization programs, an increasing number of studies have incorporated KC training (McMullen and Uhl 2000, Sciascia and Cromwell 2012, Yamauchi, Hasegawa et al. 2015, Miyakoshi, Umehara et al. 2019). The proximal to distal movement sequence was utilized in KC-based exercises involving the trunk and/or legs. The core and lower extremities function as the generator of force, and energy is transferred to the distal arm via the linkage components (McMullen and Uhl 2000). Aaron Sciascia et al. deduced that proper core stabilization drives KC function and that KC is advantageous for better scapular stabilization, i.e., to reeducate the core muscle, improve the flexibility of upper and lower extremities (UE and LE), and restore muscle balance in the scapular region (Sciascia and Cromwell 2012).

The suggested position for KC training places the scapula in retraction; the intensity of training should maintain low loads with high repetitions (Kibler, Ludewig et al. 2013, Kibler, Press et al. 2006, Tate, McClure et al. 2008) and include trunk movements, such as flexion, extension, or rotation (Yamauchi, Hasegawa et al. 2015, Miyakoshi, Umehara et al. 2019) and it should combine with LE motions, such as squat, lunge, one leg squat (De Mey, Danneels et al. 2013). Similarly, a comprehensive study indicated that KC training is more beneficial for LT and SA activation than non-KC exercises (Richardson, Lewis et al. 2020).

KC training includes both open kinetic chain (OKC) and closed kinetic chain (CKC) activities. For instance, push-ups are one type of CKC exercises in which the participant's hands remain fixed on the ground, which gives an axillary load to the shoulder joints, raises articular compressive forces (Turgut, Pedersen et al. 2016), and stimulates the inhibited periscapular muscles (Sciascia and Cromwell 2012). Some CKC

doi:10.6342/NTU202302157

exercises, including 1) the push-up and its modifications: half push-up, knee push-up, push-up plus, knee plus up plus (Maenhout, Van Praet et al. 2010, Sciascia and Cromwell 2012, Karabay, Emuk et al. 2020) and 2) the press-up (Sciascia and Cromwell 2012, Mendez-Rebolledo, Morales-Verdugo et al. 2021), are suitable for activating the periscapular muscle. On the other hand, OKC exercises permit the distal region to move freely without fixation (not hold on to ground or slings), e.g., 1) shoulder abduction with external rotation, 2) horizontal abduction (scapular retraction) cooperating with trunk rotation in prone, sitting, or standing positions (Yamauchi, Hasegawa et al. 2015, Miyakoshi, Umehara et al. 2019), 3) Scapular retraction training with squat, lunge, one-leg stand (De Mey, Danneels et al. 2013); 4) shoulder dump exercise combining trunk rotation with weight shifting via PNF D2 flexion-extension pattern (McMullen and Uhl 2000, Voight and Thomson 2000).

Balance the force couples of the periscapular muscle is critical for SD rehabilitation, particularly establishing adequate trapezius activation, while activating the LT and inhibiting the UT. Researchers (Cools, Dewitte et al. 2007) supported keeping the muscle balance ratio of UT/LT below 1.0 as an ideal ratio, that indicates LT activates more than UT while performing arm motions. The suggested KC exercises for ideal UT/LT are pone push up (UT/LT ratio: 0.34), half push up (UT/LT ratio 0.48-0.50), one hand push up (UT/LT ratio: 0.38), one hand knee push up (UT/LT ratio : 0.28), scapular retraction (UT/LT ratio: 0.40), unstable plank (UT/LT ratio: 0.35), one hand plank (UT/LT ratio: 0.28- 0.48); seated position: press up (UT/LT ratio: 0.34-0.48); standing position: half pull up (UT/LT ratio: 0.58) and isometric pull up (UT/LT ratio: 0.08) (Karabay, Emuk et al. 2020, Mendez-Rebolledo, Morales-Verdugo et al. 2021).

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In addition, studies found that non-functional positions, such as prone, side-lying, and spine orientations, inhibit KC activation (Cools, Dewitte et al. 2007, Schory, Bidinger et al. 2016), whereas erect training positions seem to facilitate UT, particularly within the shoulder flexion of 60 to 120 degree (Schory, Bidinger et al. 2016). However, UT activation in an upright training position is controversial (Cools, Dewitte et al. 2007, De Mey, Danneels et al. 2013, Mendez-Rebolledo, Morales-Verdugo et al. 2021).

Importantly, the foundation of KC is "anticipatory postural adjustments (APAs)," which refers to a preprogrammed muscle activation. Before kicking or serving a ball, for instance, athletes should stabilize themselves to achieve a stable position capable of withstanding the disturbance caused by an external force (McMullen and Uhl 2000). The characteristic of APAs is stabilization followed by mobilization of the limbs, which is also present in aquatic training exercises.

According to our knowledge, KC-based exercises improve scapular stability. In addition to the extensive research on the content of KC-based exercises, the following problems are still the subject of debate: 1) According to researchers, performing the exercises in a side-lying or prone position reduces UT activation (Cools, Dewitte et al. 2007, Schory, Bidinger et al. 2016). That is, anti-gravity movements that are performed in functional positions activate the upper trapezius; whereas "nonfunctional positions discourage proper KC activation" (Sciascia and Cromwell 2012). 2) Unstable training situations reduces LT and SA activation (Lehman, Gilas et al. 2008, De Mey, Danneels et al. 2013, De Mey, Danneels et al. 2014, Piraua, Pitangui et al. 2014). Performing scapular retraction exercises in stable positions, such as the static squat, static lunge, and static one-leg standing, resulted in greater activation of the periscapular muscles (De Mey, Danneels et al. 2013). Until now, there is no study reveals that unstable positions

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in water discourage periscapular muscles' recruitment.

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Aquatic shoulder rehabilitation and Ai Chi exercises

For ages, water has been used for healing, relaxation, and training. Contributing to buoyancy and water temperature, which promote an increased range of joint mobility and passive stretching. For aquatic exercises, hydrostatic pressure, water viscosity, and fluid dynamics supply the supporting and resistive modules. During water training, cardiovascular function and core stabilization improve. The protocols for aquatic rehabilitation for injured swimmers and volleyball players, as well as for rotator cuff problems, shoulder instability, and impingement are well documented (Thein and Brody 1998, Thein and Brody 2000, Brady, Redfern et al. 2008, Burmaster, Eckenrode et al. 2016). After shoulder surgery, shoulder range of motion is improved with early aquatic therapy intervention. Passive flexion range of motion is considerably enhanced following six sessions of aquatic therapy, with a mean difference of 46 degrees (95 % Confidence Interval (CI): 17– 75, *p* = .005) at three weeks and 30 degrees (95 % CI: 8–51, *p* = .01) at six weeks (Brady, Redfern et al. 2008). As stated previously, buoyancy and water resistance, which can serve as training protocols for fluid motions throughout kinetic chains, are advantageous to aquatic exercises.

"Ai Chi" is a popular water exercise performed by physiotherapists around the world that was developed by Jun Konno in the 1990s. Ai Chi exercises encourage fluid motions generated from the core and lower extremities, gradually moving towards the distal part of the extremities (Brody, 2009), all of which are performed in functional positions (e.g., squat, lunge, one-leg stand) to enhance kinetic chain activation (Sciascia & Cromwell, 2013).

In addition, performing Ai Chi exercises in water, buoyancy can lessen the

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compressive loads on joints, support the limbs, and facilitate stretching. Since soft tissue flexibility and muscular performance are the most important rehabilitation method for shoulder rehabilitation (Cools, Struyf et al. 2014), aquatic Ai Chi activities may be the optimal KC training.

Ai Chi is a fluid motion technique with sequences and diaphragmatic breathing (Konno and Brody 2009). Ai Chi has demonstrated advantages for balance, functional mobility, quality of life, gait performance, and trunk muscle endurance; it is applicable to neurological patients with Parkinson's disease and stroke, as well as orthopedic patients with low back pain (Kurt, Buyukturan et al. 2018, So, Ng et al. 2019, Ku, Chen et al. 2020, Perez-de la Cruz 2021). Slow motion speed in Ai Chi is safe and effective, and research indicates that less than 30 degrees per second in water is beneficial for shoulder range of motion in individuals with shoulder instability (Lauer, Vilas-Boas et al. 2018a, 2018b). Ai Chi is an alternative to shoulder rehabilitation that is safe. Floating, Uplifting, Folding and Gathering are Ai Chi movement patterns that involve shoulder flexion-extension, abduction-adduction, external-internal rotation, scapular retraction- protraction, horizontal abduction-adduction and spinal rotation.

Begin Ai Chi with the depressed shoulder position, maintaining a long distance between the ear lobe and acromion to heighten awareness of the scapular position (Konno 1999). Ai Chi corresponds to the "correct training postures and motions, promoting scapular motion, regulating protraction and exaggerating retraction, and working in numerous planes" advised by Kibler and Sciascia (2019) in the kinetic chain rehabilitation paradigm.

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In addition, gravity-eliminating exercises decrease UT activation (Schory, Bidinger et al. 2016) and Ai Chi offers a variety of functional positions conducted in a reduced gravity setting. As a result of buoyancy, the human body is unstable and floats, posing a challenge to the core muscle every minute; therefore, individuals must maintain their stability prior to moving. Along the same lines, the fundamental of Ai Chi movement patterns is "heavy feet and light body" (Konno 1999), which is in accordance with the KC notion of "anticipatory postural adjustments (APAs)" via stabilization first and mobilization second (Sciascia, Thigpen et al. 2012). The effect of KC-based water exercises on periscapular muscles is important to uncover for SD rehabilitation but has not yet been investigated.

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Underwater muscle activation of core and shoulder regions

The modern surface electromyography (sEMG) equipment is wireless, lightweight, and transportable. Bluetooth communication eliminates the restrictions of laboratory settings and body motions. In comparison to conventional sEMG, wireless sEMG is less affected by water drag (Psycharakis, Coleman et al. 2019). Measuring the muscle activations in water, underwater EMG has been applied in water for decades and is maturing progressively (Kelly, Roskin et al. 2000, Colado, Tella et al. 2008, Castillo-Lozano, Cuesta-Vargas et al. 2014, Cuesta-Vargas and Cano-Herrera 2014, Pinto, Alberton et al. 2015, Lauer, Vilas-Boas et al. 2018a, 2018b).

As far we know, increased motion speed brings larger water resistance. If the angular velocity increases by 10 %, the joint load will increase by 25 % (Castillo-Lozano, Cuesta-Vargas et al. 2014). When water exercises are performed at 84 to 86 degrees per second, the mechanical strain on the shoulder is greater than when the same speed is performed on land. At 90 degrees per second, the periscapular muscle is much more activated than on land (Kelly, Roskin et al. 2000, Castillo-Lozano, Cuesta-Vargas et al. 2014). According to a study by Jessy Lauer et al. (2018) on the shoulder mechanics of water exercises, slow arm motions (30 degrees/second) impose less mechanical demand on the shoulder joints, approximately 3-4 times less than the same exercises performed on land. In line with a previous study by Romualdo Castillo-Lozano et al. (2014), the speed of arm motions in water affects shoulder muscle activity. For aquatic strengthening exercises, a higher velocity of arm motions (above 90 degrees/second) leads to higher activation of the latissimus dorsi, pectoralis major, and deltoid muscles in the water environment.

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However, higher speed results in shorter durations of shoulder stabilization, as indicated by the fact that water exercise at 90°/s reduces shoulder stabilization periods by 10 % (Lauer, Vilas-Boas et al. 2018). For early rehabilitation of the upper extremity, and for stabilizing purposes, the arm movement speeds below 30°/s are appropriate (Lauer, Vilas-Boas et al. 2018).

In addition, it is vital to consider the directions of movements, i.e., buoyancy-assistive, buoyancy-supportive, or buoyancy-resistive movements, particularly during the initial period of aquatic rehabilitation. According to research, scapular stabilization training in water should begin with shoulder flexion, then advance to shoulder abduction, and conclude with scaption exercises. Moreover, the study reported the underwater shoulder exercises in abduction and scaption challenge shoulder stability and significantly engage pectoralis major and latissimus dorsi, even at slow speed of 30 degrees/second (Castillo-Lozano, Cuesta-Vargas et al. 2014).

In conclusion, aquatic exercises offer a variety of intensities and training positions that can be tailored to each individual's needs. Regarding stability goals, the speed of water exercises must be below 30 degrees per second, and the first exercise should be “the shoulder flexion and extension exercise”, as the “Floating exercise” of Ai Chi movement pattern.

Aquatic activities stimulated the trunk stabilizers and proximal muscles (e.g., gluteal region and thigh) more than land-based exercises, according to systematic reviews examining muscle activations using underwater sEMG (Cuesta-Vargas and Cano-Herrera 2014, Silva, Dias et al. 2020). To core muscle activation in water, research revealed no

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statistically significant difference between water levels (Colado, Borreani et al. 2013). That is to say, the water environment challenges core muscles while individuals exercising all the time and that facilitates KC chain function and should benefit the scapular stabilization. However, the effect of water exercise on the stabilizers of the upper quarter, the scapular stabilizers, is still unknown.

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Chapter 3: Methods

Study design

The study was a cross-sectional observational study.

Subjects

Sample size estimation

Based on the pilot study, a sample size of 25 subjects was calculated to achieve 80% power in detecting the effect size (Cohen's d value of 0.93) on SA activity during Floating exercise when comparing two conditions (water versus land) with an anticipated dropout rate of 20%.

The pilot study was initiated in April 2022. The investigator recruited five healthy participants who performed Ai Chi exercises, including Floating, Uplifting, Folding, Enclosing, Soothing, and Accepting with grace, along with conventional scapular stabilizers training exercises, i.e. push-up plus and press-up between 2 conditions. The investigator observed that the activation of the lower trapezius and serratus anterior muscles was higher during Floating, Uplifting, and Folding exercises in the water environment compared to when these exercises were performed on land. Moreover, the investigator executed a reliability test for the pilot study with ICC > .9 (excellent).

Criteria

Participants were recruited from recreational athletes engaged in overhead sports

doi:10.6342/NTU202302157

activities for at least 3 hours per week, aged between 20 and 35 years old. The investigator conducted a scapular dyskinesis test (SDT, McClure et Al., 2009) to assess the scapular motions of each participant (see Figure 3). Participants weighing less than 68.1 kg used 3-lb dumbbells, while participants weighing more than 68.1 kg used 5-lb dumbbells. Those showing asymmetrical scapular motion were included in this study.

The exclusion criteria included individuals who had experienced shoulder/neck pain in the last 3 months (Visual Analog Scale > 7/10), severe shoulder trauma (such as shoulder sprains, strains, or collisions), severe scoliosis (Cobb angle > 25 degrees), upper extremity surgery (including the shoulder, clavicle, or elbow), peripheral nerve injury, neurological diseases affecting sensation or motor function (numbness, tingling, muscle weakness), or a body mass index (BMI) > 25. Additionally, participants with infectious diseases (such as upper respiratory tract infection or skin infection) were also excluded. All eligible volunteers provided written and informed consent prior to their participation. The study was approved by the Institutional Review Board of the National Taiwan University Hospital.

Instrumentation

For EMG measurements, the 4-channel Mini-Wave Waterproof EMG system (Cometa SRL, Milan, Italy) was used. This system was wireless and waterproof, substantially reducing active drag in water and movement inhibition compared with systems with external cables connecting electrodes to amplifiers. Special rubber gaskets were applied to affix the clip which bore a pre-gelled surface on the opposite side of the electrode. The waterproof electrodes were secured onto the skin surface by double-sided tape. The

doi:10.6342/NTU202302157

sampling rate was performed at 2000 Hz. The EMG signals detected by a Wave Plus receiver (Cometa, Milan, Italy) connected to the computer. The remote acquisition mode in Data Acquisition Tools (DAT) software (Cometa, Milan, Italy) was used for wireless transmission within a distance of 20 m. The signals acquired were exported as ASCII format into a .c3d file to be analyzed.

Procedures

The procedure of this study is illustrated in Figure 1. Participant were dressed in swimming suits. The skin sites for the electrodes were gently abraded and cleaned with alcohol pads (Kelly et al., 2000). The electrode placements for UT, LT, SA, and LD muscles followed the guidelines from Criswell & Cram (2011), Tsuruike & Ellenbecker (2015), Zanca et al. (2014), as shown in Figure 2. To establish a normalization reference for sEMG data, the investigator conducted the maximal voluntary isometric contraction (MVIC) test for each participant's target muscles of the dominant hand (see Figures 4 to 7). The MVIC was performed to estimate maximal sEMG amplitude for UT, LT, SA and LD as presented in Table 3. Three MVIC trials were performed for each muscle, with each trial lasting 5 seconds and 1-minute rest period between trials. To normalize muscle activation during water exercises, land-based MVIC were used as a reference, following the approach of Pinto et al. (2010). The investigator collected data from the 0.75 seconds before and after the peak MVIC value, resulting in a total of 1.5 seconds of data used for analysis.

