AMERICAN UNIVERSITY OF BEIRUT

ELECTROMYOGRAPHY ANALYSIS OF MAXIMUM VOLUNTARY CONTRACTION TECHNIQUES FOR SHOULDER, NECK, AND TRUNK MUSCLES

by

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AN ABSTRACT OF THE THESIS OF

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Title: Electromyography Analysis of Maximum Voluntary Contraction Techniques for Shoulder, Neck, and Trunk Muscles

Due to numerous technical and physiological factors, raw EMG signals can be misleading when conducting electromyographic analysis. It is therefore essential to properly normalize EMG signals. Normalization in reference to a Maximum Voluntary Contraction (MVC) has been proven to be the most appropriate, reliable and common normalization technique. However, there are no clear and conclusive recommendations for eliciting MVC from healthy patients. This poses a serious challenge to modern ergonomists, as an erroneous normalization technique would jeopardize the reliability of results.

Therefore, the objective of this research is to compare literature-based MVC techniques for six muscles in the neck, shoulder, and low back regions in healthy subjects. The six muscles chosen were: the thoracic erector spinae, the lumbar erector spinae, the latissimus dorsi, the posterior deltoid, the upper trapezius, and the sternocleidomastoid. These muscles were chosen based on the amount of attention they receive in ergonomic research. EMG activities were measured while 15 healthy participants performed specific MVC techniques for each muscle chosen.

The results indicated that the lumbar and thoracic subdivisions of the erector spinae muscle can be maximally activated by four similar MVC technique. Furthermore, it was recommended to use the “Prone Extension” test or the “Chest Supported ROW” test to normalize EMG signals from the latissimus dorsi. The “Shoulder Abduction in Slight Extension” test or the “Transvers Abduction” test were recommended as the MVC technique for the posterior deltoid. The results showed that the levels of EMG signal generated by the upper trapezius in the “Abduction 125” test, the ”Elevation and Abduction 90” test, and the “Abduction 90” test were not significantly different. Therefore, either one of the former three tests can be used as a MVC technique for the upper trapezius. Finally, the “Anterolateral Flexion” was found to be the optimal MVC technique for the sternocleidomastoid muscle.

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CHAPTER 1

INTRODUCTION

1.1 Work-Related Diseases

1.1.1 Definition and Cost of Work-Related Diseases

Work-related diseases are defined as disorders other than and in addition to recognized occupational diseases that occur among working people when the work environment and performance contribute significantly, but in varying magnitude to disease causation (WHO, 1985). These diseases have grown to become a major problem in modern industrialized societies as their costs in the US were estimated to be more than $250 billion dollars in 2007, which is more than the cost of diabetes, coronary heart diseases, and strokes. However, work-related diseases do not receive the same amount of attention on the public, medical, and research level (Leigh, 2011). Work-related diseases include a wide variety of illnesses and disorders such as: hypertension, heart diseases, respiratory diseases, musculoskeletal disorder, mental stress, burn injuries, and violence in the work place.

1.1.2 Work Related Musculoskeletal Disorders

The European Agency for Safety and Health at Work defines work related musculoskeletal disorders (WMSD's) as:

Impairments of bodily structures such as muscles, joints, tendons, ligaments, nerves, bones or a localized blood circulation system that are caused or aggravated primarily by the performance of work and by the effects of the immediate environment where the work is carried out (Podniece & Taylor, 2008, p.12).

The term “musculoskeletal disorders” can refer to all kind of diseases and disorders that affect the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels. Common musculoskeletal diseases include: carpel tunnel syndrome, trigger finger, rotator cuff disorders, and lateral epicondylitis (tennis elbow).

WMSD are the most costly work-related diseases (Punnett & Wegman, 2004), with their rates representing 34% of all work-related injuries and illnesses in the US (BLS, 2012), 36% of all lost time claims, and 41% of all costs between 1994 and 2002 (Silverstein et al., 2007). Rates are even more alarming in the UK with musculoskeletal disorders accounting for 42% of all work-related diseases (Health and Safety Executive, 2014). In Europe more than 45% of all workers report having symptoms of muscular pain and backaches (EUROFOUND, 2007). Nursing is considered one of the most affected professions by work-related musculoskeletal disorders in the US (BLS, 2014) and the UK (Health and Safety Executive, 2014). Other highly affected occupations include heavy truck drivers, maintenance workers, and postal services.

Statistics show that the low back and upper limbs are the most affected body parts by WMSD’s. The term upper limbs when discussing musculoskeletal disorders refers to disorders affecting the hand, wrist, arm, elbow, shoulder, and neck. In the US, low back and shoulder musculoskeletal disorders alone represent 49% of all work-related musculoskeletal disorders, with the total percentage of low back and upper limbs musculoskeletal disorders being 60% of all WMSD's (BLS, 2012). In the UK low back work-related musculoskeletal disorders have the highest prevalence of WMSD's followed by those of the upper limbs (Health and Safety Executive, 2014).

Therefore, the choice of the six muscles investigated in this thesis was restricted to muscles from the low back, shoulder, and neck since these areas are highly affected by WMSD's and have been the primary focus of ergonomic research.

1.2 Ergonomics and Physical Ergonomics

1.2.1 Ergonomics

The word ergonomic is derived from two Greek words: 'ergo' (work) and 'nomos' (law). Ergonomics is defined by the IEA as "*the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies the theory, principles, data and methods to design in order to optimize human well-being and overall system performance.*" (IEA council, 2000)

Even though the first professional ergonomic research group was established in 1949 the foundations of ergonomics can be traced back to the 18^{th} century. Currently, ergonomics is an established field of science with its application being used in fields such as: aviation, product design, health care, road design, office design, and many others.

1.2.2 Benefits of Ergonomics

The economic cost of work-related injuries and illnesses is increasing at a rapid rate. However, due to the large number of factors associated with work-related injuries these costs could not be accurately calculated. These factors include direct costs, such as medical costs and continuation of payment, and indirect costs, such as legal cost and lost productivity (Pulat, 1997). Several studies have attempted to quantify the cost of some work-related injuries and illnesses; Table 1 summarizes the results of four of those studies.

Table 1: Cost of work related injuries and illness

Title	Authors	Country	Work related disorder	Total Cost	Remarks
Occupational injury and illness in the United States	(Leigh et al., 1997)	USA	All physical injuries	$171 billion	Did not include the cost of pain
The costs ofworkplace bullying	(Giga et al., 2008)	UK	Job related mental stress	£ 13.75 billion	Included the cost of absenteeism, turnover and productivity due to bullying.
Work-related musculoskeletal disorders of the neck, back, and upper extremity in Washington State, 1997-2005	(Silverstein & Adams, 2007)	USA	Work Related Musculoskeletal disorders (WMSD's)	$ 4.1 billion	Direct costs only from 1997 to 2005
The economic burden of non–influenza-related viral	(Fendrick et al., 2003)	USA	Non-influenza related viral respiratory tract	$ 40 billion	Direct cost: $17 billion.

respiratory tract infection in the United States			infection in the workplace		Indirect cost: $22.5 billion.

It is clear that an intervention aimed at reducing the risk of injury in the work place would benefit both the employer and the employee. From an economical point of view, an ergonomic intervention is justified only if its benefits surpass its cost. The literature presents strong evidence in favor of the economic efficacy of ergonomic interventions. Table 2 summarizes the findings of four ergonomic studies that evaluated the benefits of ergonomic interventions.

Table 2: Benefits of ergonomic interventions

Tittle	Authors	Intervention	Savings
An economic evaluation of a participatory ergonomics process in an auto parts manufacturer	(Tompa et al., 2009)	Ten change projects in a Canadian car parts manufacturer.	NPV = $244,416 Benefit-to-cost ratio =10.6
Economic impact of ergonomic intervention. Four case studies	(Kemmlert, 1996)	Four ergonomic interventions in: 1- Radiator manufacturing worker 2- VDU operator 3- Metal industry worker 4- Nurse assistant	Average monthly gain= $ 4464 Average pay-off period = 2.75 months

Net-cost model for workplace interventions	(Lahiri et al., 2005)	Three ergonomic interventions in: 1- Wood processing plant (123 workers) 2- Major automotive supplier (637 workers) 3- Automobile and truck body plant (1,500 workers)	Benefit to cost ratios: Case A: 15 Case B: 84 Case C: 5.5
The three-year economic benefits of a ceiling lift intervention aimed to reduce healthcare worker injuries	(Chhokar et al., 2005)	Use of ceiling lifts to transfer patients in a care facility. Duration of study: 3 years	Total savings: $1,257 ,605 Payback period: 0.82 years

The four previous studies discuss the benefits of ergonomic interventions from an economical point of view which is only the employer's concern. However, the benefits of ergonomics can be felt at the employees' level by improving the health of individuals which would lead to beneficial results for the whole society.

1.2.3 Physical Ergonomics

The IEA divides ergonomics into three main domains: physical ergonomics, cognitive ergonomics, and organizational ergonomics. Physical ergonomics is primarily concerned with the human biomechanical, anthropometrical, and physiological characteristics and their relation to physical activities. Alternatively, cognitive ergonomics' primary concern is humans' mental capabilities and skills. Human-machine interaction is also a main focus of cognitive ergonomics. Finally, organizational ergonomics deals with organizational structures and their effect on employees' productivity. The main focus of this thesis, (MVC) techniques, lies under physical ergonomics. (Price, 1989)

One of the main focuses of modern physical ergonomists is to measure the physical cost of certain jobs to make sure it is within the worker's physical capabilities. Several physiological indicators can be used to measure the physical cost of a certain task such as: EMG, heart rate, O_2 consumption and heart rate variability. Any one or a combination of these indicators can be used as a measurement of a task's physical cost.

1.3 Electromyography (EMG)

1.3.1 Definition and Application

"Electromyography (EMG) is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fiber membranes" (Basmajian & De Luca, 1985). In other words, EMG is the measurement of the electrical activity of muscles.

EMG can be a helpful tool in ergonomic research as it can provide ergonomists with an understanding of muscles' function and reactions. EMG can help ergonomists answer five main questions about a muscle's activity (Pulat, 1997):

1- Which muscles are active when performing a physical task?

2- Is the muscle more or less active (with respect to time, other muscles, or different tasks)?

3- When during the task is the muscle active?

4- How active is the muscle?

5- Does the muscle fatigue?

Electrical activity of the muscles can be recorded by one of three types of electrodes: surface electrodes, needle electrodes, and wire electrodes. Therefore, EMG recording methods are divided into two main categories: intramuscular EMG and surface EMG (sEMG). Intramuscular EMG requires the insertion of a needle or a fine wire into the muscle under the skin. Whereas, sEMG uses self-adhesive surface electrodes placed on the skin. Both methods have their disadvantages; intramuscular EMG is considered to be an invasive method in comparison to sEMG and needles may move after insertion thus leading erroneous readings (Basmajian & De Luca, 1985). Alternatively, fears of crass-talk from neighboring muscles (De Luca & Merletti, 1988; Perry et al., 1981; Solomonow et al., 1994) in addition to possible movements of the muscle under the electrode (Rainoldi et al., 2000) have been two of the biggest concerns related to using sEMG. Additionally, sEMG can only be used to record EMG activities of surface muscles.

1.3.2 EMG Normalization: Necessity and Techniques

One of the most important aspects of using EMG is that it provides ergonomists with the ability to compare activation levels between: a) different muscles performing the same task, b) same muscle during different tasks or different days, c) different groups of subjects (e.g. healthy vs. patients), d) different electrodes sites. However, performing such comparisons requires the use of normalized EMG signals instead of raw EMG signals (Cram et al., 1998; De Luca, 1997; Kumar & Mital, 1996; Mathiassen et al., 1995). The need for normalizing EMG signals comes from a number of physiological and technical reasons. Technical reasons include: differences in pick-up and conductivity characteristics of electrodes (Kumar & Mital, 1996), electrodes placement (Jensen et al., 1993), and electrodes configuration (De Luca, 1997). On the other hand physiological reasons include: skin temperature changes (Winkel & Jørgensen, 1991), muscle length (McGill & Norman, 1986), cross talk from neighboring muscles (Koh & Grabiner, 1993), and blood flow in the muscle (De Luca, 1997). Therefore, EMG normalization techniques have been a focus point in ergonomic research.

EMG normalization is simply achieved by dividing EMG signals by a signal recorded during a reference activity, as shown in equation 1:

$$\boldsymbol{Normalized\ EMG} = \frac{\boldsymbol{Task\ EMG}}{\boldsymbol{Reference\ EMG}}$$

The choice of the reference activity has been a debatable topic in recent ergonomic studies. Burden (2010) reviewed EMG normalization techniques and identified eight common normalization techniques: 1) mean of task, 2) peak of task, 3) isometric sub-MVC, 4) dynamic sub-MVC, 5) Arbitrary angle isometric maximal voluntary contraction, 6) Angle specific maximal isometric voluntary contraction, 7) angle specific maximal dynamic voluntary contraction, and 8) angle and angular velocity specific maximal isokinetic voluntary contraction. All these terms refer to the choice of the reference activity used to generate the EMG signal used as the denominator in equation 1. Burden (2010) recommended the use of isometric maximum voluntary contractions. Moreover, isometric maximum voluntary contraction have been proved to be reliable for: test-retest comparisons (Bolgla & Uhl, 2007), across electrodes sites comparisons (Morris et al., 1998), intramuscular EMG and sEMG (Burnett et al., 2007), and across groups comparisons (Allison et al.,1993). Thus, normalizing EMG signals by using signals from maximum voluntary contractions remains the most appropriate, reliable, and common technique. A major downfall of using maximum voluntary contractions (MVC) as an EMG normalization technique is the production of normalized EMG signals over 100% MVC, especially if EMG signals from dynamic tasks are being used in the numerator in equation 1 (Clarys, 2000). Hence, the success of normalizing EMG signals using MVC depends heavily on the techniques used to elicit MVC from subjects, which is the main focus of this thesis.

1.3.3 Maximum Voluntary Contraction Techniques

Isometric tests and Manual Muscle Testing (MMT) are the most widely used techniques to elicit MVC (Brinkmann et al., 1997). MMT is a safe, simple, and non-expensive method to examine muscles strength. However, MMT has been proven to be less sensitive to changes in muscle activity (Aitkens et al., 1989; Bohannon, 2005), which cast some doubt on its reliability. On the other hand, isometric tests require devices that can be expensive or unpractical. The major problem with both techniques remains the lack of consensus on the appropriate technique to elicit the maximum voluntary contraction from a certain muscle (Chopp et al., 2010b). Several studies have reported that muscles are maximally activated in more than one technique which limits the possibility of recommending only one test to elicit maximum voluntary contraction from a certain muscle (Boettcher et al., 2008; Ekstrom et al., 2005; Ng et al., 2002; Nieminen et al., 1993; Vera-Garcia et al, 2010). Therefore, the literature presents multiple recommendations for eliciting the MVC of any certain muscle. Nonetheless, as far as known, no study has been able to describe or compare all the tests able to maximally activate any of the eight muscles investigated in this thesis.

1.4 Research Objective and Significance

The objective of this thesis is to compare literature-based MVC techniques for six muscles in the neck, shoulder and low back regions. The muscles chosen were: the lumbar erector spinae, the thoracic erector spinae, the latissimus dorsi the posterior deltoid, the sternocleidomastoid, and the upper trapezius. The results of this research will benefit the ongoing effort to identify the appropriate MVC techniques of muscles that are frequently investigated in ergonomic research.

CHAPTER 2

LITERATURE REVIEW

2.1 Selection of Muscles

As explained before, the selection of muscles to be investigated in this study was restricted to muscles from the low back, shoulder, and neck areas. Since low-back musculoskeletal disorders constitute 36% of all work related injuries (BLS, 2012) three muscles were chosen from the low-back area whereas two muscles were chosen from the shoulder area and one muscle from the neck area. The selection of the muscles was dependent on the amount of attention each muscle receives in ergonomic research. Ergonomic studies using sEMG to investigate WMSD's in the three pre-selected body regions were reviewed and the muscles they examined were listed. Eventually, the muscles with the most citations were selected for further investigation.

A manual search was performed using Google scholar for ergonomic and biomechanical studies concerning low back, shoulder, and neck WMSD's. The "cited by" and "related articles" functions in Google scholar were utilized to find additional related research. Only articles that used sEMG to record EMG signals from low back, shoulder, and neck muscles were included in this study.

2.1.1 Ergonomic Research Discussing Low Back WMSD’s

Forty-five ergonomic studies concerned with low back WMSD’s were chosen for reviewing. Each study’s abstract was reviewed to make sure it fits the criteria for selection and then the muscles investigated in the study were listed. Table 3 summarizes the results of this review.