Following the MVIC tests, the participants practiced Ai Chi exercises (Figures 8 to 11) for about 5 minutes to become familiar with the movements. The coordinated movements of body parts and the diaphragmatic breathing patterns involved in Ai Chi are

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listed in Tables 4 and 5. Land-based Ai Chi exercises, i.e. Floating, Uplifting, Folding and Gathering, were performed in 5 trials, with the motion speed controlled less than 30 degrees per second. During Ai Chi exercises, the muscle activity of UT, LT, SA and LD of the dominant hand was recorded using sEMG. There was a 10-second rest between trails and one-minute rest between exercises. The investigator used a metronome, provided verbal cues, and demonstrated the Ai Chi motions facing the participant simultaneously. For the participants' convenience, the Ai Chi movements were first performed on land and then repeated in the water. The time interval between land-based and aquatic Ai Chi exercises was 10 minutes.

In the water environment, performing shoulder movements in different planes presented challenges to arm stability, with increasing difficulty observed in the following sequence: shoulder flexion, followed by shoulder abduction (Castillo-Lozano R et al. 2013). The exercise sequence in this study began with the Floating exercise, followed by the Uplifting, Folding, and Gathering exercises. Participants performed aquatic exercises at the water level between the xiphoid and shoulder to assess muscle activation in the arms. This approach was based on Colado et al.'s study (2013), which reported higher activation of the latissimus dorsi (LD) muscle at the xiphoid level compared to the neck level.

Participants performed water exercises at a water depth between the xiphoid and shoulder levels, with the water temperature maintained at 30-32 degrees Celsius (see Figure 12). The total duration of this study was approximately 1.5 hours, including sEMG setup, MVIC tests, and Ai Chi exercises in both aquatic and land-based settings. The land-based and aquatic sEMG data collection setup is illustrated in Figure 21.

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Outcome measures

The outcomes of periscapular muscle activation was shown as the percentage of MVIC of UT, LT, SA, LD and the muscle balance ratio was calculated as UT/SA, UT/LT and LT/SA.

Data reduction

The data were collected at a sampling rate of 2000 Hz and then the input signals were amplified and converted into digital signals. The EMG signals were analyzed by applying a bandpass filter (20 Hz high pass, 300 Hz low pass, Criswell & Cram, 2011), followed by rectification and smoothing using a 100-millisecond window. The data were then converted into root mean square (RMS) values and normalized based on the maximal voluntary isometric contraction (MVIC) as a percentage of muscle contraction.

The investigator selected the most consistent sEMG amplitudes of each movement for analysis. For MVIC, land-based Ai Chi exercises, and aquatic Ai Chi exercises, three trials were conducted to average the mean values and calculate the standard errors of measurement, as well as the median value of the muscle activities. The data processing results are shown in Figures 22 to 25.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS) 22.0 (IBM, USA) was used for data analysis. The Shapiro-Wilk test was performed to confirm the normal distribution of outcomes. Wilcoxon Signed Ranks Test and Paired Samples Test were used to analyze the

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normalized RMS of periscapular muscle activation between land-based Ai Chi and aquatic Ai Chi exercises. The alpha level was set at .05/4 due to multiple comparisons of the UT, LT, SA, and LD muscles. A *p*-value under .0125 indicated significance.

Chapter 4: Results

This study included a total of 23 overhead athletes with scapular dyskinesis (SD), among whom 4 exhibited obvious SD and 19 showed subtle SD. The data of two participants were not included in the analysis. One female athlete reported pain and was unable to achieve maximum muscle strength during the maximal voluntary isometric test, while another participant showed abnormally low activation of the serratus anterior muscle. These two individuals were considered symptomatic and were subsequently excluded from the study. In the end, 21 participants were included, with 3 showing obvious SD and 18 showing subtle SD. The 21 participants, consisting of 18 male and 3 female athletes, with a mean age of 24.3 ± 3.6 years old, mean height of 174.5 ± 6.2 cm, mean weight of 68.1 ± 8.7 kg, mean BMI of 22.3 ± 2.0, and 18 participants were right-hand dominant while 3 were left-hand dominant. Table 6 provides a summary of the participants' demographic data. The test-retest reliability of muscle activations during Ai Chi exercises ranged from .76 to .98, indicating good to excellent reliability (Table 7).

As shown in Table 8, the study measured the normalized root mean square (RMS) of periscapular muscle activation, including the upper trapezius (UT), lower trapezius (LT), serratus anterior (SA), and latissimus dorsi (LD), during the performance of Ai Chi exercises on land and in water. Muscle activation of the UT, LT, and SA significantly decreased when performing the Ai Chi exercises in water ($p < .0125$, see Figure 13-16). However, no significant difference was found between environments for the LT activation during the Uplifting and Folding exercises ($p = 0.014$, 0.033, respectively) and for the SA activation during the Folding exercise ($p = 0.434$), as presented in Table 8. Additionally, no significant difference in LD activation was observed between environments for Uplifting, Folding, and Gathering exercises (p = 0.95, 0.26, 0.10, respectively, see Table 8).

Furthermore, the study calculated the muscle balance ratios of UT/LT, UT/SA, and LT/SA and computed their means and standard error of the mean (SEM), which are presented in Table 9. The data showed statistically significant differences between aquatic Ai Chi and land-based Ai Chi for UT/LT and UT/SA ($p < .001$, see Table 9). Specifically, for aquatic Ai Chi exercises, the UT/LT ratios ranged from 0.4 to 0.7, and the UT/SA ratios ranged from 0.3 to 1.0. However, for land-based Ai Chi exercises, the UT/LT ratios ranged from 1.1 to 3.9, and the UT/SA ratios ranged from 0.9 to 3.5.

In terms of LT/SA, the aquatic Uplifting and Gathering exercises showed increased values compared to land-based Uplifting and Gathering (2.3 vs 0.6, $p < .001$; 2.2 vs 1.2, $p = .009$, respectively, see Table 9). These findings suggest that the condition in which aquatic Ai Chi exercises were performed can significantly affect the activation of periscapular muscles in individuals with scapular dyskinesis.

Our study also compared periscapular muscle activations among 4 water-based Ai Chi exercises (see tables 10 to 13 & Figures 17 to 20). For the LT muscle, the aquatic Uplifting elicited greater activation compared to that in aquatic Floating ($p = .006$), while aquatic Folding and Gathering showed comparable activation ($p = .068$). For the SA muscle, higher activation on aquatic Floating and Gathering exercises compared to those on aquatic Uplifting and Folding exercises ($p < 0.001$). For the LD activation, progressed significant decrease from Floating, Uplifting to Folding ($p < .001$). It is noteworthy that water-based Folding exercises exhibited the highest LD activation, reaching 21.7% of maximal voluntary isometric contraction (MVIC), while the other exercises remained below 10% MVIC. The Gathering exercise elicited similar LD activation as Uplifting (*p* = .768) and Floating (*p* = .339).

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Chapter 5: Discussion

In the present study, the Ai Chi exercises were performed at a controlled speed of less than 30 degrees per second, resulting in slight but effective activation of scapular stabilizers and improved periscapular muscle balance. The results revealed that the muscle activation of UT, LT, SA, and LD were generally lower in water compared to land, except for the LT activation during Uplifting and Folding exercises, the SA activation during Folding exercises, and the LD activation, which showed no significant differences during Uplifting, Folding, as well as Gathering exercises between water and land conditions.

According to Lauer et al. (2018), it is recommended to control the speed of arm movements in water exercises at less than 30 degrees per second to enhance shoulder stability. However, performing slow motions in water may result in lower water resistance and reduced mechanical demands on the shoulders compared to the same exercises performed on land, leading to less activation of the shoulder muscles (Kelly et al., 2000; Castillo-Lozano et al., 2014; Lauer et al., 2018). The trade-off between lower muscle activation and increased scapular stabilization was evident in the improved muscle ratios of UT/LT, UT/SA, and LT/SA compared to those ratios observed on land.

The non-proportional decrease in periscapular muscle activities resulted in the UT/LT and UT/SA ratios being lower than 1.0, indicating decreased UT activations compared to LT and SA. Additionally, findings revealed that the recruitment of the UT was low during these exercises due to the buoyancy of the water, which facilitated arm lifting and reduced the effort required by the UT.

The LD muscle is connected to the thoracolumbar fascia and can be one of the core

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muscles activated during challenging stability. As the exercises progressed and challenged body balance, particularly in the Uplifting and Folding exercises, the activation of the LD muscle significantly increased in the water.

For LT activation, our findings suggest that when transferring energy from the core to the upper extremities in the water environment, trunk movements effectively targeted the LT muscle and required thoracolumbar stabilization. The LT muscle plays a crucial role in transferring energy from the core to the upper extremities. In individuals with scapular dyskinesis, the LT muscle is supposed to be in a lengthening condition, as demonstrated in a sonography study by Seitz et al. (2015). According to the length-tension relationship, a lengthened muscle is more susceptible to weakness (Kendall et al., 2010). Our study on aquatic exercises demonstrated that the LT muscle exhibited high recruitment during unstable training positions, necessitating individuals to maintain a stable and firm posture to stabilize the core muscles and lower extremities, thereby generating more power from the core for arm movements. Trunk rotation exercises, specifically Gathering, utilizing the kinetic chain, were shown to elicit LT muscle activation, as supported by previous studies involving trunk rotation into arm motions (Miyakoshi et al., 2019 and Yamauchi et al., 2015). In our study, we observed lower ratios of UT/LT compared to those in Yamauchi T et al.'s study (2015). The UT/LT ratio was 0.4 ± 0.1 (our study) vs 0.6 ± 0.4 (Yamauchi T et al. 2015). It is possible that less recruitment of the UT was likely due to the buoyancy provided by the water. Relatively less decreased LT muscle activity was due to buoyancy lessening the arm weight and the slightly increased LT activation due to buoyancy lessening the body weight of individuals, thereby stabilizing the core and the upper trunk,

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including the thoracoscapular joint during trunk rotation. Our findings are in line with the study advocated by Bid et al. (2013), supporting the role of the LT muscle in stabilizing the scapula and thoracolumbar region, ultimately enhancing the transmission of force along the kinetic chain.

For SA activation, our findings suggest that performing the Floating exercises in water can be as effective as the unstable Gathering exercise for SA muscle activation. During aquatic Floating exercises, buoyancy assists shoulder flexion and provides continuous resistance for shoulder extension. Individuals with shoulder impingement, who tend to experience early deactivation of the SA muscle (Phadke et al, 2013), may benefit from the aquatic Floating exercises because buoyancy serves as an external cue for continuous force during SA eccentric contraction. Moreover, aquatic Folding exercises can be advantageous for both the core muscle (LD) and the scapular stabilizer (SA). As the inspiratory muscles of LD and SA, the diaphragmatic breathing during aquatic Ai Chi exercises may enhance the flexibility of LD and SA, as well as the periscapular muscles and soft tissues that attach to the rib cage and the scapula. In the water environment, the hydrostatic pressure also leads to harder breathing and encourages rib cage mobility, enhancing pulmonary function, which is important for sports recovery. There was a notable trend of increased SA activation during aquatic Folding, with nearly half of the participants (10 out of 21 participants) showing higher SA muscle activation in water compared to land-based Folding. Additionally, the activation of the LD during aquatic Folding was consistently above 20% of MVIC, while other aquatic exercises (aquatic Floating, aquatic Uplifting, and aquatic Gathering) showed LD activation below 10%. This finding led the investigator to

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speculate that aquatic Folding exercises may enhance LD activation, which could help lower the humeral head and create more space in the subacromial region. This, in turn, could potentially provide the SA muscle with more space to perform upward scapular rotation and improve glenohumeral function and space. The LD muscle functions as a humeral shaft depressor, similar to the teres major, and may contribute to a better acromion-humeral distance, as reported by Chien et al. (2023). Moreover, the LD muscle showed increased activations during aquatic Floating, aquatic Uplifting, and aquatic Folding, which represented a progression from easier to harder stability challenges. However, in the most difficult exercise, aquatic Gathering, the LD muscle exhibited lower activation compared to aquatic Folding. The investigator attempted to explain these results from two perspectives: 1. During aquatic Gathering exercises, the LD muscle may primarily function as a shoulder adductor rather than a core stabilizer. As a result, the role of the LD muscle in this exercise was focused on moving the arm rather than stabilizing the trunk. 2. The higher level of instability in aquatic Gathering, beyond what the stabilizer muscles could tolerate, might have led to decreased muscle activation of the stabilizers. This phenomenon is supported by previous studies such as Lehman et al. (2008), De Mey et al. (2013, 2014), Piraua et al. (2014).

In general, aquatic Ai Chi exercises effectively targeted the scapular stabilizers, specifically the LT and SA, without excessive activation of the UT. The UT/LT ratio (range: 0.4-0.7) and UT/SA ratio (range: 0.3-1.0) significantly decreased during all water-based Ai Chi exercises, indicating greater activation of LT and SA with reduced UT contraction. A larger LT/SA ratio is associated with improved scapular and shoulder

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function, as observed in a subacromial pain study by Michener LA et al. (2016). Notably, significant increases in the LT/SA ratio were observed during water-based Uplifting and Gathering exercises (range: 2.2-2.3). Compared to the SA, the LT muscle is more susceptible to weakness, leading to destabilization of the scapular rotation axis (Bid et al., 2013). Thus, when considering the LT/SA ratio, it is supposed to have a higher value, indicating a higher activation of LT compared to SA, which promotes better stabilization of the thoracoscapular joint and scapular retraction.

Ai Chi exercises involve slow and graceful arm movements and results in low muscle activations of the arms. To address the issue of intensity variations, it is suggested to incorporate larger devices and/or water currents. Colado et al. (2013) indicated that there were no significant differences in arm muscle activation when using different devices (such as small or large sizes, drag devices, or float devices) for water resistance. The use of smaller devices may result in faster movement, while larger devices lead to slower movement, resulting in similar arm muscle activations. Another approach is to add water currents, as performing shoulder horizontal abduction and adduction exercises with water currents elicits greater muscle activation in the chest and trunk regions compared to the same exercises performed on land (Colado et al., 2008). As mentioned above, we suggest incorporating larger devices on the hands and/or adding water currents to enhance the power transfer from the kinetic chains and potentially recruit more scapular stabilizer activation.

The Ai Chi motions, combined with arm exercises while maintaining squat or lunge positions, are supported by De Mey et al. (2013), who reported that scapular retraction

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exercises with squat or lunge positions facilitate activation of the lower trapezius muscle. In our study, the Gathering exercise in water resulted in 12.7 ± 1.8% of maximal voluntary isometric contraction (MVIC) for the lower trapezius muscle with trunk rotation movements. This is comparable to the mean value of 15.93% MVIC reported by De Mey et al. (2013) during land-based kinetic chain exercises. Additionally, the researchers found no significant difference in activations of the upper trapezius and lower trapezius muscles between concentric, isometric, and eccentric phases. However, in our opinion, buoyancy provides assistive, supportive, and resistive external forces and stimulation to the human body, so it is necessary to examine the different phases of arm movements in a water environment to clarify the force direction exerted by buoyancy.

Limitations of the study should be noted. Firstly, we did not provide specific sEMG data for each phase (concentric/eccentric) of the Ai Chi exercises. Instead, the results presented average muscular activities during exercises performed on land and in water. Therefore, it is not possible to determine the exact timing and duration of the highest recruitment within each phase. Furthermore, our study did not utilize a three-dimensional analysis device to assess the consistency of range of motion in the shoulder and spinal joints. Additionally, in some instances, the data recorded for UT activations in the water environment exhibited abrupt signals, possibly due to larger water eddies splashing on the sEMG electrodes caused by poor control of the arm motions. These abnormal data points were excluded from the analysis. Moreover, the joint angles of squatting and lunge positions during land-based Ai Chi and aquatic Ai Chi exercises were not accurately examined in this study. The leg positions on land were performed comfortably for the

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subjects. Further investigation is required to validate the effect of different angles of the lower extremities during exercise on periscapular muscle activities.