Table 3: Low back WMSD's

#	Authors	Objective of Study	Muscles Investigated
1	(Babski-Reeves et al., 2005)	To identify and quantify the effects of monitor height and chair classification on risk factors associated with developing musculoskeletal pain/discomfort of the back and neck.	- Erector Spinae (L1 and L5 region)
2	(Laing et al., 2005)	To evaluate the effectiveness of a participatory ergonomics program implemented in an automotive parts manufacturing factory.	- Lumbar portion of erector spinae
3	(Kim et al., 2011)	To quantify the effect of a new technology designed to increase productivity in residential construction	-Internal oblique -External oblique -Rectus abdominis -Iliocostalis lumborum pars lumborum -Latissimus dorsi -Multifidus -Longissimus thoracis pars lumborum -Longissimus thoracis pars thoracic
4	(Sundaravalli et al., 2000)	To measure time-endurance limits for maintaining non-neutral trunk postures, identify the significant predictors of endurance time, and develop a database that describes postural capabilities of workers	- Left and right Erector Spine

5	(Hansen et a1., 998)	To study the significance of mat and shoe softness during prolonged work in upright position based on physiological, biomechanical and comfort measurements related to the lower extremities and low back.	- Left and right Erector Spinae at L3 level
6	(van Dieën, et al., 2003)	To assess trunk muscle recruitment in patients with low back pain.	- Rectus Abdominis - External Oblique - Internal Oblique - Thoracic Erector Spinae - Lumbar Erector Spinae - Multifidus
7	(McGill et al., 1996)	To develop a method of estimating spinal loading in a 3-D model that was sufficiently simple for ergonomic use but that retained as much anatomical and physiological content validity as the authors could incorporate.	- Rectus Abdominis - External Oblique - Internal Oblique - Thoracic Erector Spinae - Lumbar Erector Spinae - Latissimus Dorsi - Anterior superior iliac spine
8	(McGill, 1991)	a) To find a method to obtain the maximum myoelectric signal amplitude for normalization of the trunk musculature, b) To examine the myoelectric activity-axial torque relationship of various trunk muscles, c) To combine myoelectric signal information with an analytical model in an effort to increase insight into muscular axial torque production.	- Rectus Abdominis - External Oblique - Internal Oblique - Thoracic Erector Spinae - Lumbar Erector Spinae - Latissimus Dorsi
9	(Van Dieen et al., 2001)	To study the effects of dynamic office chairs on the low back.	- Erector Spinae at the L3 and T10 level
10	(Durkin et al., 2006)	To examine the effects of three different lumbar massage systems on lumbar and thoracic erector	- Erector Spinae at the L3 and T9 level

		spinae muscle fatigue, oxygenation, blood flow and driver discomfort and performance during prolonged driving tasks.	
11	(Granata & Marras, 1993)	To develop a model of low-back mechanics and spinal loading which accounts for muscle coactivity, employing dynamically interpreted EMG and muscle kinematics.	- Latissimus Dorsi - Erector Spinae - Rectus Abdominis, - Internal Oblique - External Oblique
12	(Granata & Marras, 1995a)	To accurately predict multi-dimensional, dynamic trunk moments and spinal loads with valid and repeatable model performance.	- Latissimus Dorsi - Erector Spinae - Rectus Abdominis, - Internal Oblique - External Oblique
13	(Radebold et al., 2000)	To identify differences in muscle response patterns between patients with low back pain and healthy control subjects in response to multidirectional load release	- Rectus Abdominis - External Oblique - Internal Oblique - Thoracic Erector Spinae - Lumbar Erector Spinae - Latissimus Dorsi - Anterior superior iliac spine
14	(Chaffin, et al., 1999)	To examine the potential effect of short-term practice on low-back stresses during manual lifting and lowering of a 15 kg load, and while using two different types of materials handling devices (MHDs) to lift and lower a 40 kg load.	- Rectus Abdominis - External Oblique - Internal Oblique - Thoracic Erector Spinae - Lumbar Erector Spinae - Latissimus Dorsi
15	(Ng et al., 2002)	To examine the EMG activity of three pairs of abdominal muscles and three pairs of back muscles during isometric axial rotation at different exertion levels in back pain patients and matched controls.	- Rectus Abdominis - External Oblique - Internal Oblique - Latissimus Dorsi - Iliocostalis lumborum - Multifidus

16	(Marras et al., 2001)	To evaluate how low back pain influences spine loading during lifting tasks.	- Rectus Abdominis - External Oblique - Internal Oblique - Latissimus Dorsi - Erector Spinae
17	(Graham et al., 2009)	To assess changes in spring excursion and PLAD‟s moment arm as a result of varying degrees of trunk and knee flexion	- Thoracic Erector Spinae - Lumbar Erector Spinae - Rectus Abdominis
18	(Radebold et al., 2001)	To determine whether patients with low back pain will exhibit poorer postural control, this will be associated with longer average muscle response times.	- Rectus Abdominis - External Oblique - Internal Oblique - Thoracic Erector Spinae - Lumbar Erector Spinae - Latissimus Dorsi - Anterior superior iliac spine
19	(Nemeth et al., 1990)	To investigate the load on the lumbo-sacral and hip joints and muscle activity in ten professional milkers simulating 20 different standardized machine-milking work postures in our laboratory.	- Erector Spinae - Oblique Abdominis
20	(Granata & Marras, 1999)	To examine the relationship between predicted biomechanical load factors on the spine and the probability of high LBD risk.	- Rectus Abdominis - External Oblique - Internal Oblique - Lumbar Erector Spinae - Latissimus Dorsi
21	(Kingma et al., 2004)	To investigate the effects of initial load height and foot placement instruction in four lifting techniques: free, stoop (bending the back), squat (bending the knees) and a modified squat technique (bending the knees and rotating them outward).	- Thoracic Erector Spinae - Lumbar Erector Spinae - Rectus Abdominis - External Oblique - Internal Oblique

22	(Skotte et al., 2002)	To investigate the low-back loading during common patient-handling tasks.	- Lumbar Erector Spinae
23	(van Dieën & Kingma, 1999)	To test the assumption that asymmetric trunk loading requires a higher total muscle force and thus entails a higher compression forces on the spine as compared to symmetric loading.	- Longissimus - Multifidus - Iliocostalis - Rectus Abdominis - External Oblique - Internal Oblique
24	(Hoozemans et al., 2004)	To quantify the mechanical load on the low back and shoulders during pushing and pulling in combination with three task constraints: the use of one or two hands, three cart weights, and two handle heights	- Longissimus - Multifidus - Iliocostalis - Rectus Abdominis - External Oblique - Internal Oblique
25	(S. McGill & Kavcic, 2005)	To quantify the friction reducing ability of three different patient transfer devices during push, pull and twist transfers, together with the effect on the low backs of workers performing the transfers.	- Thoracic Erector Spinae - Lumbar Erector Spinae at L5 and L3 - Rectus Abdominis - External Oblique - Internal Oblique - Latissimus dorsi
26	(Davis et al., 1998)	To estimate three dimensional spinal loads during various lifting and lowering tasks	- Rectus Abdominis - External Oblique - Internal Oblique - Lumbar Erector Spinae - Latissimus Dorsi
27	(Hoozemans et al., 2008)	To quantify the effect of lifting height and lifting mass on the peak low back load in terms of net moments, compression forces and anterior–posterior shear forces	- Rectus Abdominis - External Oblique - Internal Oblique - Iliocostalis lumborum - Longissimus thoracis pars lumborum and pars thoracis

28	(Nelson-Wong et al., 2008)	To examine muscle activation patterns prior to, and during, the development of low back pain in asymptomatic individuals	- Thoracic Erector Spinae - Lumbar Erector Spinea - Rectus Abdominis - External Oblique
29	(S. McGill & Norman, 1987)	To reassess the role of IAP as a viable mechanism of reducing spinal loading during stressful lifts	- Rectus Abdominis - Anterior superior iliac spine - External Oblique - Internal Oblique - Latissimus Dorsi - Thoracic Erector Spinae - Lumbar Erector Spinae
30	(Cholewicki et al., 2005)	To determine whether delayed muscle reflex response to sudden trunk loading is a result of or a risk factor for sustaining a low back injury (LBI).	- Thoracic Erector Spinae - Lumbar Erector Spinae - Rectus Abdominis - External Oblique - Internal Oblique - Latissimus Dorsi
31	(Kingma & van Dieën, 2004)	To examine the effect of one-handed lifting with support of the free hand	- Rectus Abdominis - External Oblique - Internal Oblique - Iliocostalis lumborum - Longissimus thoracis pars lumborum and pars thoracis
32	(Dankaerts et al., 2006)	To determine differences in trunk muscle activation during usual unsupported sitting.	- Rectus Abdominis - External Oblique - Internal Oblique - Lumbar Multifidus - Iliocostalis lumborum
33	(Gregory & Callaghan, 2008)	To compare of the effect of different floor surfaces on low back discomfort	- Thoracic Erector Spinae - Lumbar Erector Spinea - Rectus Abdominis - External Oblique
34	(Marras & Granata, 1997)	To address these limitations of previous efforts biomechanical assessment models have been developed that intended to assess the load profile imposed upon the spine during lifting and thus,	- Rectus Abdominis - External Oblique - Internal Oblique - Erector Spinae - Latissimus Dorsi

		intended to facilitate the control of LBD risk in the workplace.	
35	(Lavender & Marras, 1995)	To evaluate the biomechanical preparations exhibited in anticipation of any sudden loading	- Rectus Abdominis - External Oblique - Lumbar Erector Spinae - Latissimus Dorsi
٣٦	(Pope et al., 1998)	To study of the relationship between whole-body vibration and low back pain	- Erector Spinae
37	(Marschall et al., 1995)	To examine the effects of work station design (ergonomic versus traditional) on neuromuscular activation patterns of select postural muscles, sitting posture, tracing performance and subjective preference in a group of young children.	- Latissimus Dorsi - Lumbar Erector Spinae
38	(Essendrop et al., 2002)	To apply sudden load to the trunk during static lifting and compare situations with alternating low levels of IAP realistic to actual work situations	- Lumbar Erector Spinae - Rectus Abdominis - Iliocostalis lumborum - External Oblique - Internal Oblique
39	(Keir & MacDonell , 2004)	To examine muscle activity patterns during patient handling during manual transfers, and transfers using floor and ceiling lifts	- Latissimus Dorsi - Lumbar Erector Spinae - Thoracic Erector Spinae
40	(Granata & Marras, 1995b)	To examine the effect of muscle co-activation in spinal loading.	- Erector Spinae - Latissimus Dorsi - Internal Oblique - External Oblique - Rectus Abdominis
41	(Kim & Chungl, 1995)	To determine the patterns of recruitment and the relative activation levels of eight primary trunk muscles as a function of body posture, weight and frequency combinations;	- Erector Spine - Latissimus Dorsi - External Oblique - Rectus Abdominis

42	(Marras et al., 1986)	To investigate the internal and external trunk loading factors as a function of trunk velocity	- Erector Spinae - Latissimus Dorsi
43	(Marras, 1987)	To evaluate the temporal relation among the LD and ES muscles and external force generation capacity	- Erector Spinae - Latissimus Dorsi
44	(Potvin et al., 1991)	To assess interplay between muscular and ligamentous source of extensor moments	- Thoracic Erector Spinae - Lumbar Erector Spinea - Rectus Abdominis - External Oblique - Internal Oblique - Latissimus Dorsi
45	(O'Sullivan et al., 2006)	To compare spinal-pelvic curvature and trunk muscle activation in 2 upright sitting postures ("thoracic" and "lumbo-pelvic") and slump sitting in a pain free population.	- Lumbar Multifidus - Iliocostalis lumborum pars thoracis - Thoracic Erector Spinae - External Oblique - Internal Oblique - Rectus Abdominis

The thoracic and lumbar erector spinae were used the most in the literature (38/45) due to their unique role. These two muscles are frequently used in ergonomic studies concerned with material handling and office ergonomics, two major areas of concentration for recent ergonomic research. On the other hand, 24 studies investigated the activity of the latissimus dorsi. Most of these studies were related to lifting tasks under different conditions. Therefore, the five muscles chosen from the trunk for further examination were:

- Lumbar Erector Spinae
- Thoracic Erector Spinae
- Latissimus Dorsi

2.1.2 Ergonomic Research Discussing Shoulder WMSD's

Forty ergonomic studies concerned with shoulder WMSD's were chosen for reviewing. Each study's abstract was reviewed to make sure it fits the criteria for selection and then the muscles investigated in the study were listed. Table 4 summarizes the results of this review.

Table 4: Shoulder WMSD's

#	Authors	Objective of Study	Muscles Investigated
1	(Madeleine et al., 2003)	To evaluate the possible differences in motor strategies to a new standardized low-load repetitive work task in between healthy experienced workers and a reference group	- Anterior Deltoid - Middle Deltoid - Infraspinatus - Trapezius
2	(Kleine et al., 1999)	To investigate temporal changes of activation of shoulder and back muscles in workers at visual display units by means of surface EMG.	- Posterior Deltoid - Anterior Deltoid - Upper Trapezius - Sternocleidomastoid
3	(Madeleine et al., 2008)	To investigate changes in the size of motor variability with experience and pain	- Anterior Deltoid - Middle Deltoid - Infraspinatus - Trapezius
4	(Antony & Keir, 2010)	To evaluate the effects of arm posture and hand loading on shoulder muscle activity during both isometric and dynamic conditions.	- Anterior deltoid - Middle deltoid - Posterior deltoid - Pectoralis major - Infraspinatus - Latissimus dorsi - Biceps brachii - Superior trapezius
5	(Qin et al., 2014)	To determine shoulder muscle loading as well as its temporal patterns among young and older female adults during an 80-minute	- Anterior Deltoid - Posterior Deltoid - Middle Deltoid - Infraspinatus

		low-intensity repetitive manual task, which was designed to simulate light assembly tasks in occupational settings.	- Upper Trapezius
6	(Björklund et al., 2000)	To investigate the impact of low-intensity repetitive arm work to fatigue on the position sense acuity of the shoulder	- Anterior deltoid - Middle deltoid - Posterior deltoid - Lower Trapezius - Biceps - Triceps
7	(Raina & Dickerson, 2009)	To determine the consequences of rotating between two functionally different, standardized tasks involving the same primary muscle group on indicators of fatigue and/or exertion.	- Anterior deltoid - Middle deltoid - Posterior deltoid
8	(R. Mehta & Agnew, 2008)	To quantify the synergistic impact of fatigue and aging on the performance of spatially constrained drilling tasks that are representative of those that exist within the construction industry	- Anterior Deltoid - Upper Trapezius
9	(Hager, 2003)	To measure the reliability of fatigue measures in an intermittent overhead work task.	- Anterior Deltoid - Middle Deltoid - Upper Trapezius
10	(Mehta & Agnew, 2011)	To quantify the effects of concurrent physical and mental demands on the upper extremity muscle activity during static exertions	- Anterior deltoid - Posterior deltoid
11	(Lim et al., 2011)	To understand the effects of coordination between the back and shoulder angles on the subjective discomfort ratings, heart rates and muscle activities of seven muscle groups associated with eight different postures that were combinations of two back angles and four shoulder angles.	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius - Lower Trapezius - Biceps - Triceps

12	(Chopp et al., 2010a)	To quantify shoulder muscle activity for several overhead working configurations, target angles and hand force directions to determine how differences in overhead work conditions influence specific muscle activation.	- Biceps Brachii - Triceps Brachii - Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius - Lower Trapezius - Latissimus Dorsi - Infraspinatus - Pectoralis Major (clavicular Insertion) - Pectoralis Major (Sternal Insertion)
13	(Ebaugh, et al., 2006)	To study the effect of fatigue caused by repetitive overhead work on muscular activity and shoulder motion	- Anterior Deltoid - Posterior Deltoid - Serratus Anterior - Infraspinatus - Upper Trapezius - Lower Trapezius
14	(Herberts et al., 1984)	To address the problem of increasingly common occupational shoulder disorders	- Anterior Deltoid - Posterior Deltoid - Middle Deltoid - Trapezius - Infraspinatus - Supraspinatus
15	(Sigholm et al., 1983)	To assess the influence of hand tool weight and arm position on shoulder muscle load	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Infraspinatus - Supraspinatus - Upper Trapezius
16	(Cook & Kothiyal, 1998)	To study the effect of mouse position relative to the keyboard influences activity in the shoulder flexors and abductors (anterior and middle deltoid and middle trapezius)	- Middle Deltoid - Anterior Deltoid - Middle Trapezius
17	(Kronberg et al., 1990)	To assess normal standards of EMG patterns of shoulder	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Pectoralis Major

		muscles during loaded, standardized movements.	- Latissimus Dorsi
18	(Cooper & Straker, 1998)	To compare the dominant shoulder muscle load measured from upper trapezius and anterior deltoid, gross postures and discomfort during mousing and keyboarding	- Anterior Deltoid - Lower Trapezius
19	(Nikooyan et al., 2012)	To develop an EMG-driven model of the shoulder that can consider possible muscle co-contractions.	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius - Lower Trapezius - Middle Trapezius - Infraspinatus - Biceps - Triceps
20	(Mell et al., 2006)	To test the hypothesis that wearing a wrist splint while performing a common light manufacturing task (moving an object from a bin) increases shoulder muscle activity	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius - Infraspinatus
21	(van Roon, et al., 2005)	To examine whether individuals with cerebral palsy (CP) systematically vary motion of the trunk and co-contraction in the upper limb as a function of accuracy demands	- Anterior Deltoid - Posterior Deltoid - Triceps
22	(Hodder & Keir, 2012)	To determine if the effect of visually targeted gripping on shoulder muscle activity was maintained with repeated exposures	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Biceps - Triceps - Infraspinatus - Latissimus Dorsi
23	(Crosbie, 1993)	To describe the patterns of muscle activation during swing-through non-weight-bearing (NWB) gaits	- Anterior Deltoid - Posterior Deltoid - Biceps