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Chapter 6: Conclusion

Aquatic Ai Chi exercises effectively reeducated the periscapular muscles, enhancing scapular stabilization and improving muscular control in overhead athletes with scapular dyskinesis. Compared to land-based Ai Chi exercises, aquatic Ai Chi resulted in lower shoulder muscle activation. The findings showed a substantial decrease in upper trapezius (UT) activation in water, along with minor decreases in lower trapezius (LT) and serratus anterior (SA) activation, leading to UT/LT and UT/SA ratios below 1.0. This indicated efficient engagement of scapular stabilizers without overactivating the UT during aquatic Ai Chi exercises. Notably, certain aquatic Ai Chi exercises exhibited a significantly higher LT/SA ratio, providing evidence for superior thoracoscapular stabilization in the aquatic setting. Incorporating aquatic Ai Chi exercises into scapular dyskinesis rehabilitation protocols may lead to improve the thoracoscapular stabilization outcomes.

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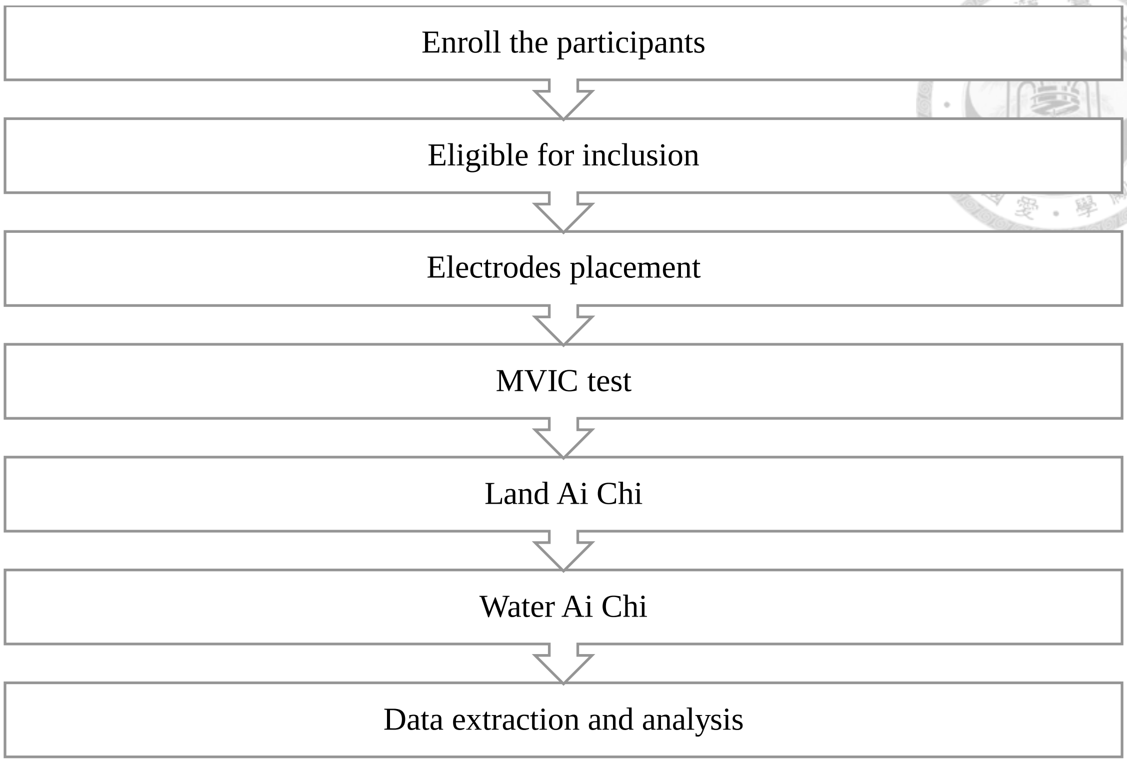

Figure 1. Flowchart of the experiment

The scapular dyskinesis test (SDT) was performed on individuals eligible for inclusion

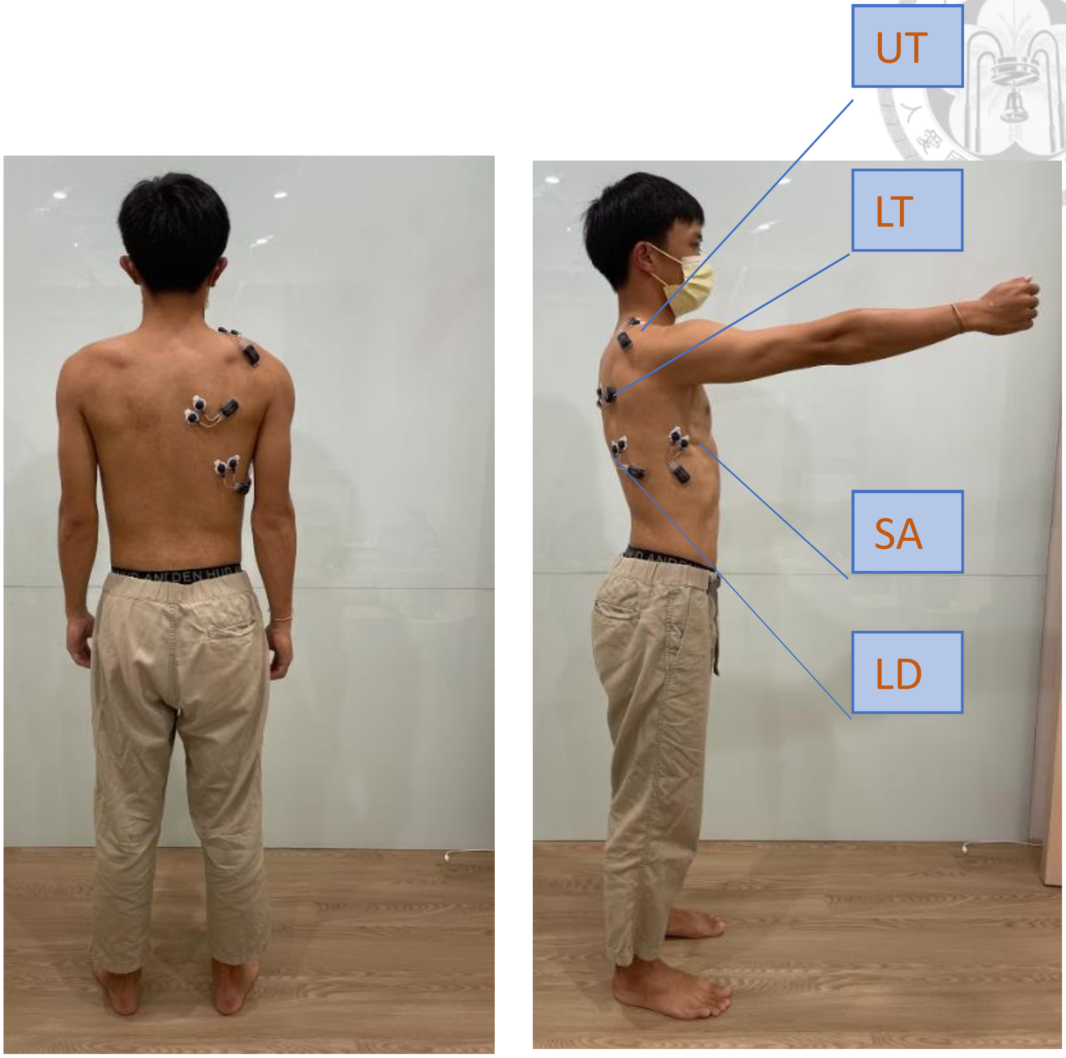

Figure 2. Posterior and lateral views of electrodes placement

These pictures show the sEMG electrodes attached to the upper trapezius (UT), lower trapezius (LT), serratus anterior (SA), and latissimus dorsi (LD).

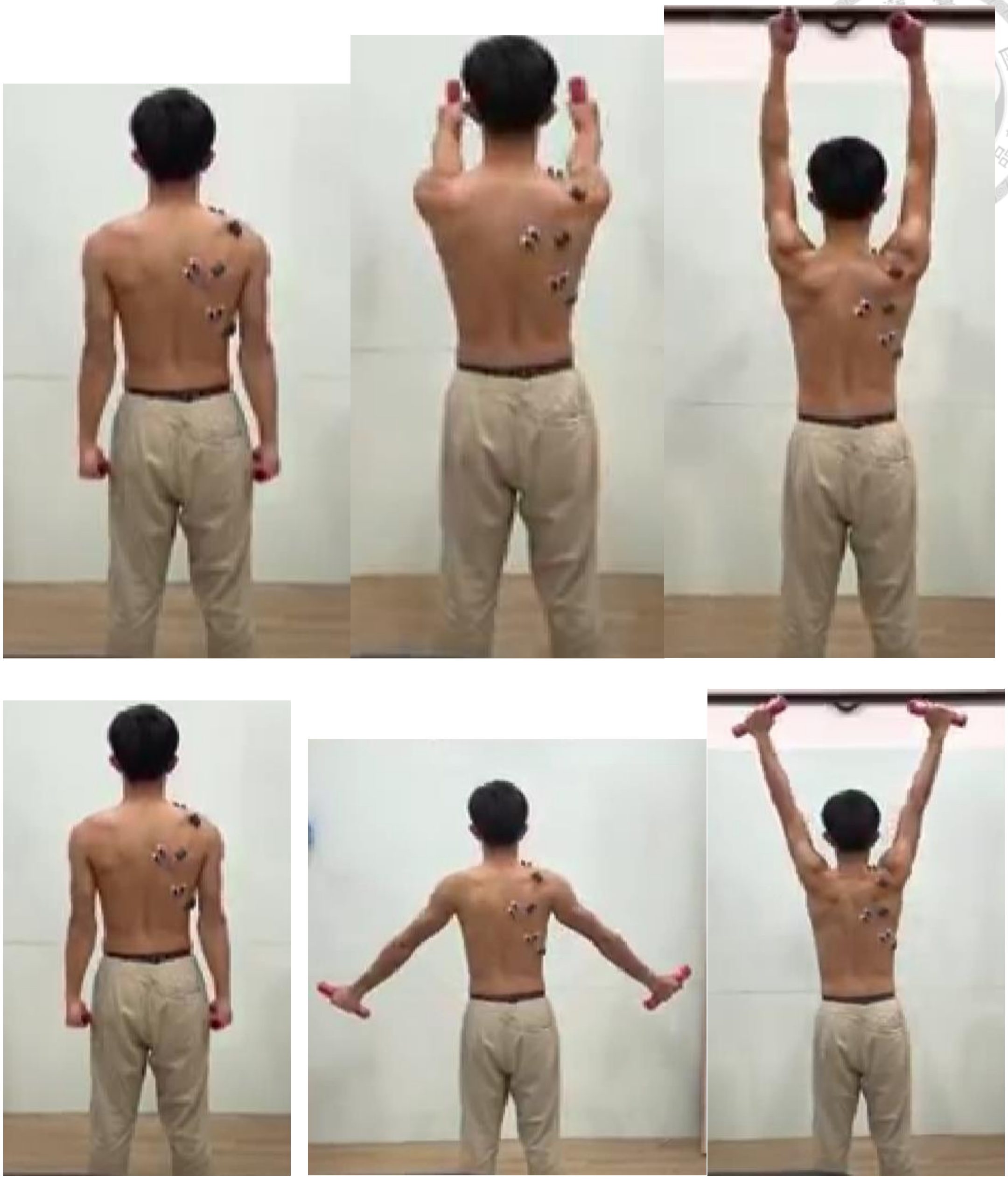

Figure 3. Scapular dyskinesis test (SDT)

The participant performed shoulder flexion-extension exercises for 5 repetitions and shoulder abduction-adduction exercises for 5 repetitions. This study recruited individuals with asymmetrical motions of the scapula, classified as subtle or obvious scapular dyskinesis (McClure et al., 2009).

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Figure 4. Maximal voluntary isometric contraction test of upper trapezius (UT)

For UT activation, individual performed the resisted shoulder 90-degree flexion.

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Figure 5. Maximal voluntary isometric contraction test of serratus anterior (SA)

For SA activation, individuals performed resisted shoulder 135-degree flexion and protraction.

doi:10.6342/NTU202302157

Figure 6. Maximal voluntary isometric contraction test of lower trapezius (LT)

For LT activation, individuals performed resisted shoulder elevation at the position of shoulder abducted to 135 degrees.

doi:10.6342/NTU202302157

Figure 7 Maximal voluntary isometric contraction test of latissimus dorsi (LD)

For LD activation, individuals performed resisted shoulder adduction and extension in the position of shoulder extension, internal rotation, and adduction.

doi:10.6342/NTU202302157

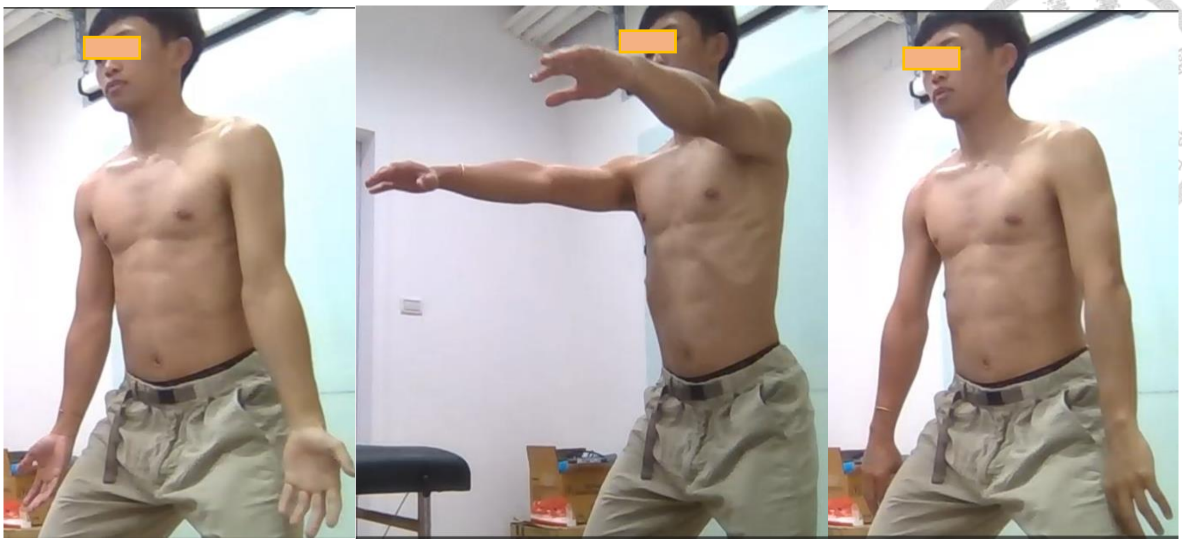

Figure 8. Ai Chi – Floating exercise

Perform shoulder flexion and extension exercises with diaphragmatic breathing:

Inhale through the nose, turn the palms up and let the arms float up to 90-degree shoulder flexion. Exhale through the mouth, turn the palms down and let the arms lower in front of the body (Konno and Brody 2009).

Figure 9. Ai Chi – Uplifting exercise

Perform shoulder abduction and adduction exercises with diaphragmatic breathing:

Inhale through the nose, turn the palms up and let the arms float up to 90-degree shoulder abduction. Exhale through the mouth, turn the palms down and let the arms lower to the sides of the body (Konno and Brody 2009).

Figure 10 Ai Chi – Folding exercise

Perform shoulder external rotation and internal rotation exercises with diaphragmatic breathing: Inhale while external rotating the shoulders, retract the scapula, open the chest with the elbows in; exhale while internal rotating the shoulder and let the hands on the belly (Konno and Brody 2009).

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Figure 11. Ai Chi – Gathering exercise

Perform unilateral horizontal adduction and abduction with spinal rotation in a lunge position. If the dominant hand is the right hand, the right side should be the front leg. Keep the eyes and head following and turning in the same direction as the arm moves. Inhale through the nose while externally rotating and horizontally abducting the dominant shoulder, and simultaneously retract the scapula with neck and upper trunk rotation. Exhale through the mouth while internally rotating and horizontally adducting the dominant shoulder, and protract the scapula with neck and upper trunk rotation to return to the neutral position (Konno and Brody, 2009).

doi:10.6342/NTU202302157

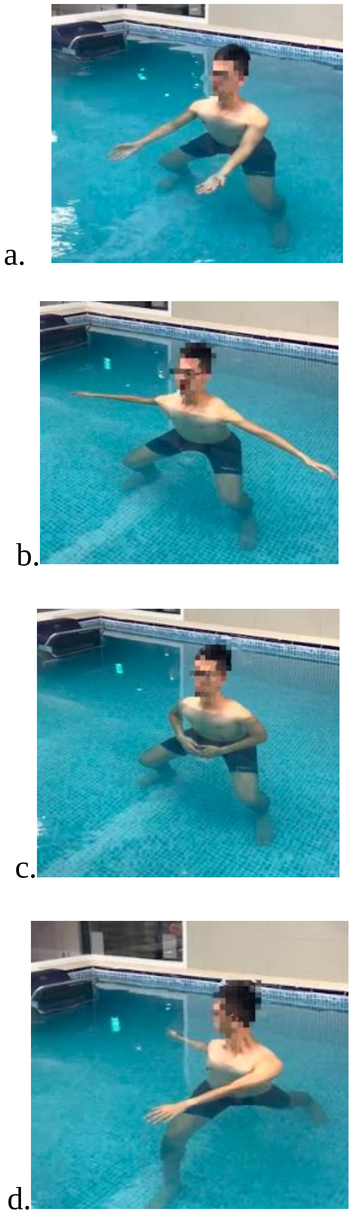

Figure 12 Aquatic Ai Chi exercises

(a) Floating, (b) Uplifting, (c) Folding and (d) Gathering

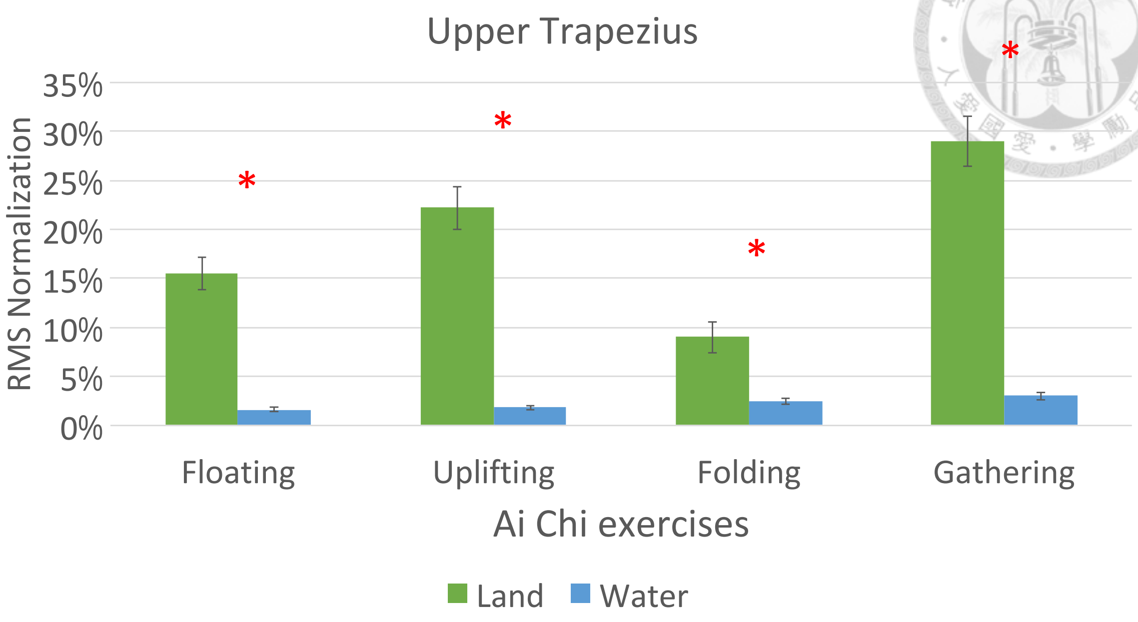

Figure 13. Upper Trapezius activations during Ai Chi exercises

The X-axis represents the Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The green bar indicates the land-based Ai Chi exercises, and the blue bar indicates the aquatic Ai Chi exercises. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC).

doi:10.6342/NTU202302157

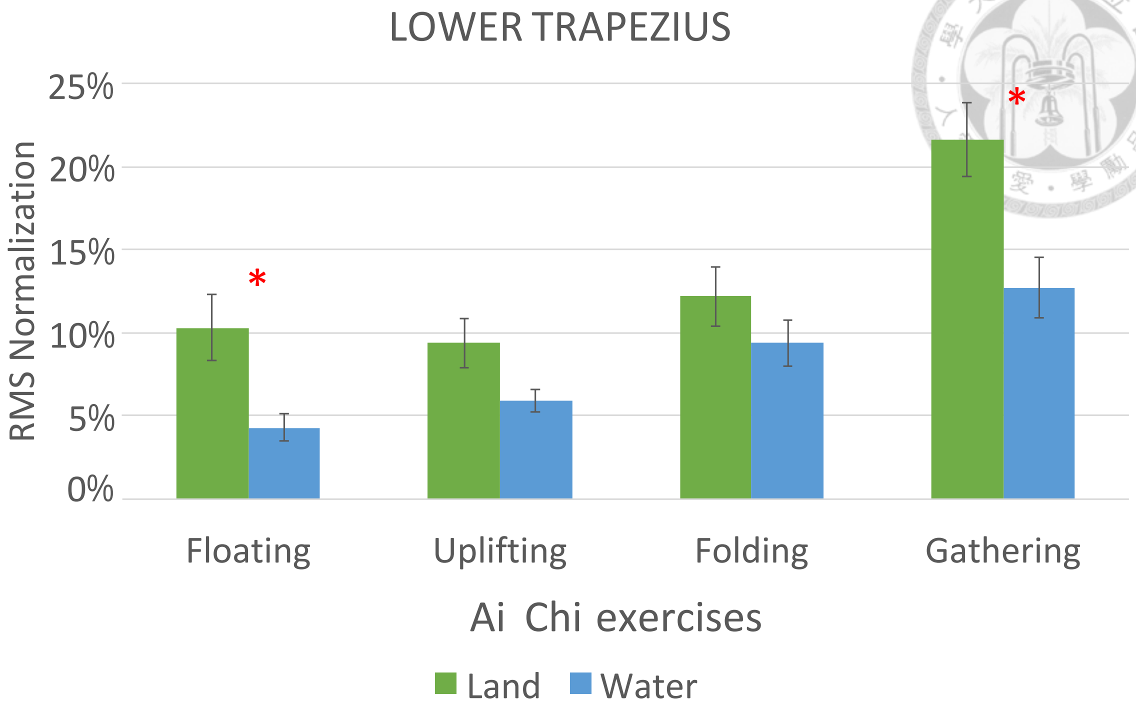

Figure 14. Lower Trapezius activations during Ai Chi exercises

The X-axis represents the Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The green bar indicates the land-based Ai Chi exercises, and the blue bar indicates the aquatic Ai Chi exercises. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC).

doi:10.6342/NTU202302157

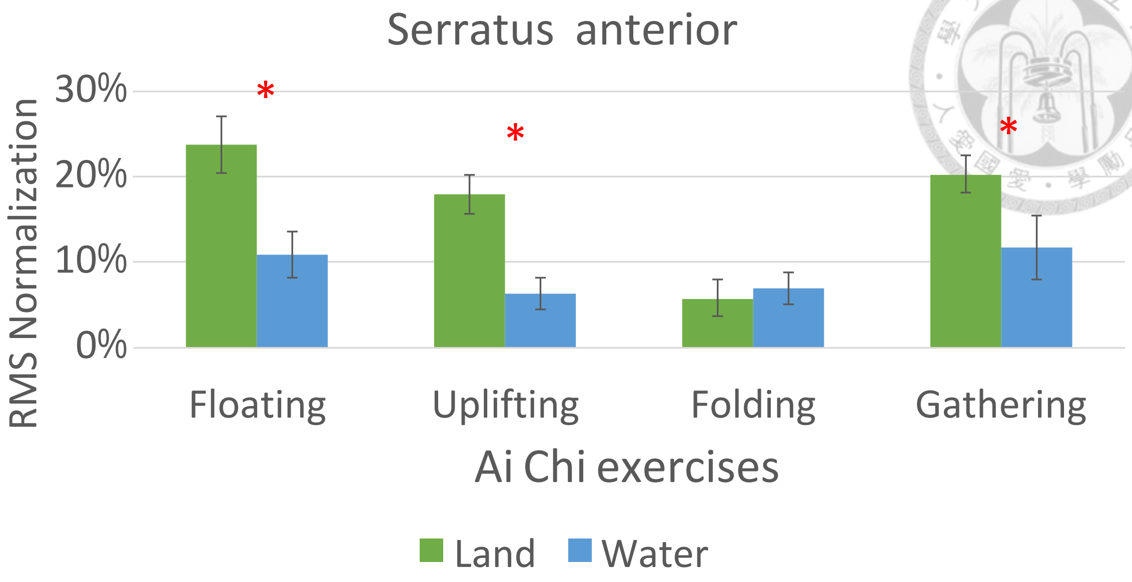

Figure 15. Serratus Anterior activations during Ai Chi exercises

The X-axis represents the Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The green bar indicates the land-based Ai Chi exercises, and the blue bar indicates the aquatic Ai Chi exercises. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC).

doi:10.6342/NTU202302157

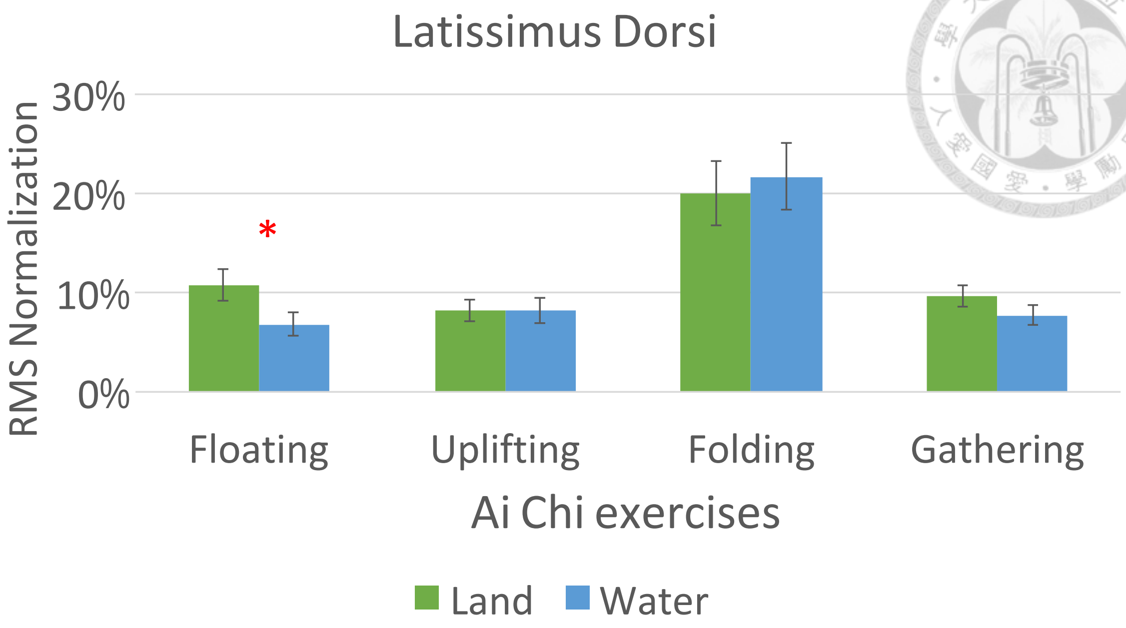

Figure 16. Latissimus Dorsi activations during Ai Chi exercises

The X-axis represents the Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The green bar indicates the land-based Ai Chi exercises, and the blue bar indicates the aquatic Ai Chi exercises. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC).

doi:10.6342/NTU202302157

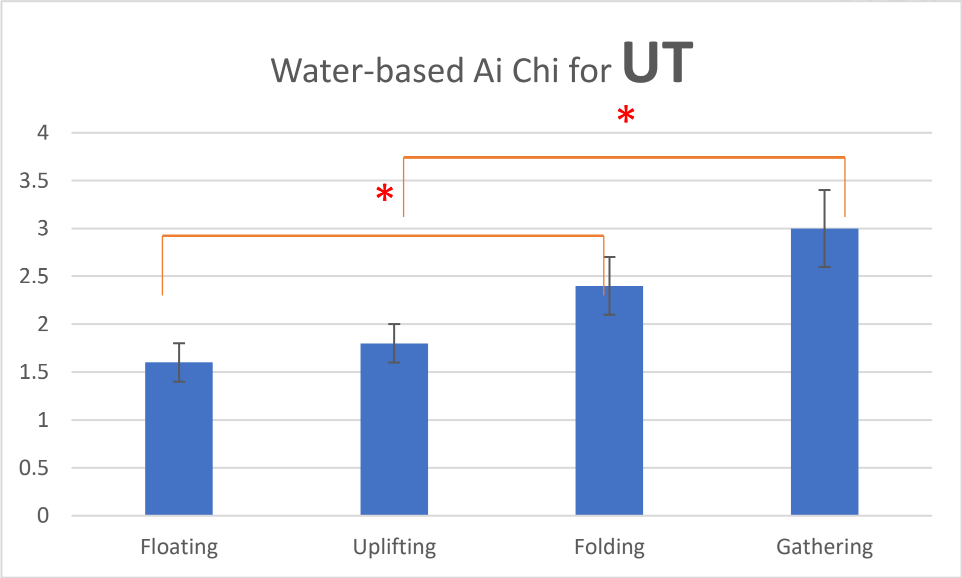

Figure 17. Upper Trapezius activation during aquatic Ai Chi exercises

The X-axis represents the aquatic Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC). To better clarification the analysis, please refer to Table 10 along with the Figure 17.

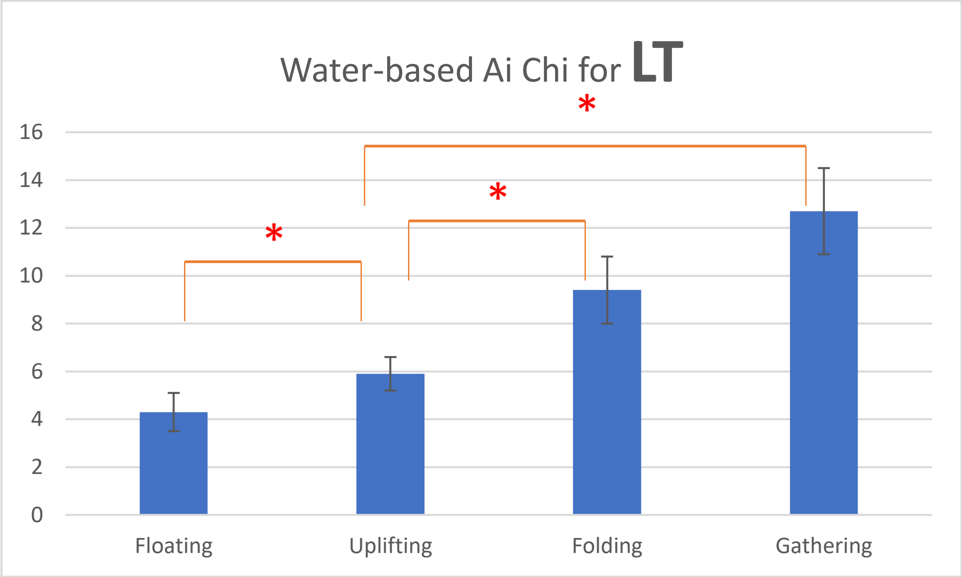

Figure 18. Lower Trapezius activation during aquatic Ai Chi exercises

The X-axis represents the aquatic Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC). To better clarification the analysis, please refer to Table 11 along with the Figure 18.