		using elbow (Canadian) crutches and partially weight-bearing (PWB) gait using forearm support ('rheumatoid') crutches.	- Triceps - Latissimus Dorsi - Pectoralis major
24	(Carnide et al., 2006)	To analyze the existence of associations among biomechanical, morphological and personal risk factors and the prevalence of musculoskeletal symptoms and disorders of the neck and upper limbs in a specialized group of paint workers.	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius
25	(Au & Keir, 2007)	To examine the effects of multitasking on muscular activity in the upper extremity by examining simultaneous shoulder and grip exertions with increased task precision and mental processing demands.	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius
26	(Ferguson et al., 2011)	To quantify exposure to MSD risk factors as a function of vehicle rotation angle during assembly tasks.	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius
27	(MacDonell & Keir, 2005)	To examine the interfering effects of physical and mental tasks on shoulder isometric strength in different postures	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius - Biceps - Infraspinatus
28	(Schantz et al., 1999)	To study the patterns of movement and muscle activation in wheelchair ambulation	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius - Biceps - Triceps - Pectoralis major

30	(Ferguson et al., 2009)	To quantify how musculoskeletal disorder exposure risk changes in an auto assembly task as a function of car body rotation.	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius
31	(Mehta et al., 2009)	To investigate the interactive effects of physical and mental demands on muscle activity of the upper extremity.	- Anterior Deltoid - Posterior Deltoid - Biceps - Triceps
32	(Kothiyal & Kayis, 2000)	To examine if there was any preferred movement direction for one handed material handling activities	- Anterior Deltoid - Posterior Deltoid - Middle Deltoid - Upper Trapezius - Infraspinatus
33	(Dickerson, et al., 2008)	To evaluate the performance of a novel shoulder muscle force prediction model with empirical EMG data for a dynamic task.	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius - Lower Trapezius - Biceps - Triceps - Infraspinatus - Pectoralis major - Latissimus Dorsi
34	(Dickerson et al., 2007)	To assess physical exposure for a series of reaching tasks.	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius - Lower Trapezius - Infraspinatus - Pectoralis major - Latissimus Dorsi - Biceps - Triceps
35	(Veeger et al., 1991)	To describe net torques around the wrist, elbow, and shoulder joints during submaximal wheelchair propulsion at different levels of mechanical advantage and to relate them to muscular activity of	- Anterior Deltoid - Posterior Deltoid - Biceps - Triceps - Upper Trapezius

		selected muscles around those joints.	
36	(Smets et al., 2009)	To determine the modulating effect of adding a constrained handgrip task (30% of MVG) on peak arm strength and muscle activation in various directions and hand heights.	- Anterior Deltoid - Posterior Deltoid - Middle Deltoid - Biceps - Triceps
37	(Jonsson & Jonsson, 1975)	To analyze the function and coordination of the shoulder and arm muscles in car driving.	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid
38	(Murphy & Oliver, 2011)	To assess the efficacy of the newly designed dynamic armrest in the forward and backward movements of a standard hydraulic-actuation joystick in a stationary environment.	- Anterior Deltoid - Posterior Deltoid - Upper Trapezius
39	(Rosati et al., 2014)	To investigate the influence of gender, work height, and paint tool design on shoulder muscle activity and the horizontal force applied to a vertical paint surface by the paint roller during simulated wall painting.	- Anterior Deltoid - Middle Deltoid - Posterior Deltoid - Upper Trapezius - Biceps - Pectoralis Major
40	(McKinnon et al., 2014)	To quantify the influence of a police cruiser compartment configuration for a Crown Victoria police vehicle.	- Anterior Deltoid - Middle Deltoid - Upper Trapezius - Infraspinatus - Supraspinatus

The anterior deltoid and the posterior deltoid were used in 39 and 32 studies, respectively. Thus, they were selected for further investigation. However, MVC techniques of the anterior deltoid received a lot of attention in ergonomic research due to its high importance and results from different studies have been consistent (Boettcher et al., 2008;

Kelly et al., 1996; Chopp et al., 2010). On the other hand, information about the MVC techniques of the upper trapezius is still very much at the basic level. Therefore, the anterior deltoid was excluded from the study and replaced by the upper trapezius.

2.1.3 Ergonomic Research Discussing Neck WMSD's

Thirty ergonomic studies concerned with neck WMSD's were chosen for reviewing. Each study's abstract was reviewed to make sure it fits the criteria for selection and then the muscles investigated in the study were listed. Table 3 summarizes the results of this review.

Table 5: Neck WMSD's

#	Authors	Objective of Study	Muscles Investigated
1	(Nimbarte et al., 2012)	To determine the effect of overhead pushing and pulling exertions on the behavior of major neck and shoulder muscles.	- Upper Trapezius - Cervical Trapezius - Sternocleidomastoid
2	(Ng et al., 2014)	To assess the activity levels of the sternocleidomastoid muscle and upper trapezius muscle during static postures under controlled and standardized conditions.	- Upper Trapezius - Sternocleidomastoid
3	(Szeto & Sham, 2008)	To compare the effects of three different computer-screen positions (central, angled left and angled right) on the neck–shoulder muscle activities and the experience of subjective discomfort in computer users.	- Upper Trapezius - Cervical Trapezius
4	(Tepper et al., 2003)	To investigate whether an ergonomic computer device decreases the muscle activity of the upper trapezius muscle	- Upper Trapezius
5	(McNee et al., 2013)	To investigate the contraction pattern of the sternocleidomastoid and trapezius muscles in differing conditions of an orthodontist's	- Upper Trapezius - Sternocleidomastoid

		natural work and life environments	
6	(Samani et al., 2009)	To assess the acute effects of experimental muscle pain on spatial electromyographic (EMG) activity of the trapezius muscle with active and passive pauses during computer work.	- Upper Trapezius - Middle Trapezius - Lower Trapezius
7	(Hamilton, 1996)	To examine the three-way relationship between task, head posture, and muscle tension.	- Sternocleidomastoid - Cervical Erector Spinae
8	(Johnston et al., 2008)	To explore aspects of cervical musculoskeletal function in female office workers with neck pain.	- Sternocleidomastoid - Cervical Erector Spinae - Upper Trapezius
9	(Lannersten & Harms-Ringdahl, 1990)	To analyze the levels of neck and shoulder muscle activity recorded from subjects operating cash registers	- Sternocleidomastoid - Cervical Erector Spinae - Levator Scapulae
10	(Kim et al., 2008)	To assess the electromyography (EMG) activities of the neck muscles and the head posture in children aged 9–11 years while they were carrying three alternative types of schoolbag	- Sternocleidomastoid - Upper Trapezius - Midcervical paraspinal (MPS)
11	(SCHÜLDT et al., 1986)	To analyze the effect of changing the sitting posture on the level of neck and shoulder muscular activity	- Levator Scapulae - Sternocleidomastoid
12	(Sundelin & Hagberg, 1989)	To evaluate muscular load in the shoulder region during work periods with VDU word processors when different kinds of pauses are introduced.	- Upper Trapezius - Cervical Trapezius - Levator Scapulae
13	(Strimpakos et al., 2005)	To address these limitations by assessing the test re-test reliability of an EMG assessment of cervical muscle fatigue and the Borg assessment of perceived fatigue	- Sternocleidomastoid - Levator Scapulae - Splenius Capitis - Cervical Trapezius

		for all planes of movement in the standing position	
14	(Wærsted & Westgaard, 1997)	To examine whether there were distinct differences in body posture or in the EMG activity pattern of the trapezius, when a paper-based task is compared with a VDU-based task with the same cognitive work content.	- Upper Trapezius
15	(Lundberg et al., 1999)	To examine psychological and physiological stress, as well as muscle tension and musculoskeletal symptoms, among 72 female supermarket cashiers.	- Upper Trapezius
16	(Barton & Hayes, 1996)	To determine the test-retest reliability of a new method for measuring muscular strength, efficiency, and relaxation times of the neck flexor musculature of healthy adults.	- Sternocleidomastoid
17	(Hansson et al., 2000)	To assess differences in physical workload between jobs, selected to represent high and low degrees of repetitiveness.	- Upper Trapezius - Infraspinatus
18	(Nevala-Puranen et al., 2003)	To compare the effects of 2 different intervention models on the neck, shoulder and arm symptoms of newspaper employees.	- Cervical Erector Spinae
19	(Hägg & Åström, 1997)	To assess the EMG work pattern in the trapezius muscle, EMG gaps in particular, PPT, psychosocial work environment and type A behavior in medical secretaries with and without shoulder-neck disorders.	- Upper Trapezius
20	(Oksanen et al., 2008)	To compare the maximal force, EMG/force ratio and co-activation characteristics of the neck-shoulder muscles between 30 adolescents with migraine-type headache, 29 with tension-type	- Upper Trapezius - Sternocleidomastoid - Cervical Erector Spinae