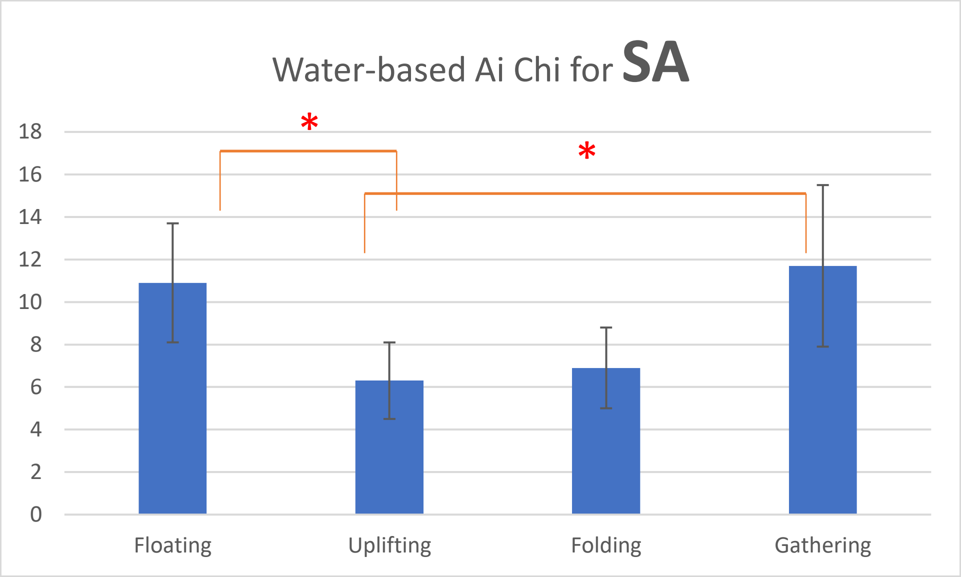

Figure 19. Serratus Anterior activation during aquatic Ai Chi exercises

The X-axis represents the aquatic Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC). To better clarification the analysis, please refer to Table 12 along with the Figure 19.

doi:10.6342/NTU202302157

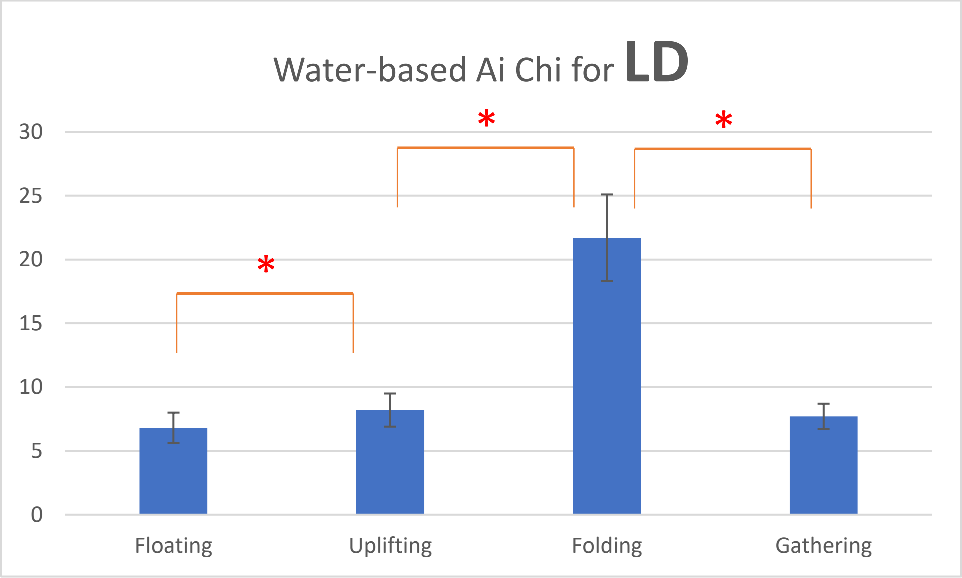

Figure 20. Latissimus Dorsi activation during aquatic Ai Chi exercises

The X-axis represents the aquatic Ai Chi exercises: Floating, Uplifting, Folding, and Gathering. The Y-axis represents the root mean square (RMS) values of muscle activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC). To better clarification the analysis, please refer to Table 13 along with the Figure 20.

doi:10.6342/NTU202302157

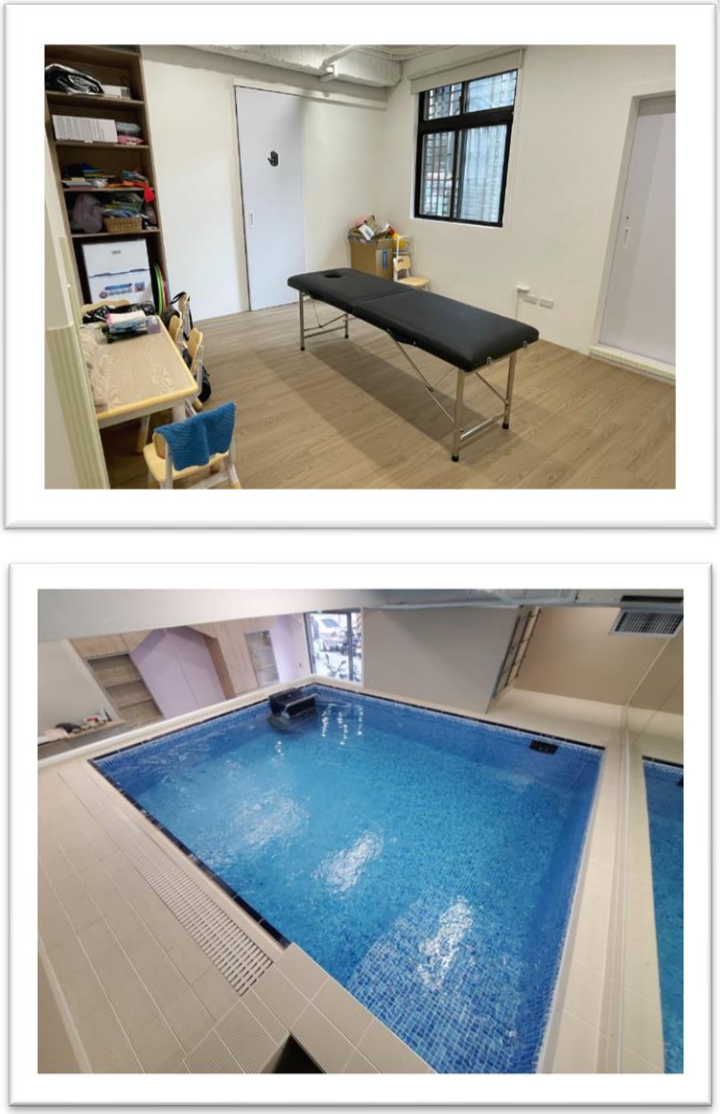

Figure 21. The land-based and aquatic sEMG data collection setup

The land-based examination and sEMG data of this experiment, including the scapular dyskinesis test, maximal voluntary isometric contraction test, and land-based Ai Chi exercises, were collected on land in the laboratory. The aquatic Ai Chi exercises were performed in the pool to collect muscle activation data using waterproof sEMG.

doi:10.6342/NTU202302157

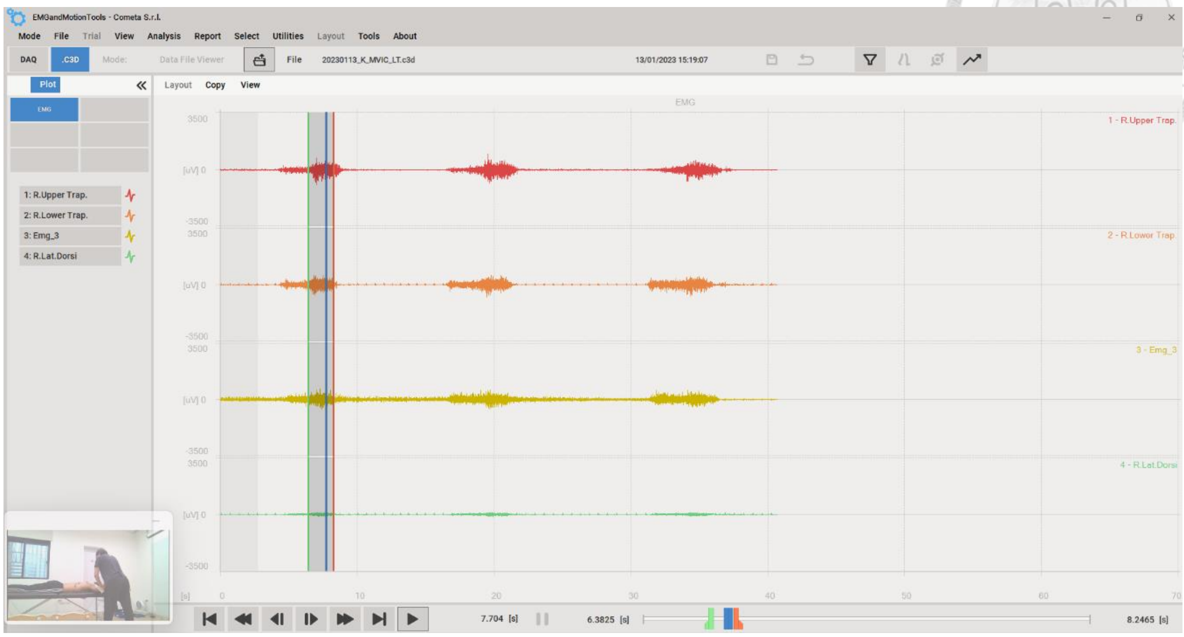

Figure 22. Selected sEMG signals

The investigator selected the sEMG signals corresponding to the real-time video during the muscle contractions. The red line represented the upper trapezius muscle activities, the orange line represented the lower trapezius muscle activities, the yellow line represented the serratus anterior muscle activities, and the green line represented the latissimus dorsi muscle activities.

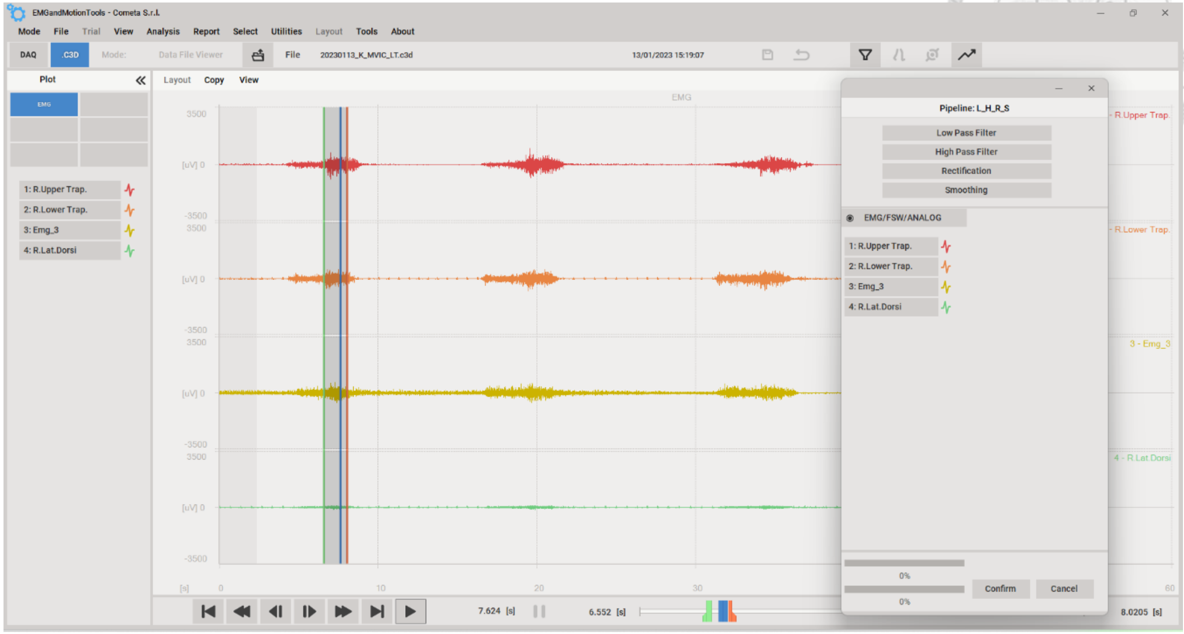

Figure 23. Data processing of the sEMG

The investigator created a pipeline to process the sEMG data, which included the application of a low-pass filter, high-pass filter, rectification and smoothing.

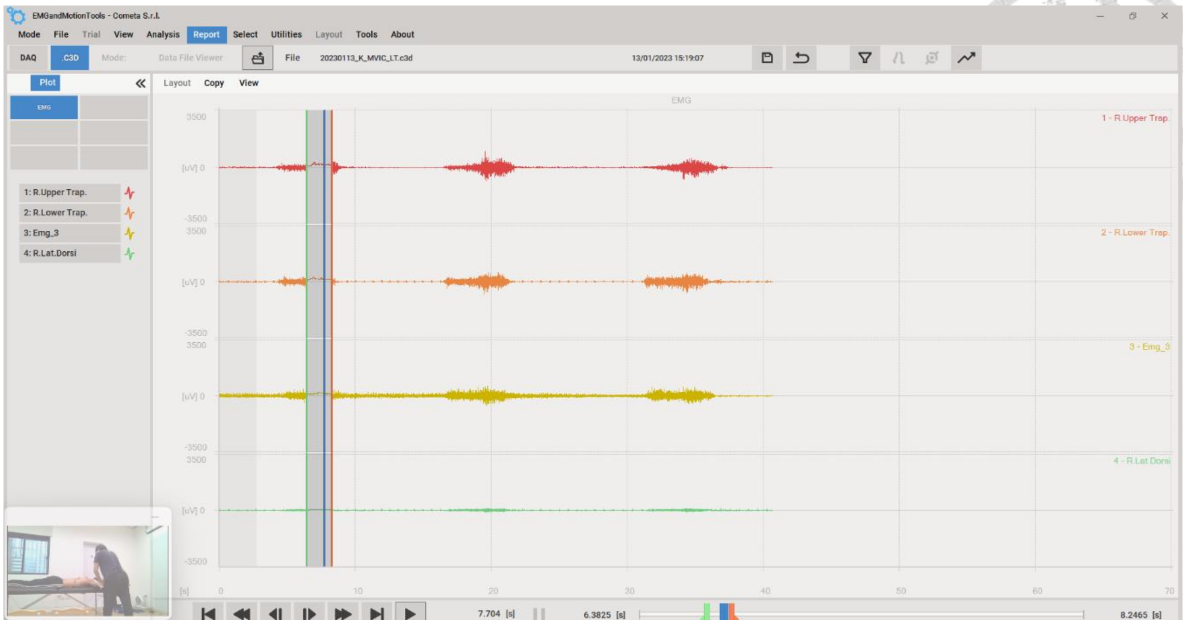

Figure 24. Rectification of the sEMG signals

The data underwent filtering to remove any noise and artifacts, using a low-pass filter to eliminate high-frequency noise and a high-pass filter to remove baseline drift.

After filtering, the data were rectified to convert negative values to positive values, effectively converting the signal into a unipolar form. Next, a smoothing algorithm was applied to the rectified data to reduce any remaining noise and produce a cleaner signal.

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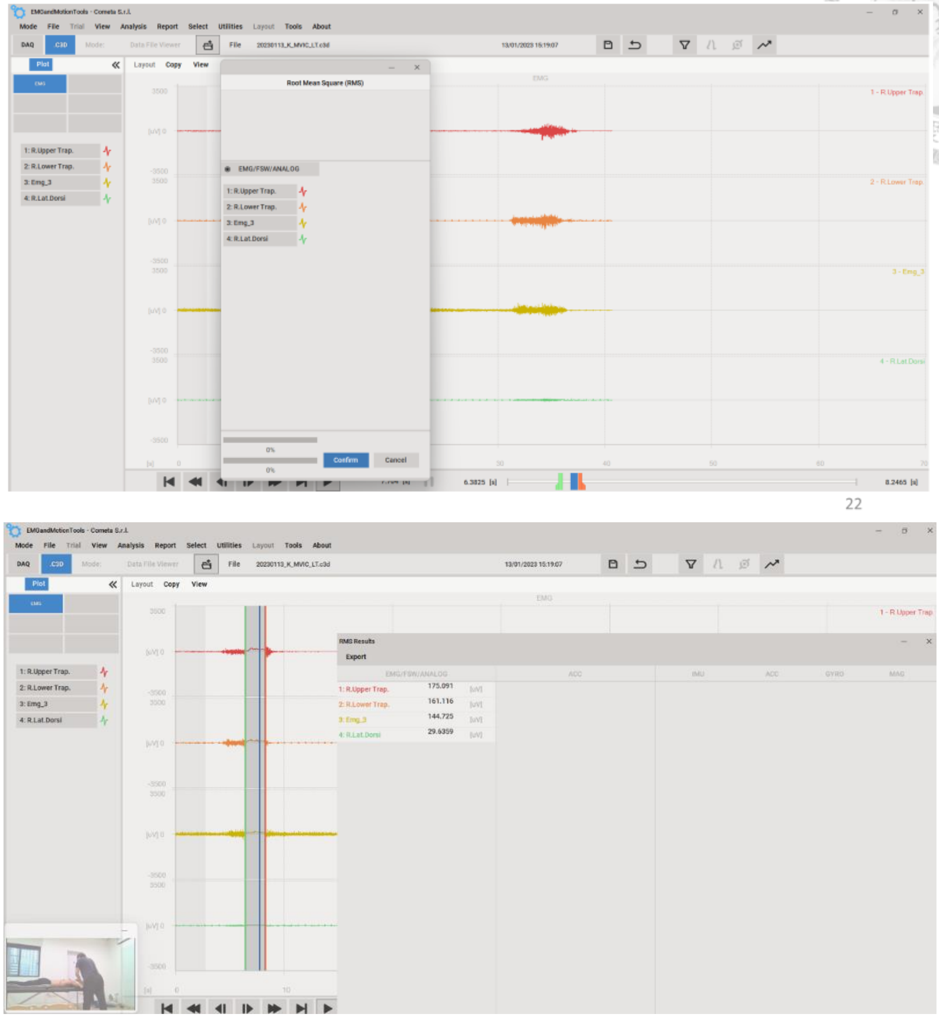

EMG/FSW/ANALOG		
1: R.Upper Trap.	175.091	[uV]
2: R.Lower Trap.	161.116	[uV]
3: Emg_3	144.725	[uV]
4: R.Lat.Dorsi	29.6359	[uV]

Figure 25. RMS of the sEMG signals

Once the sEMG data were processed and cleaned, further analysis was performed to calculate the root mean square (RMS) values, which represent the magnitude of muscle activation. The RMS values were then normalized using the maximal voluntary isometric contraction (MVIC) as a reference, expressing the muscle activation as a percentage of its maximum potential.

Table 1. The anatomy and muscle function of periscapular muscle

Muscle	Serratus Anterior (SA)	Trapezius	Latissimus Dorsi (LD)
Origin	Ribs 1-9	Occipital bone, ligamentum nuchae, spinous processes of C1-T12	Spinous processes of vertebra T7-T12 and L1- L5 ant the sacrum, thoracolumbar fascia, inferior portion of the scapula, posterior third of the iliac crest, and ribs 9-12
Insertion	Medial border of the scapula	Spine of the scapula, acromion and lateral third of the clavicle	Intertubercular groove of the humerus
Muscle function	Scapula depression, abduction and upward rotation, assist inspiration	Upper trapezius (UT): scapular elevation and upward rotation Middle trapezius (MT): scapular adduction Lower trapezius (LT): scapula depression and upward rotation	Downward rotation, depression and adduction of the scapula, assist expiration

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Table 2. Locations and orientations of electrodes on target muscles

Target muscle	Location of Electrode	Orientation of Electrode
Upper Trapezius (UT)	Along the ridge of the shoulder, slightly lateral to and one-half the distance between the cervical spine at C-7 and the acromion.	Parallel to the muscle fibers
Serratus Anterior (SA)	At mid-axillary line, anterior to latissimus dorsi and posterior to pectoralis major at the 7th intercostal space	Parallel to the muscle fibers
Lower Trapezius (LT)	Place the electrodes on an oblique angle, approximately 5 cm down from the scapular spine	Next to the medial edge of the scapula at a 55-degree oblique angle
Latissimus Dorsi (LD)	Approximately 4 cm below the inferior tip of the scapula, half the distance between the spine and the lateral edge of the torso	In a slightly oblique angle of approximately 25 degrees

The electrode placements followed the guidelines from the book "Introduction to Surface Electromyography" by Criswell & Cram (2011). EMG placement of SA was from Januario et al. (2022).

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Table 3. Maximal voluntary isometric contraction test on target muscles

Target muscle	Position
Upper Trapezius	Assume a seated position. Perform a resistive shoulder elevation at 90 degrees (Castillo-Lozano et al., 2014)
Serratus Anterior	Assume a seated position. Perform a resistive shoulder elevation with the shoulder protracted and flexed at 135 degrees. (Januario et al., 2022)
Lower Trapezius	Assume a prone position with the shoulder abducted to 135 degrees along the muscle belly of the LT, thumb up, and then perform a resistive arm elevation. (Castillo-Lozano et al., 2014)
Latissimus Dorsi	Assume a prone position with shoulder extended 20 degrees; the forearm pronated and adducted with the hand positioned on the ipsilateral buttock. Then, perform a resistive shoulder extension and adduction. (Tse et al., 2022).

The electrode placements followed the guidelines from the book "Introduction to Surface Electromyography" by Criswell & Cram (2011). The novel studies, which presented higher muscle activities during MVIC, served as complementary references in Table 3. The MVIC in this study followed the protocols of these novel studies.

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Table 4. The descriptions of kinetic chain exercises, Ai Chi

Ai Chi	Description
Floating	Assume a squat position. Hands are beside the body. Inhale through the nose while turning the palms up and lifting the arms in shoulder flexion at 90 degrees (or just beneath the water surface). Exhale through the mouth while turning the palms down and lowering the arms to the sides of the thighs.
Uplifting.	Assume a squat position. Hands are beside the body. Inhale through the nose while turning the palms up and lifting the arms in shoulder abduction at 90 degrees (or just beneath the water surface). Exhale through the mouth, turn the palms down, and let the arms lower to the sides of the thighs.
Folding	Assume a squat position. Hands are on the abdomen of the body. Inhale through the nose, keep the elbows in at the waist, turn the palms up, and open the forearms to the side, retract the scapula, and open the chest. Exhale through the mouth, bring the arms across the midline of the body, turn the palms down, and let the arms lower and cross in front of the body.
Gathering	Assume a lunge position with the dominant hand's side front (if right hand dominant, the right leg is the front leg) with both hands reaching forward at shoulder 90 degrees flexion, elbow fully extended, forearms pronated, palms down. Inhale through the nose while turning the dominant hand's palm up, rotate the body to the side of the moving arm with unilateral horizontal abduction movement, and track the arm movements with the eyes, neck, and upper trunk rotation. Exhale while performing horizontal adduction and vice versa.

(Konno and Brody 2009)

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Table 5. The components of Ai Chi movement patterns

Ai Chi movement	Leg motion	Spinal motion	Arm motion	Breathing coordination
Floating Uplifting Folding	Squat	Erect	Flexion - Extension, Abduction - Adduction, External rotation - Internal rotation, Protraction- Retraction	Inhale with shoulder flexion, abduction, horizontal abduction or external rotation; exhale with shoulder extension, adduction, horizontal adduction or internal rotation
Gathering	Lunge with right/left leg lead	Rotation	Horizontal abduction – Horizontal adduction, External rotation - Internal rotation, Protraction- Retraction	

(Konno and Brody 2009)

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Table 6. The demographic data (n=21)

Age (yr)	24.3 ±3.6
Height (cm)	174.5 ±6.2
Weight (kg)	68.1 ±8.7
BMI	22. 3 ±2.0
Sports type	Baseball: 5 Volleyball:6 Tennis:4 Badminton:6
Dominant hand	Right:18 Left:3
Gender	Male:18 Female:3

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Table 7. Test-retest and intra-rater reliability of Ai Chi exercises and maximal voluntary isometric contraction (MVIC)

	Upper Trapezius (ICC; SEM)	Lower Trapezius (ICC; SEM)	Serratus Anterior (ICC; SEM)	Latissimus Dorsi (ICC; SEM)	ICC type
Land_Floating	.94; 1.91	.92; 2.15	.90; 3.63	.93; 1.72	ICC (2.1)
Land_Uplifting	.93; 2.70	.95; 1.83	.94; 2.75	.80; 1.30	ICC (2.1)
Land_Folding	.90; 2.40	.91; 2.66	.85; 3.18	.76; 4.73	ICC (2.1)
Land_Gathering	.94; 2.87	.91; 2.43	.94; 2.41	.78; 1.25	ICC (2.1)
MVIC	.94; 43.99	.98; 64.88	.96; 74.89	.87; 19.12	ICC (2.1)
Water_Floating	.77; .38	.98; 1.85	.96; 6.04	.97; 2.57	ICC (2.3)
Water_Uplifting	.94; .19	.95; .78	.96; 1.99	.96; 1.46	ICC (2.3)
Water_Folding	.88; .51	.96; 2.15	.96; 3.03	.95; 5.35	ICC (2.3)
Water_Gathering	.95; .38	.98; 1.86	.96; 3.87	.97; 1.07	ICC (2.3)

ICC: intraclass correlation coefficient; SEM: standard error of measurement; 0-0.39 Poor reliability; 0.40-0.74 Modest reliability; 0.75-1.00 Excellent reliability

Table 8. Scapular muscle activation in Land-based Ai Chi and Aquatic Ai Chi

Muscles	Exercises	%MVIC on land Mean ± SEM (Median)	%MVIC in Water Mean ± SEM (Median)	95% CI^{a} or Mean Rank^{b}
Upper Trapezius	Floating	15.5±1.7 (15.9)	1.6±0.2 (1.6)	[10.3, 17.4] ^{a} $p < 0.001$**
	Uplifting	22.2±2.2 (20.9)	1.8±0.2 (1.7)	[15.8, 25.1] ^{b} $p < 0.001$**
	Folding	9.0±1.6 (6.3)	2.4±0.3 (2.2)	[.0, 11.0] ^{b} $p < 0.001$**
	Gathering	29.0±2.6 (26.6)	3.0±0.4 (2.4)	[.0, 11.0] ^{b} $p < 0.001$**
Lower Trapezius	Floating	10.3±2.0 (7.1)	4.3±0.8 (3.2)	[6.5, 11.5] ^{b} $p < 0.001$**
	Uplifting	9.4±1.5 (7.9)	5.9±0.7 (5.6)	[9.0, 11.6] ^{b} $p = 0.014$
	Folding	12.2±1.8 (10.5)	9.4±1.4 (8.2)	[9.0, 11.8] ^{b} $p = 0.033$
	Gathering	21.6±2.2 (21.9)	12.7±1.8 (11.1)	[9.7, 11.2] ^{b} $p =0.003$*
Serratus Anterior	Floating	23.7±3.3 (17.5)	10.9±2.8 (8.0)	[9.0, 11.1] ^{a} $p < 0.001$**
	Uplifting	17.9±2.3 (13.1)	6.3 ±1.8 (4.0)	[15.0, 10.8] ^{b} $p < 0.001$**
	Folding	5.8±2.1 (3.1)	6.9±1.9 (3.4)	[13.8, 8.5] ^{b} $p = 0.434$
	Gathering	20.3±2.2 (17.0)	11.7±3.8 (6.3)	[21.0, 10.5] ^{b} $p =0.001$**
Latissimus Dorsi	Floating	10.8±1.6 (10.3)	6.8±1.2 (5.5)	[10.0, 11.1] ^{a} $p = 0.001$**
	Uplifting	8.2±1.1 (7.2)	8.2±1.3 (7.8)	[10.6, 11.4] ^{b} $p =0.958$
	Folding	20.0±3.2 (16.1)	21.7±3.4 (16.3)	[10.6, 11.9] ^{a} $p =0.259$
	Gathering	9.7±1.1 (9.2)	7.7±1.0 (6.4)	[- .4, 4.4] ^{b} $p =0.102$

The data were presented as "95% confidence interval [lower, upper] ^{a}" using the Paired T Test; for the others, they were shown as "mean rank [negative, positive]^{b}" using the Wilcoxon Signed Ranks Test.

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Table 9. Scapular muscle activation ratios in Land-based Ai Chi and Aquatic Ai Chi

Muscles	Exercises	Land	Water	95%CI or Mean Rank
Upper Trapezius/ Lower Trapezius	Floating	2.6±.5 (1.6)	0.7±0.2 (0.4)	[3.0, 11.4] $p < 0.001$**
	Uplifting	3.9±0.7 (2.8)	0.4±0.1 (0.3)	[.0, 11.0] $p < 0.001$**
	Folding	1.1±0.3 (0.6)	0.4±0.1 (0.2)	[7.5, 11.4] $p < 0.001$**
	Gathering	1.8±0.3 (1.3)	0.4±0.1 (0.2)	[2.0, 12.0] $p < 0.001$**
Upper Trapezius/Serratus Anterior	Floating	0.9±0.1 (0.7)	0.3±0.1 (0.2)	[2.5, 11.9] $p < 0.001$**
	Uplifting	1.7±0.3 (1.3)	0.7±0.2 (0.4)	[7.0, 11.2] $p < 0.001$**
	Folding	3.5±0.7 (3.0)	1.0±0.3 (0.7)	[.0, 11.0] $p < 0.001$**
	Gathering	1.8±0.2 (1.5)	0.5±0.1 (0.4)	[0.9, 1.6] $p < 0.001$**
Lower Trapezius/Serratus Anterior	Floating	0.5±0.1 (0.4)	0.9±0.3 (0.5)	[11.3, 10.3] $p = 0.063$
	Uplifting	0.6±0.1 (0.5)	2.3 ±0.6 (1.4)	[12.1, 47] $p < 0.001$**
	Folding	5.4±1.4 (2.3)	3.9±0.9 (1.9)	[12.5, 10.4] $p = 0.159$
	Gathering	1.2±0.2 (0.9)	2.2±0.4 (1.9)	[11.2, 10.0] $p = 0.009$*

The data were presented as "95% confidence interval [lower, upper]^{a}" using the Paired T Test; for the others, they were shown as "mean rank [negative, positive]^{b}" using the Wilcoxon Signed Ranks Test.

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Table 10. Comparisons of the Land/ Aquatic Ai Chi exercises of the Upper Trapezius

Exercise comparisons	Upper Trapezius during **Land** Ai Chi exercises 95%CI or Mean Rank	
Uplifting-Floating	[6.7, 8.9]^{a}	*P* < .001 **
Folding-Floating	[12.7, 5.6]^{b}	*P* = .002**
Gathering-Floating	[1.0, 11.5]^{b}	*P* < .001**
Folding-Uplifting	[11.5, 1.0]^{b}	*P* < .001**
Gathering-Uplifting	[11.5, 11.0]^{b}	*P* = .001**
Gathering-Folding	[.0, 11.0]^{b}	*P* < .001**
Exercise comparisons	Upper Trapezius during **Aquatic** Ai Chi exercises 95%CI or Mean Rank	
Uplifting-Floating	[.2, .4]^{a}	*P* = .134
Folding-Floating	[9.0, 11.5]^{b}	*P* = .006*
Gathering-Floating	[1.0, 11.5]^{b}	*P* < .001**
Folding-Uplifting	[6.7, 13.2]^{b}	*P* = .017
Gathering-Uplifting	[8.0, 11.2]^{b}	*P* < .001**
Gathering-Folding	[10.5, 11.2]^{b}	*P* = .068

The data were presented as "95% confidence interval [lower, upper]^{a}" using the Paired T Test; for the others, they were shown as "mean rank [negative, positive]^{b}" using the Wilcoxon Signed Ranks Test.

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Table 11. Comparisons of the Land/ Aquatic Ai Chi exercises of the Lower Trapezius

Exercise comparisons	Lower Trapezius during **Land** Ai Chi exercises 95%CI or Mean Rank	
Uplifting-Floating	[11.4, 10.6] ^{b}	*P* = .958
Folding-Floating	[12.2, 10.6] ^{b}	*P* = .058
Gathering-Floating	[4.0, 11.8] ^{b}	*P* < .001**
Folding-Uplifting	[9.4, 11.8] ^{b}	*P* = .085
Gathering-Uplifting	[.0, 11.0] ^{b}	*P* < .001**
Gathering-Folding	[3.0, 11.4] ^{b}	*P* < .001**
Exercise comparisons	Lower Trapezius during **Aquatic** Ai Chi exercises 95%CI or Mean Rank	
Uplifting-Floating	[9.0, 11.5] ^{b}	*P* = .006*
Folding-Floating	[7.5, 11.4] ^{b}	*P* < .001**
Gathering-Floating	[13.0, 10.9] ^{b}	*P* < .001**
Folding-Uplifting	[3.6, 5.4] ^{a}	*P* = .001**
Gathering-Uplifting	[6.0, 11.5] ^{b}	*P* < .001**
Gathering-Folding	[9.0, 12.0] ^{b}	*P* = .068

The data were presented as "95% confidence interval [lower, upper] ^{a}" using the Paired T Test; for the others, they were shown as "mean rank [negative, positive]^{b}" using the Wilcoxon Signed Ranks Test.

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Table 12. Comparisons of the Land/ Aquatic Ai Chi exercises of the Serratus Anterior

Exercise comparisons	Serratus Anterior during **Land** Ai Chi exercises Mean Rank	
Uplifting-Floating	[12.0, 6.8]	*P* = .002*
Folding-Floating	[10.9, 13.0]	*P* < .001**
Gathering-Floating	[12.2, 9.1]	*P* = .140
Folding-Uplifting	[10.7, 18.0]	*P* = .001**
Gathering-Uplifting	[10.3, 11.3]	*P* = .063
Gathering-Folding	[15.0, 10.8]	*P* < .001**
Exercise comparisons	Serratus Anterior during **Aquatic** Ai Chi exercises Mean Rank	
Uplifting-Floating	[11.4, 3.0]	*P* < .001**
Folding-Floating	[11.5, 9.7]	*P* = .046
Gathering-Floating	[9.6, 12.5]	*P* = .741
Folding-Uplifting	[9.8, 12.1]	*P* = .543
Gathering-Uplifting	[2.0, 12.0]	*P* < .001**
Gathering-Folding	[13.0, 10.5]	*P* = .027

The data were presented as "mean rank [negative, positive]" using the Wilcoxon Signed Ranks Test.