		headache, and 30 headache-free controls	
21	(Horgen et al., 1995)	To investigate whether wearing multifocal lenses over a longer period of time leads to an adaptation that it is possible to measure by a reduction in the trapezius load.	- Upper Trapezius
22	(Harvey & Peper, 1997)	To examine muscle tension and subjective muscle tension awareness while using a computer mouse positioned to the right of a standard computer keyboard and a centrally positioned trackball.	- Upper Trapezius - Sternocleidomastoid - Lower Trapezius - Posterior Deltoid
23	(Turville et al., 1998)	To examine the biomechanical, performance, physiological and visual effects on the user of a 40° and a 15° monitor position.	- Upper Trapezius - Sternocleidomastoid - Cervical Erector Spinae - Levator Scapulae - Thoracic Erector Spinae
24	(Maithel et al., 2005)	To test whether a lightweight head-mounted display system worn by the surgeon improves task performance and the ergonomics of laparoscopy.	- Sternocleidomastoid
25	(Nimbarte et al., 2008)	To evaluate the biomechanical contribution of neck muscles by examining their activity using electromyography (EMG).	- Upper Trapezius - Sternocleidomastoid
26	(Nimbarte et al., 2010)	To evaluate the effect forceful arm exertions on the behavior of the neck muscles.	- Upper Trapezius - Sternocleidomastoid
27	(Harms-Ringdahl et al., 1986)	To evaluate EMG activity levels in shoulder-neck muscles in sitting work postures, and the influence of different trunk inclinations and use of load-reduction equipment during static and dynamic arm work	- Upper Trapezius - Sternocleidomastoid - Cervical Erector Spinae - Middle trapezius - Levator Scapulae - Thoracic Erector Spinae
28	(Sommerich et al., 1998)	To characterize computer viewing angle on operators.	- Upper Trapezius - Sternocleidomastoid - Cervical Erector Spinae

29	(Aghazadeh et al., 2011)	To determine the effects of varying amount of lifted weight on upper extremity joint angles and muscle activity of the neck and shoulder	- Upper Trapezius - Sternocleidomastoid
30	(Wu & Chu, 2011)	To investigate the differences in performance and muscle effort between guideline and preferred setting of keyboard and mouse when using a computer in supine posture.	- Sternocleidomastoid - Extensor carpi Ulnaris

The sternocleidomastoid muscle was used in 20 out of the 30 reviewed studies. The location of this muscle along the lateral part of the neck makes it an integral part in all the neck's basic movement.

Thus, the final list of muscles chosen is as follows:

1- Lumbar Erector Spinae

2- Thoracic Erector Spinae

3- Latissimus Dorsi

4- Posterior Deltoid

5- Upper Trapezius

6- Sternocleidomastoid

2.2 Maximum Voluntary Contraction Techniques

This section reviews the MVC techniques used in the literature of ergonomic research. Each section discusses the MVC techniques for one of the eight muscles selected in the preceding chapter.

2.2.1 Lumbar/Thoracic Erector Spinae

The erector spinae is a large muscle that spans along the vertebral column and lies in the groove on the side of the vertebral column (Gray, 1918). Figure 1 shows the exact location of the erector spinae. In medical text books, the erector spinae is considered to be a group of muscles containing more than 12 subdivisions, due to its large surface area and great variance in its size along the vertebral column. However, in ergonomic research the erector spinae is subdivided into three main subdivisions: lumbar, thoracic, and cervical. As proven in the previous chapter, the lumbar and thoracic subdivisions of the erector spinae muscle are widely used in ergonomic research.

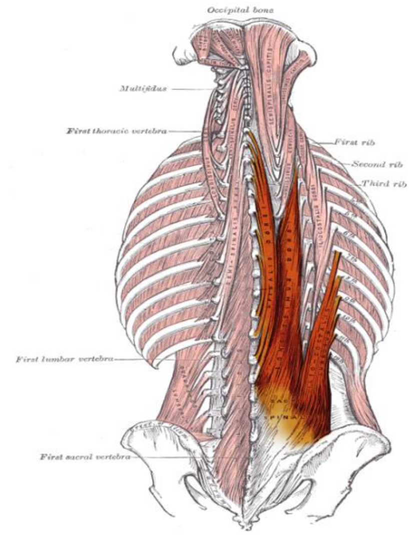

Figure 1: Erector spinae muscle subdivisions

Due to the fact that extending the back is the main function of the erector spinae, the trunk holding technique has been the dominant MVC technique in the literature. The literature describe this technique as an attempted extension of the back while participants are in a supine position with their lower body strapped to an examination table and their upper body hanging off the examination table. The subject must maintain the erect position of the back for 5 seconds (McGill, 1991). Higher erector spinae EMG signals during the trunk holding test have been reported when the upper body formed a 60^o angle with the horizontal (Plamondon et al., 1999). A moderate modification of this technique would be if the participant lays prone on the examination table and tried to lift their upper body of the table against the resistance off a strap; this test is labeled resisted trunk extension (O'Sullivan et al., 2006).

However, little research has been done to prove the efficacy of this technique to elicit MVC from both the lumbar and thoracic erector spinae. The only paper to discuss the matter of appropriate MVC technique for the erector spinae muscle is presented by McGill (1991) who investigated the following techniques on ten men and five women: resisted sit ups, flexion / extension / bending of the trunk in prone and standing positions, and twisting of trunk in a standing position. The lumbar erector spinae was maximally activated by the resisted extension in a prone position test and was the only muscle to be maximally activated by only one test. However, the MVC of the thoracic erector spinae was achieved in: 53.3% of the participants by the resisted extension in a prone position test, 40% of the participants by twisting of the trunk, and 6.7% of the participants by the resisted lateral bending test in a standing position.

Other possible MVC techniques for the erector spinae include “the arch test” and resisted trunk extension in a standing position. The arch test is a technique where subjects lie prone and try to raise the head, hands, and legs until the vertical height cannot be increased. This position is held for 5 seconds. Activity levels of more than 60%MVC for the thoracic erector spinae in the arch test when normalized to the techniques describe by McGill (1991) has been reported by Callaghan et al. (1998). However, the arch test in this study was performed to a “comfortable level”. On the other hand NG et al. (1994) used EMG signals from the arch test to normalize EMG signals of the lumbar erector spinae during trunk holding and leg holding tests. Neither tests produced activity levels of over 100% MVC. Due to the lack of scientific data regarding its efficacy as a MVC technique, only few ergonomic studies have considered using the arch test as a MVC technique.

The second technique, resisted trunk extension in a standing position, is performed when standing, facing a wall with the shoulder strapped to the wall. In this position, maximal attempted backward extension is performed with the pelvis supported. This technique is a better indicator of trunk extensor endurance than the trunk holding test (JØrgensen & Nicolaisen, 1986). Thus, this test might produce higher EMG signals than the trunk holding test. Additionally, Vera-Garcia et al. (2010) reported maximal activity of the lumbar erector spinae in 76.19% of subjects during lower trunk extension. The same technique elicited thoracic erector spinae MVC in 14.58% of Vera-Garcia et al.'s (2010) study.

The functions of the lumbar and thoracic subdivisions of the erector spinae are similar. However, the literature does not provide enough evidence to conclude that both muscles are maximally activated by the same technique. Additionally, the literature presents five techniques as possible MVC technique of the erector spinae. Therefore comparison of activity levels during those five techniques is of great interest. These five tests were chosen for further investigation:

1- Trunk Holding with a starting position of 60°

2- Resisted Upper Trunk Extension in a prone position

3- Resisted Upper Trunk Extension in a standing position

4- Resisted Lower Trunk Extension

5- The Arch Test

2.2.2 Latissimus Dorsi

The latissimus dorsi is a triangular flat muscle that covers the lumbar region and the lower half of the thoracic region (Gray, 1918). Figure 4 shows the exact location of the latissimus dorsi. Its main functions include adduction, extension and medial rotation of the arm. Due to its large surface area and position the latissimus dorsi is also involved in upper trunk movements. However, its contribution to trunk movements is minimal; the maximum possible extensor moment exerted on the lumbar spine by the latissimus dorsi is less than 5% of the moment required for a moderately heavy lift (Bogduk et al., 1998).