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Table 13. Comparisons of the Land/ Aquatic Ai Chi exercises of the Latissimus Dorsi

Exercise comparisons	Latissimus Dorsi during **Land** Ai Chi exercises 95%CI or Mean Rank	
Uplifting-Floating	[11.2, 9.0] [b]	*P* = .001**
Folding-Floating	[7.3, 11.6] [b]	*P* = .001**
Gathering-Floating	[13.9, 7.8] [b]	*P* = .192
Folding-Uplifting	[11.8, 17.1] [a]	*P* < .001**
Gathering-Uplifting	[1.5, 2.5] [a]	*P* = .008*
Gathering-Folding	[-10.3, -4.9] [a]	*P* = .001**
Exercise comparisons	Latissimus Dorsi during **Aquatic** Ai Chi exercises 95%CI or Mean Rank	
Uplifting-Floating	[2.7, 12.4] [b]	*P* < .001**
Folding-Floating	[3.0, 11.4] [b]	*P* < .001**
Gathering-Floating	[11.0, 11.0] [b]	*P* = .339
Folding-Uplifting	[4.0, 11.4] [b]	*P* < .001**
Gathering-Uplifting	[12.4, 9.7] [b]	*P* = .768
Gathering-Folding	[11.3, 6.0] [b]	*P* < .001**

The data were presented as "95% confidence interval [lower, upper] [a]" using the Paired T Test; for the others, they were shown as "mean rank [negative, positive][b]" using the Wilcoxon Signed Ranks Test.

Appendix 1. Smoothing RMS Analysis

SMOOTHING RMS ANALYSIS

The smoothing filter is a method used to elaborate the signal and reduce the noise.
Different algorithms are used to apply smoothing, one of these is the RMS.

The algorithms are applied with a moving window, for this reason, is necessary to set the interval of left and right that characterize the window.

The left and right ranges are the number of samples of the interval left and interval right of the moving window.

I try to explain with images:

***Figure* 1** - *Raw Signal.*

***Figure* 2** - *RMS smoothing filter application.*
To calculate the new value of each sample (red line), a window mobile is applied.
The window is composed of a left range (yellow rectangle) and a right range (green rectangle).
The new value, of the sample in red, is the RMS value of the samples of the moving window.

***Figure* 3** – *Smoothed section.*

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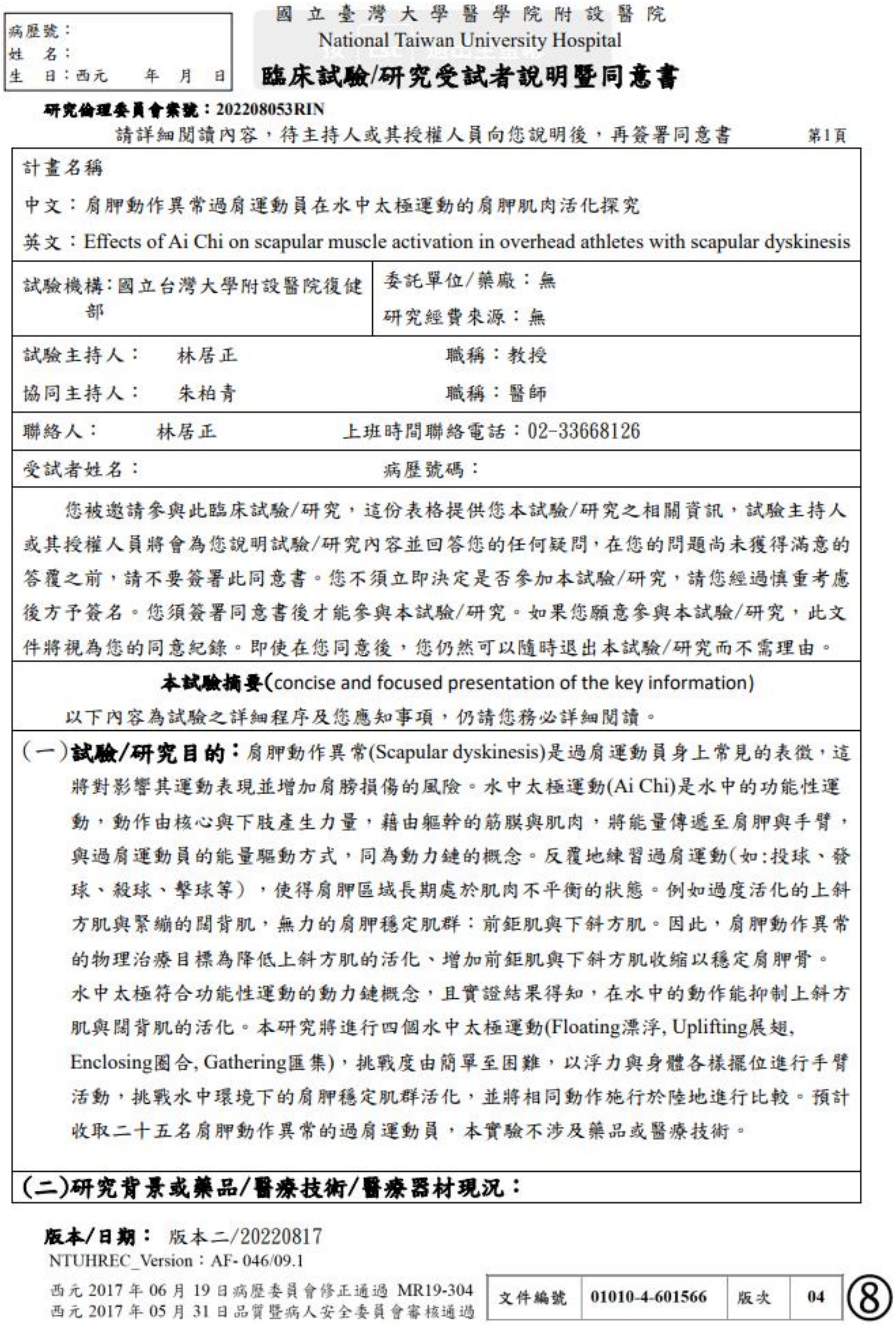
Appendix 2. Permission of Institutional Review Board and Consent



病歷號： 姓　名： 生　日：西元　　年　月　日

國立臺灣大學醫學院附設醫院
National Taiwan University Hospital
臨床試驗/研究受試者說明暨同意書

研究倫理委員會案號：202208053RIN

請詳細閱讀內容，待主持人或其授權人員向您說明後，再簽署同意書　第1頁

計畫名稱 中文：肩胛動作異常過肩運動員在水中太極運動的肩胛肌肉活化探究 英文：Effects of Ai Chi on scapular muscle activation in overhead athletes with scapular dyskinesis	
試驗機構：國立台灣大學附設醫院復健部	委託單位/藥廠：無 研究經費來源：無
試驗主持人：　林居正　　職稱：教授 協同主持人：　朱柏青　　職稱：醫師	
聯絡人：　林居正　　上班時間聯絡電話：02-33668126	
受試者姓名：　　病歷號碼：	

您被邀請參與此臨床試驗/研究，這份表格提供您本試驗/研究之相關資訊，試驗主持人或其授權人員將會為您說明試驗/研究內容並回答您的任何疑問，在您的問題尚未獲得滿意的答覆之前，請不要簽署此同意書。您不須立即決定是否參加本試驗/研究，請您經過慎重考慮後方予簽名。您須簽署同意書後才能參與本試驗/研究。如果您願意參與本試驗/研究，此文件將視為您的同意紀錄。即使在您同意後，您仍然可以隨時退出本試驗/研究而不需理由。

本試驗摘要(concise and focused presentation of the key information)

以下內容為試驗之詳細程序及您應知事項，仍請您務必詳細閱讀。

(一)**試驗/研究目的：**肩胛動作異常(Scapular dyskinesis)是過肩運動員身上常見的表徵，這將對影響其運動表現並增加肩膀損傷的風險。水中太極運動(Ai Chi)是水中的功能性運動，動作由核心與下肢產生力量，藉由軀幹的筋膜與肌肉，將能量傳遞至肩胛與手臂，與過肩運動員的能量驅動方式，同為動力鏈的概念。反覆地練習過肩運動(如:投球、發球、殺球、擊球等），使得肩胛區域長期處於肌肉不平衡的狀態。例如過度活化的上斜方肌與緊繃的闊背肌，無力的肩胛穩定肌群：前鋸肌與下斜方肌。因此，肩胛動作異常的物理治療目標為降低上斜方肌的活化、增加前鋸肌與下斜方肌收縮以穩定肩胛骨。
水中太極符合功能性運動的動力鏈概念，且實證結果得知，在水中的動作能抑制上斜方肌與闊背肌的活化。本研究將進行四個水中太極運動(Floating漂浮, Uplifting展翅, Enclosing圈合, Gathering匯集)，挑戰度由簡單至困難，以浮力與身體各樣擺位進行手臂活動，挑戰水中環境下的肩胛穩定肌群活化，並將相同動作施行於陸地進行比較。預計收取二十五名肩胛動作異常的過肩運動員，本實驗不涉及藥品或醫療技術。

(二)研究背景或藥品/醫療技術/醫療器材現況：

版本/日期： 版本二/20220817
NTUHREC_Version：AF-046/09.1
西元 2017 年 06 月 19 日病歷委員會修正通過 MR19-304
西元 2017 年 05 月 31 日品質暨病人安全委員會審核通過

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⑧

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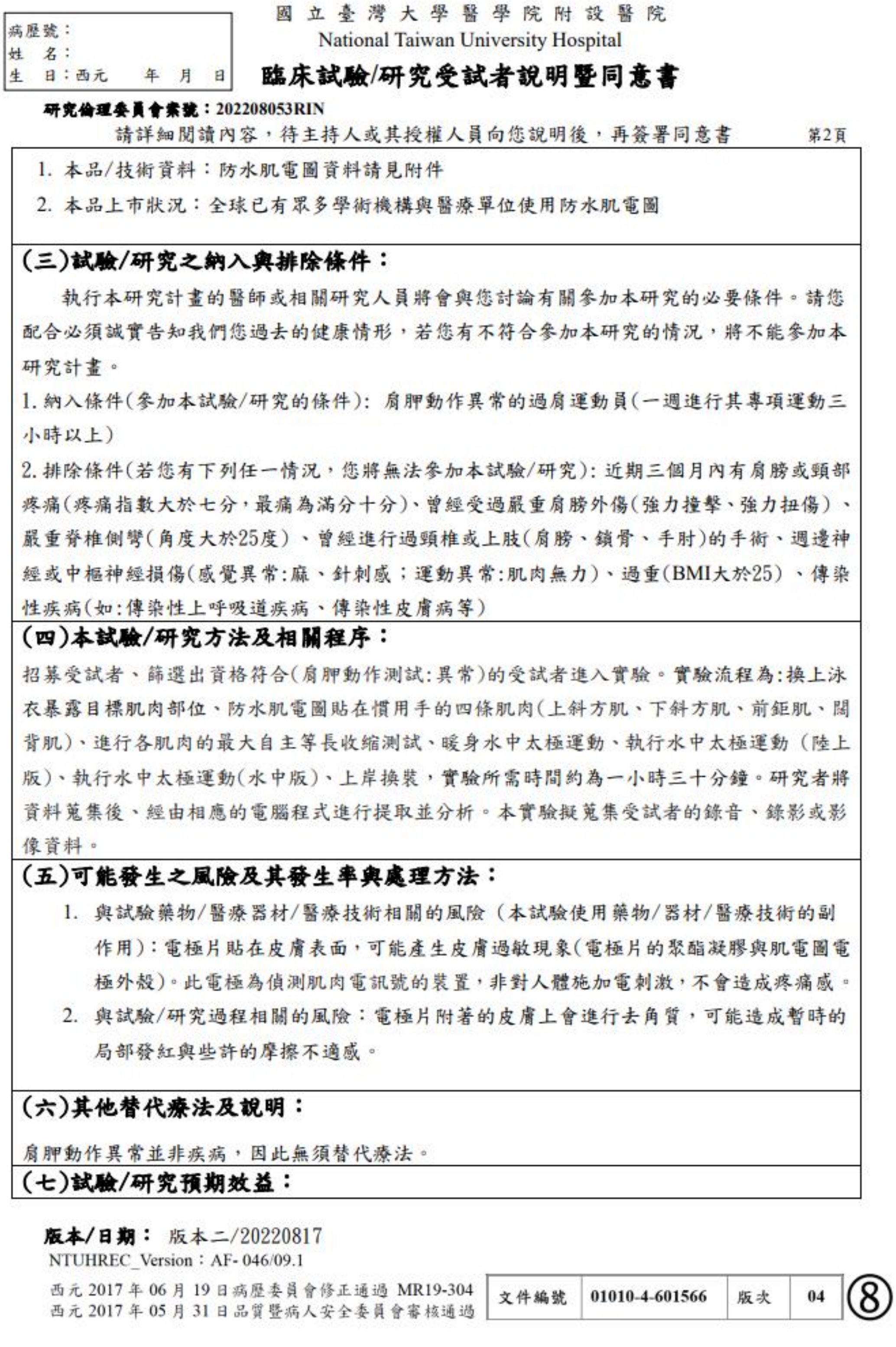

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臨床試驗/研究受試者說明暨同意書

研究倫理委員會案號：202208053RIN

請詳細閱讀內容，待主持人或其授權人員向您說明後，再簽署同意書　　第2頁

1. 本品/技術資料：防水肌電圖資料請見附件
2. 本品上市狀況：全球已有眾多學術機構與醫療單位使用防水肌電圖

(三)試驗/研究之納入與排除條件：

執行本研究計畫的醫師或相關研究人員將會與您討論有關參加本研究的必要條件。請您配合必須誠實告知我們您過去的健康情形，若您有不符合參加本研究的情況，將不能參加本研究計畫。

1. 納入條件(參加本試驗/研究的條件)：肩胛動作異常的過肩運動員(一週進行其專項運動三小時以上)
2. 排除條件(若您有下列任一情況，您將無法參加本試驗/研究)：近期三個月內有肩膀或頸部疼痛(疼痛指數大於七分，最痛為滿分十分)、曾經受過嚴重肩膀外傷(強力撞擊、強力扭傷)、嚴重脊椎側彎(角度大於25度)、曾經進行過頸椎或上肢(肩膀、鎖骨、手肘)的手術、週邊神經或中樞神經損傷(感覺異常:麻、針刺感；運動異常:肌肉無力)、過重(BMI大於25)、傳染性疾病(如:傳染性上呼吸道疾病、傳染性皮膚病等)

(四)本試驗/研究方法及相關程序：

招募受試者、篩選出資格符合(肩胛動作測試:異常)的受試者進入實驗。實驗流程為:換上泳衣暴露目標肌肉部位、防水肌電圖貼在慣用手的四條肌肉(上斜方肌、下斜方肌、前鉅肌、闊背肌)、進行各肌肉的最大自主等長收縮測試、暖身水中太極運動、執行水中太極運動（陸上版)、執行水中太極運動(水中版)、上岸換裝，實驗所需時間約為一小時三十分鐘。研究者將資料蒐集後、經由相應的電腦程式進行提取並分析。本實驗擬蒐集受試者的錄音、錄影或影像資料。

(五)可能發生之風險及其發生率與處理方法：

1. 與試驗藥物/醫療器材/醫療技術相關的風險（本試驗使用藥物/器材/醫療技術的副作用）：電極片貼在皮膚表面，可能產生皮膚過敏現象(電極片的聚酯凝膠與肌電圖電極外殼)。此電極為偵測肌肉電訊號的裝置，非對人體施加電刺激，不會造成疼痛感。
2. 與試驗/研究過程相關的風險：電極片附著的皮膚上會進行去角質，可能造成暫時的局部發紅與些許的摩擦不適感。

(六)其他替代療法及說明：

肩胛動作異常並非疾病，因此無須替代療法。

(七)試驗/研究預期效益：

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西元 2017 年 05 月 31 日品質暨病人安全委員會審核通過

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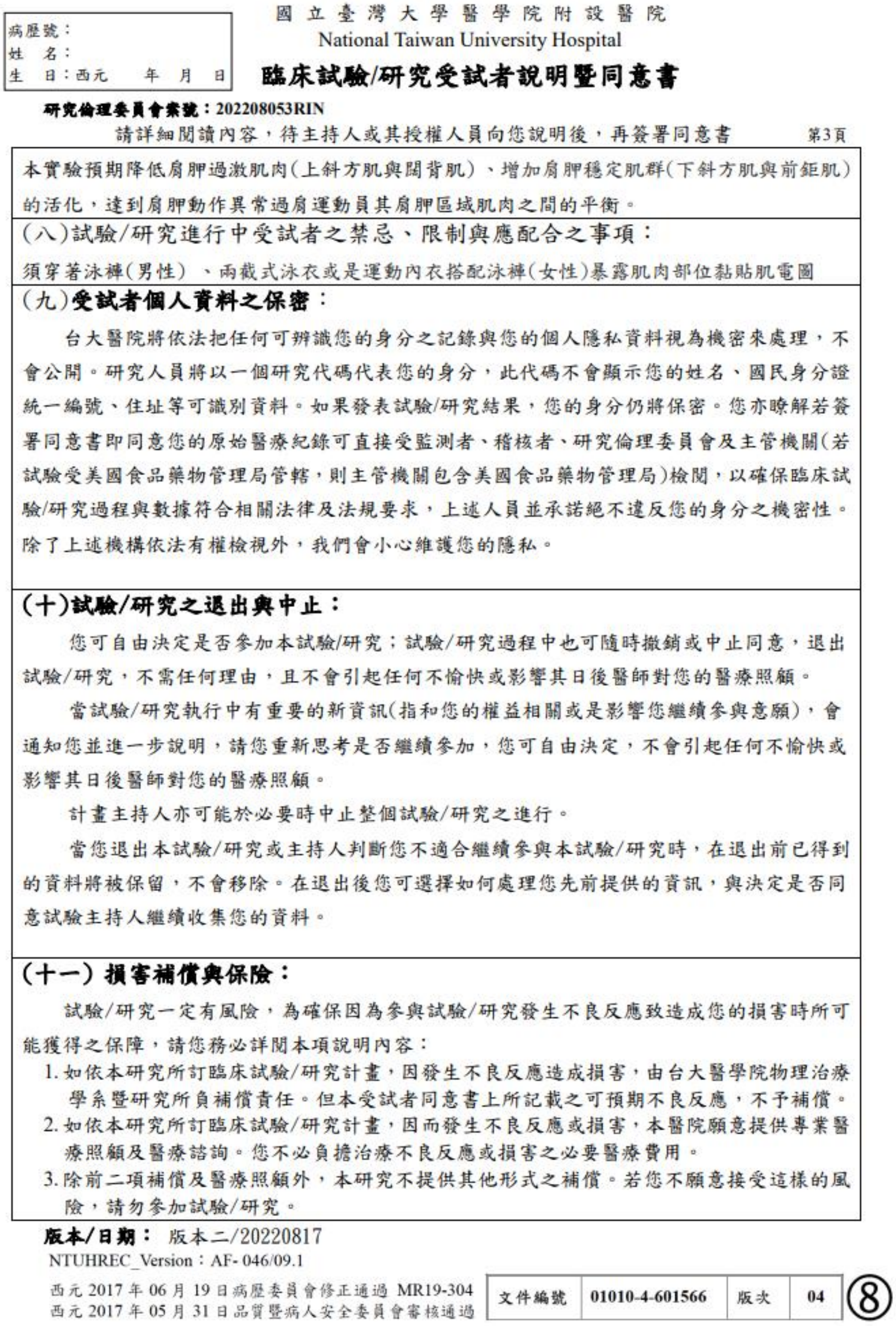

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請詳細閱讀內容，待主持人或其授權人員向您說明後，再簽署同意書　第3頁

本實驗預期降低肩胛過激肌肉(上斜方肌與闊背肌)、增加肩胛穩定肌群(下斜方肌與前鋸肌)的活化，達到肩胛動作異常過肩運動員其肩胛區域肌肉之間的平衡。

(八)試驗/研究進行中受試者之禁忌、限制與應配合之事項：

須穿著泳褲(男性)、兩截式泳衣或是運動內衣搭配泳褲(女性)暴露肌肉部位黏貼肌電圖

(九)受試者個人資料之保密：

台大醫院將依法把任何可辨識您的身分之記錄與您的個人隱私資料視為機密來處理，不會公開。研究人員將以一個研究代碼代表您的身分，此代碼不會顯示您的姓名、國民身分證統一編號、住址等可識別資料。如果發表試驗/研究結果，您的身分仍將保密。您亦瞭解若簽署同意書即同意您的原始醫療紀錄可直接受監測者、稽核者、研究倫理委員會及主管機關(若試驗受美國食品藥物管理局管轄，則主管機關包含美國食品藥物管理局)檢閱，以確保臨床試驗/研究過程與數據符合相關法律及法規要求，上述人員並承諾絕不違反您的身分之機密性。除了上述機構依法有權檢視外，我們會小心維護您的隱私。

(十)試驗/研究之退出與中止：

您可自由決定是否參加本試驗/研究；試驗/研究過程中也可隨時撤銷或中止同意，退出試驗/研究，不需任何理由，且不會引起任何不愉快或影響其日後醫師對您的醫療照顧。

當試驗/研究執行中有重要的新資訊(指和您的權益相關或是影響您繼續參與意願)，會通知您並進一步說明，請您重新思考是否繼續參加，您可自由決定，不會引起任何不愉快或影響其日後醫師對您的醫療照顧。

計畫主持人亦可能於必要時中止整個試驗/研究之進行。

當您退出本試驗/研究或主持人判斷您不適合繼續參與本試驗/研究時，在退出前已得到的資料將被保留，不會移除。在退出後您可選擇如何處理您先前提供的資訊，與決定是否同意試驗主持人繼續收集您的資料。

(十一) 損害補償與保險：

試驗/研究一定有風險，為確保因為參與試驗/研究發生不良反應致造成您的損害時所可能獲得之保障，請您務必詳閱本項說明內容：

1. 如依本研究所訂臨床試驗/研究計畫，因發生不良反應造成損害，由台大醫學院物理治療學系暨研究所負補償責任。但本受試者同意書上所記載之可預期不良反應，不予補償。
2. 如依本研究所訂臨床試驗/研究計畫，因而發生不良反應或損害，本醫院願意提供專業醫療照顧及醫療諮詢。您不必負擔治療不良反應或損害之必要醫療費用。
3. 除前二項補償及醫療照顧外，本研究不提供其他形式之補償。若您不願意接受這樣的風險，請勿參加試驗/研究。

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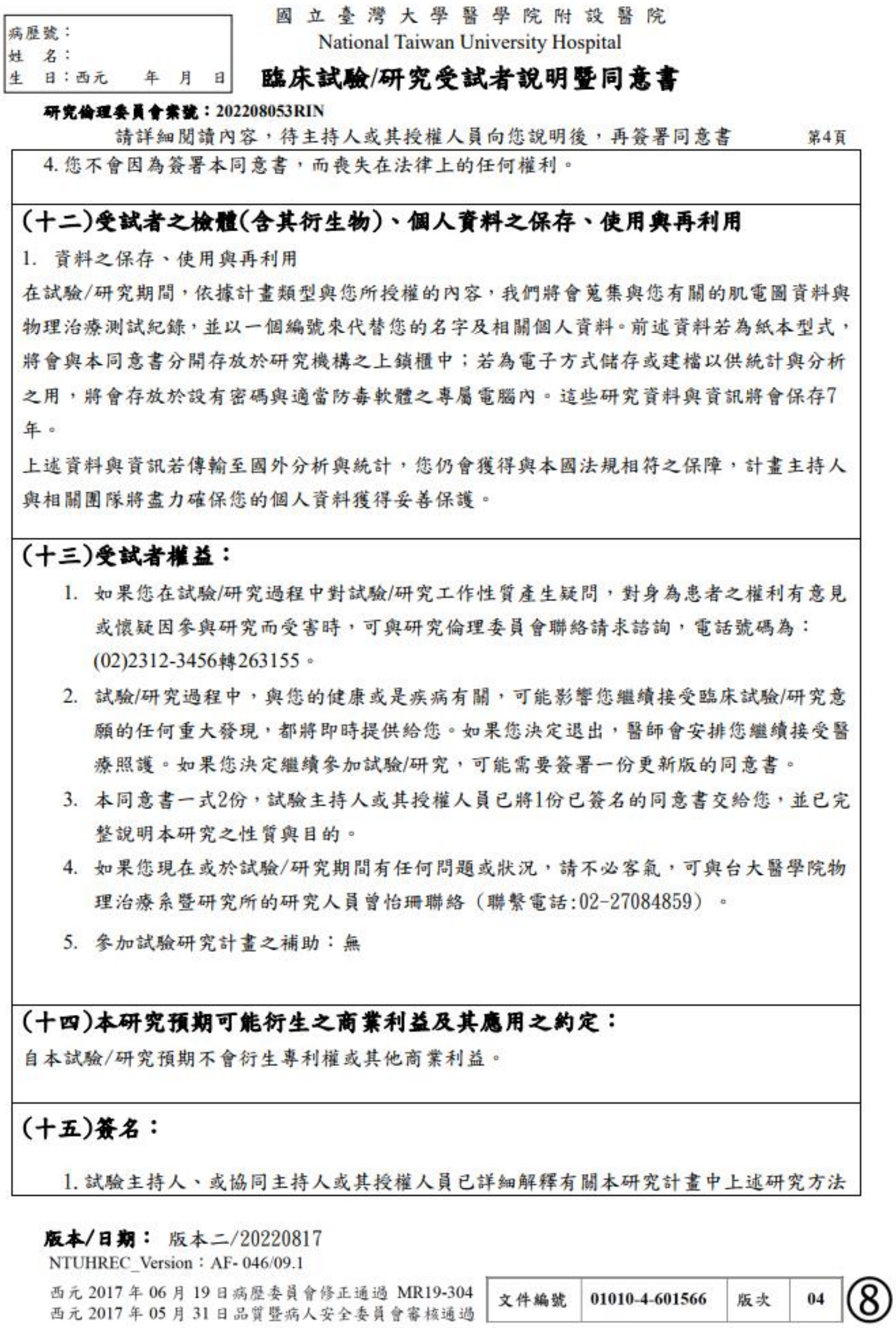

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研究倫理委員會案號：202208053RIN

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4. 您不會因為簽署本同意書，而喪失在法律上的任何權利。

(十二)受試者之檢體(含其衍生物)、個人資料之保存、使用與再利用

1. 資料之保存、使用與再利用

在試驗/研究期間，依據計畫類型與您所授權的內容，我們將會蒐集與您有關的肌電圖資料與物理治療測試紀錄，並以一個編號來代替您的名字及相關個人資料。前述資料若為紙本型式，將會與本同意書分開存放於研究機構之上鎖櫃中；若為電子方式儲存或建檔以供統計與分析之用，將會存放於設有密碼與適當防毒軟體之專屬電腦內。這些研究資料與資訊將會保存7年。

上述資料與資訊若傳輸至國外分析與統計，您仍會獲得與本國法規相符之保障，計畫主持人與相關團隊將盡力確保您的個人資料獲得妥善保護。

(十三)受試者權益：

1. 如果您在試驗/研究過程中對試驗/研究工作性質產生疑問，對身為患者之權利有意見或懷疑因參與研究而受害時，可與研究倫理委員會聯絡請求諮詢，電話號碼為：(02)2312-3456轉263155。
2. 試驗/研究過程中，與您的健康或是疾病有關，可能影響您繼續接受臨床試驗/研究意願的任何重大發現，都將即時提供給您。如果您決定退出，醫師會安排您繼續接受醫療照護。如果您決定繼續參加試驗/研究，可能需要簽署一份更新版的同意書。
3. 本同意書一式2份，試驗主持人或其授權人員已將1份已簽名的同意書交給您，並已完整說明本研究之性質與目的。
4. 如果您現在或於試驗/研究期間有任何問題或狀況，請不必客氣，可與台大醫學院物理治療系暨研究所的研究人員曾怡珊聯絡（聯繫電話:02-27084859）。
5. 參加試驗研究計畫之補助：無

(十四)本研究預期可能衍生之商業利益及其應用之約定：

自本試驗/研究預期不會衍生專利權或其他商業利益。

(十五)簽名：

1. 試驗主持人、或協同主持人或其授權人員已詳細解釋有關本研究計畫中上述研究方法

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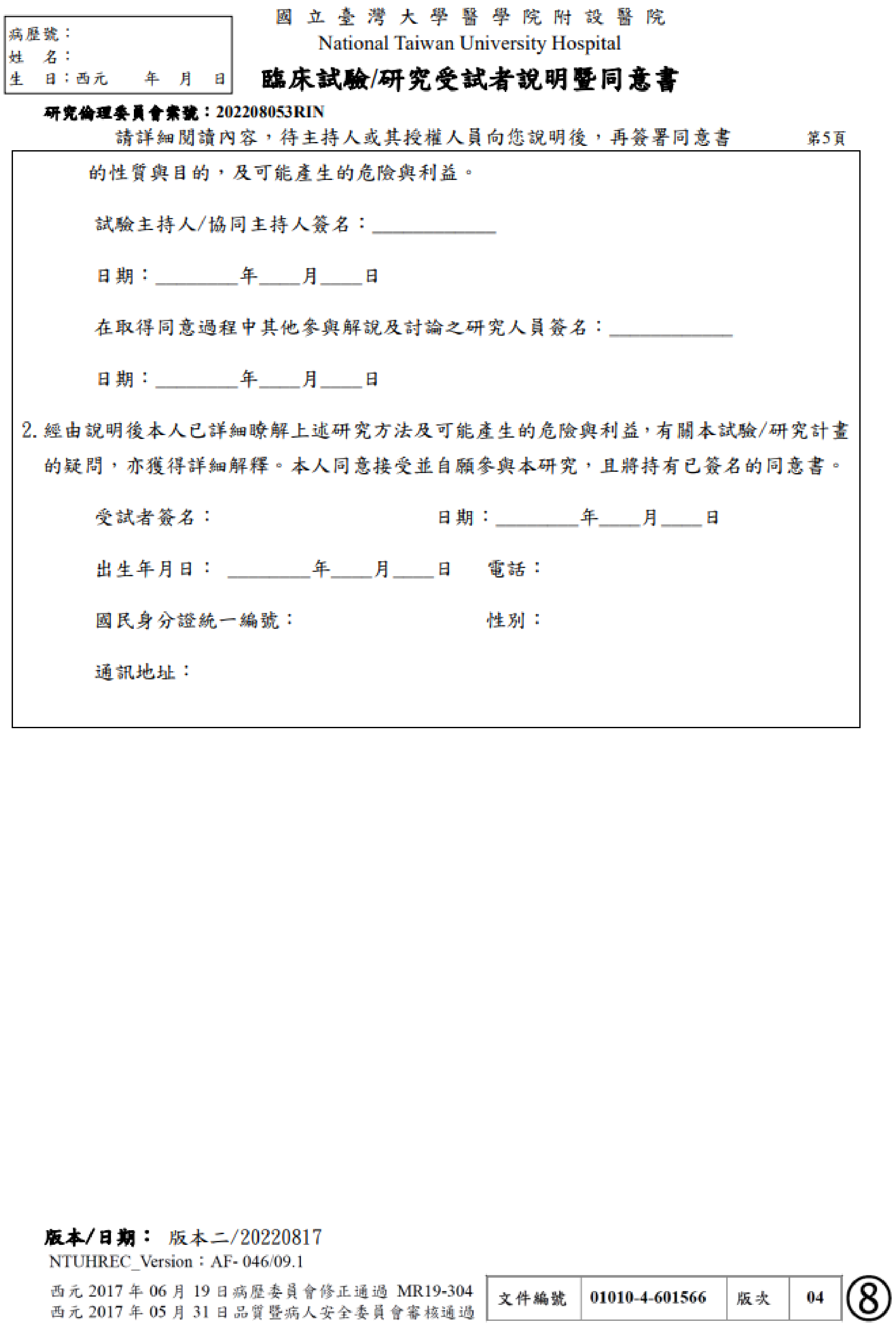

病歷號：
姓　名：
生　日：西元　　年　月　日

國立臺灣大學醫學院附設醫院
National Taiwan University Hospital

臨床試驗/研究受試者說明暨同意書

研究倫理委員會案號：202208053RIN

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的性質與目的，及可能產生的危險與利益。

試驗主持人/協同主持人簽名：____________

日期：________年____月____日

在取得同意過程中其他參與解說及討論之研究人員簽名：____________

日期：________年____月____日

2. 經由說明後本人已詳細瞭解上述研究方法及可能產生的危險與利益，有關本試驗/研究計畫的疑問，亦獲得詳細解釋。本人同意接受並自願參與本研究，且將持有已簽名的同意書。

受試者簽名：　　　　　　　　　　日期：________年____月____日

出生年月日：________年____月____日　電話：

國民身分證統一編號：　　　　　　　性別：

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