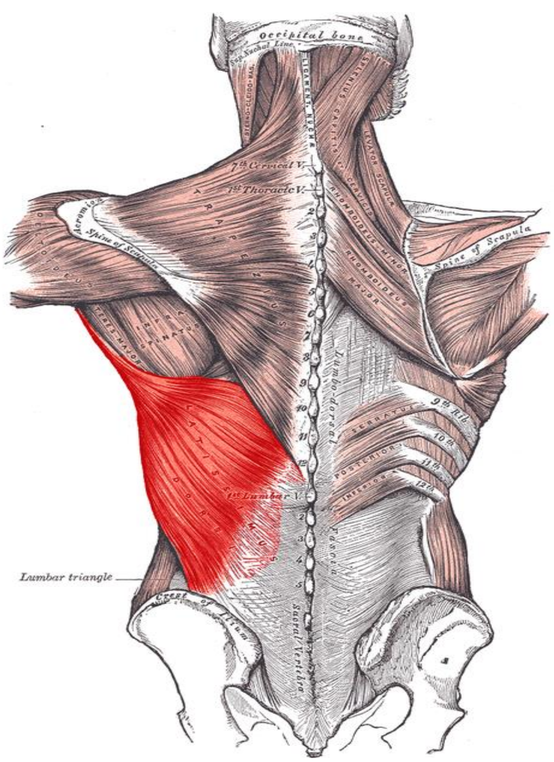

Figure 2: Latissimus dorsi muscle

Several studies have tried to identify MVC techniques for the latissimus dorsi and yet results are contradicting. McGill (1991) studied MVC techniques of the latissimus dorsi that did not include any shoulder/arm movements and were restricted to trunk movements in the three cardinal planes (trunk flexion, trunk extension, and trunk rotation). Five different techniques were reported to maximally activate the latissimus dorsi. Vera-Garcia et al. (2010) included eleven MVC techniques but only one of which included shoulder movement (shoulder rotation and adduction). However, this technique only elicited MVC in 12.5% of subjects while the remaining subjects achieved MVC during upper trunk bending (43.75%), upper trunk twisting (25%) and lower trunk twisting (18.75%). Recent ergonomic studies have focused on shoulder/arm movements for normalization of EMG signals from the latissimus dorsi.

Two studies have identified internal rotation as a proper MVC technique (Boettcher et al., 2008; Kelly et al., 1996). Nevertheless, in both studies, internal rotation of the arm was the only movement relevant to the latissimus dorsi main functions. Kelly et al. (1996) investigated only elevation, external rotation, and internal rotation movements of the shoulder and it was expected that the internal rotation, in a starting position of 90^{o} shoulder elevation and 45^{o} arm rotation, would produce the highest EMG signal in the latissimus dorsi. While Boettcher et al. (2008) investigated ١٥ different literature-based MVC techniques that included three internal rotation techniques: internal rotation 90^{o}, internal rotation 0^{o} and internal rotation with extension. As expected the latissimus dorsi was maximally activated by only those three techniques.

The aim of a recent study by Park et al. (2013) was to compare muscular activation during five different normalization techniques that induced maximal isometric contraction of the latissimus dorsi. The following five techniques were investigated: prone extension, caudal depression, body lifting, lat pull down, and upper trunk bending. Of the 16 participants: 8 produced MVC during prone extension, 7 produced MVC during lat pull down and one subject produced MVC during body lifting. It was concluded that the prone extension and lat pull down are the most effective MVC technique for the latissimus dorsi muscle.

Beaudette et al. (2014) investigated the activation level of four different electrode sites within the latissimus dorsi during common maximal voluntary isometric contractions. The four MVC techniques investigated were: shoulder adduction (ADD), shoulder adduction and internal rotation (ADD+INT), chest supported row (ROW), and shoulder extension (EXT) in a prone position. Activity levels during the EXT test and the ROW test were not statistically different from each other. Most importantly, no statistical differences in EMG activity between the four electrode sites were found. Eventually, the ROW test, paired with a T12 electrode site, was recommended as the appropriate MVC technique.

Clearly, scientific data regarding the MVC technique of the latissimus dorsi are still insufficient and there is a need to compare the EMG activity of the latissimus dorsi during internal rotation and other literature based technique. Thus, the following techniques were chosen for further investigation:

1- Chest Supported Row Contraction

2- Internal Rotation 90^{o}

3- Internal Rotation 0^{o}

4- Lat Pull Down

5- Prone Extension

2.2.3 Posterior Deltoid

The deltoid is a large, thick, triangular muscle that covers the shoulder joint in front, behind, and laterally. The posterior deltoid arises from the anterior border and upper surface of the lateral third of the clavicle and from the lower lip of the posterior border of the spine of the scapula and moves obliquely forward and laterally (Gray, 1918). Figure 5 shows the exact location of the posterior deltoid. The main functions of the posterior deltoid include shoulder extension / transverse extension, shoulder abduction / transverse abduction and external rotation. Transverse abduction is lateral rotation of the upper arm around a vertical axis with the arm is externally rotated and in 90^o abduction while the elbow flexed to 90^o. Transvers extension is lateral rotation of the upper arm around a vertical axis with the arm in (< 90^o) abduction and the elbow in 90^o flexion.

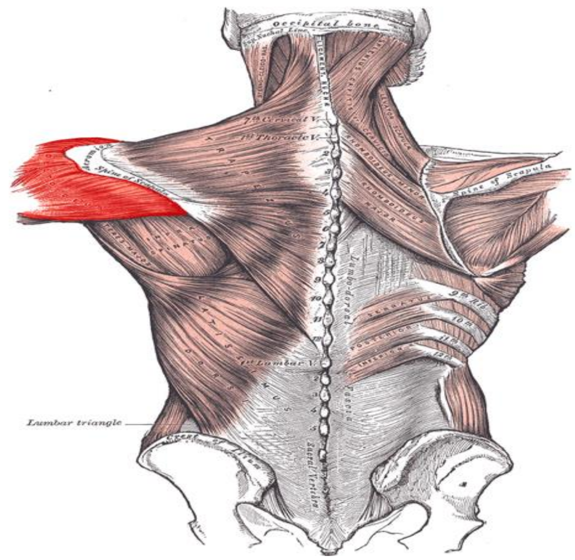

Figure 3: Posterior deltoid muscle

As far as I know only two studies have aimed at identifying the appropriate MVC technique of the posterior deltoid. The first study recommended the use of the external rotation (Kelly et al., 1996). However, the techniques examined in this study were limited to external rotation, internal rotation, and elevation which means that most of the main functions of the posterior deltoid were not examined. In the second study, 15 literature-based MVC techniques were compared, three of which maximally activated the posterior deltoid: prone elevation, the empty can, and abduction 0^o (Boettcher et al., 2008). The prone elevation test is performed in a prone position with the arm raised above head level in line with the lower trapezius muscle fibers as resistance is applied above the elbow against elevation of the arm. The empty can test is performed with the elbow flexed and the arm in 90^o of abduction and internal rotation, as resistance is applied at the wrist against further abduction of the arm. Finally, the abduction 0^o test is performed with the shoulder in pedant position and the elbow flexed 90^o as resistance is applied at the elbow against abduction of the arm. Other tests examined in this study included a resisted extension test, extension with internal rotation, two abduction tests, and three external rotation tests. This clearly indicates the low capability of external rotation techniques to maximally activate the posterior deltoid.

Another possible MVC technique is performed in an erect seating position with the arm in abduction, slight extension, and internal rotation. Resistance is applied above the elbow and the shoulder in the direction of adduction and slight flexion. This technique is similar to the regular transverse extension test and is a common strength test for the posterior deltoid (Kendall et al., 1993). Perroto et al. (1980) proposes a technique where the participant lie in a prone position with the arm in 90^o abduction and the elbow flexed 90^o and resistance is applied to transverse abduction of the arm. Both techniques have not been examined in electromyographic studies.

It is clear that abduction based techniques have received a lot of attention in studies investigating the MVC technique of the posterior deltoid. However, transverse abduction and extension of the arm have been ignored even though the posterior deltoid is a primary mover in both techniques. Thus, there is a need to compare activity levels from the following tests:

1- Prone Elevation

2- Abduction 0^o

3- Empty Can

4- Transverse Abduction: as described by Perotto et al. (1980)

5- Shoulder abduction in slight extension: as described by Kendall (1993)

2.2.4 Upper Trapezius

The trapezius is a flat, triangular muscle that covers the back and upper part of the neck and shoulders. Its upper part arises from the external occipital protuberance and the medial third of the superior nuchal of the occipital bone, and proceeds downward and laterally to insert into the posterior third of the clavicle (Gray, 1918). Figure 6 shows the exact location of the upper trapezius. Due to its large surface area and insertions the upper trapezius is involved in major neck and shoulder movements. Its main actions include shoulder elevation, shoulder upward rotation, shoulder abduction, neck extension, neck lateral flexion, and neck rotation.

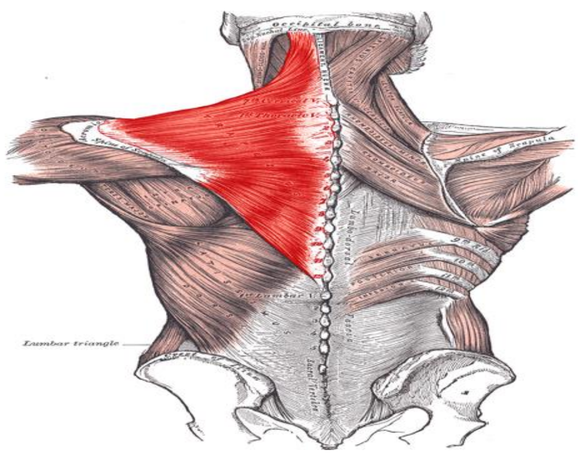

Figure 4: Upper trapezius muscle

Due to the variety of movement it is involved in, the upper trapezius' MVC techniques has been a debatable topic. Ekstrom et al. (2005) recommended the use of the following technique as a MVC technique: resisted shoulder abduction with the shoulder in

90^{o} abduction and simultaneous resistance given to the head after the neck was first side-bent to the same side, rotated to the opposite side, and then extended. Two other tests were found to maximally activate the upper trapezius with no statistical difference: shoulder flexion at 125^{o} and scapular elevation with the neck was first side-bent to the same side, rotated to the opposite side, and then extended. Techniques included in this study were all abduction, flexion, and elevation tests of the shoulder. Similar results were found by Boettcher et al. (2008) who reported maximal activity in the upper trapezius in six different techniques with no statistical difference. The six tests included: three resisted abduction tests, two resisted flexion tests, and one prone elevation test. This study also included three external rotation tests and a resisted abduction with the arm in 0^{o} initial abduction. This clearly shows that the degree of initial abduction is of concern when studying the MVC techniques of the upper trapezius while external rotation techniques are not as efficient in eliciting MVC from the upper trapezius.

Head position had no significant effect on the levels of the activity from the upper trapezius during resisted elevation, abduction, and abduction with external rotation (McLean et al., 2003). The same study has also investigated activity levels over five electrode sites in the upper trapezius and reported a significant interaction effect of electrode site and test position. Sites 1 and 4 (2 cm lateral to the midpoint between C7 spinous process and the posterolateral border of the acromion and 2 cm posterior to Site 1, respectively) were found to produce the highest signals, while a statistical difference was found between activity levels from both abduction tests and the activity levels from the elevation test. The exclusion of flexion-based techniques from this study was based on the results of a previous study by Jensen et al. (1995) that have found flexion to be less effective than elevation and abduction in eliciting MVC from the upper trapezius. However, the referenced study examined flexion in 90^{o} of initial flexion. Results from Boettcher et al. (2008) shows that flexion with either 90^{o} or 125^{o} of initial flexion can produce same levels of activity as abduction and elevation with no statistical difference; which implies the need to study the effect of head position on activity levels from elevation tests. Moreover, Mclean et al. (2003) only studied the effect of head rotation while two of the three techniques recommended by Boettcher el al. included neck bending and extension along with neck rotation.

Furthermore, no study has examined any technique containing resisted arm abduction with a starting abduction angle of over 90^{o}. Finally, Kendall et al. (1993) recommends the use of a resisted shoulder elevation test with the neck first side-bent to the same side, rotated to the opposite side, and then extended as a strength test of the upper trapezius. All the previous studies investigating shoulder elevation as a MVC technique did not use this technique and thus it is important to compare its activity levels to those of other MVC techniques.

Thus, the following tests were chosen for further investigation:

1- Abduction 90^{o} or Empty Can

2- Abduction 125^{o}

3- Flexion 125^{o}

4- Shoulder Elevation: as proposed by Kendall et al. (1983)

5- Shoulder Elevation and Abduction.

2.2.5 Sternocleidomastoid

The sternocleidomastoid is a thick and narrow muscle that arises from the sternum and the clavicle by two heads and inserts into mastoid process of the temporal bone passing obliquely through the side of the neck (Gray, 1918). Figure 7 shows the exact location of the sternocleidomastoid. Its main actions include neck flexion, extension, and lateral flexion to the same side, and neck rotation to the opposite side.

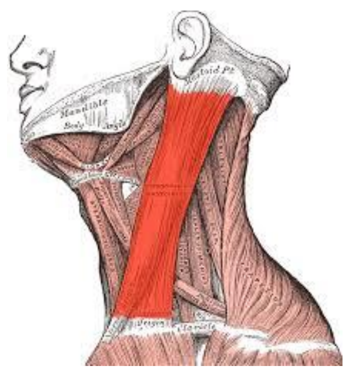

Figure 5: Sternocleidomastoid muscle

Despite its involvement in most major neck movement, and thus its importance to ergonomic research, very little effort has been done to identify the appropriate MVC technique of the sternocleidomastoid and most normalization techniques used in ergonomic research are based on the main functions of the muscle. A biomechanical model that quantitatively examined what loads arises in the neck when external loads are applied to the head predicted maximal activity of the sternocleidomastoid during maximal neck rotation (Moroney et al., 1988). Common techniques in the literature include: resisted head flexion, resisted neck extension, resisted head rotation, and resisted neck bending. Table 6 lists a number of ergonomic studies that have used surface electromyography along with the MVC techniques they have used to normalize EMG signals from the sternocleidomastoid.

Table 6: MVC techniques used in EMG studies for the sternocleidomastoid

#	Authors	Objective of Study	Sternocleidomastoid MVC technique
1	(Kumar et al., 2003)	To determine the phasic recruitment of cervical muscles with increasing magnitudes of low velocity frontal impacts, and to determine quantitative effects of awareness of impending impact in comparison to being impacted unawares.	Resisted neck flexion
2	(Clark et al., 1993)	To quantify the level of EMG activity of the SCM during maximum jaw clenching by healthy subjects and to relate this level to that achieved during maximum voluntary activity of the SCM.	Resisted neck flexion
3	(Yoon et al., 2014)	To investigate the effects of quiet inspiration versus slow expiration on sternocleidomastoid (SCM) and abdominal muscle activity during abdominal curl-up in healthy subjects	A combined movement of craniocervical and cervical flexion in the supine position for 10 s was used.

4	(Thuresson et al., 2005)	To evaluate the reliability of a method of measuring neck muscle fatigue among helicopter pilots.	Resisted neck flexion and extension
5	(Lamotte et al., 1996)	To evaluate objectively the comfort of head rests in cars using surface electromyography.	Resisted neck protraction.
6	(Nimbarte et al., 2010)	To evaluate the effect of isometric lifting tasks at elbow, shoulder and overhead heights on the activities of the sternocleidomastoid and the upper trapezius	Resisted head flexion, extension and rotation
7	(Tan et al., 2010)	To objectify the EMG value of SCM muscle at a pre-defined head rotation angle, a self-designed and self-built apparatus was used to perform the experiment.	Resisted neck rotation
8	(Nimbarte, 2014)	To quantify the biomechanical loading of neck muscles during isometric lifting tasks performed at various working heights and weight conditions.	Resisted neck flexion and bending.
9	(Lindstrøm et al., 2011)	To investigate the relationship between the extents of neck muscle co-activation, the maximum amount of neck strength and perceived pain and disability in women with persistent neck pain.	Resisted neck flexion, extension and bending.
10	(Oksanen et al., 2008)	To compare the maximal force, EMG/force ratio and co-activation characteristics of the neck-shoulder muscles between 30 adolescents with migraine-type headache, 29 with tension-type headache, and 30 headache-free controls.	Resisted neck flexion, extension and rotation.

11	(Strimpakos et al., 2005)	to address these limitations by assessing the test re-test reliability of an EMG assessment of cervical muscle fatigue and the Borg assessment of perceived fatigue for all planes of movement in the standing position	Resisted neck extension, flexion, right lateral flexion and right rotation
12	(Äng et al., 2005)	To investigate pilots with pain and compare them to others without pain with respect to the strength of the maximal voluntary contraction (MVC) of the neck extensors and flexors	Neck extension, flexion
13	(McNee et al., 2013)	To assess the contraction pattern of neck and shoulder muscles of orthodontists in natural environments.	Resisted neck rotation
14	(Harrison et al., 2009)	To use EMG in a laboratory setting to evaluate muscle fatigue in the cervical musculature to determine which muscle(s) were most susceptible to fatigue in military helicopter aircrew.	Resisted neck extension, flexion, right lateral flexion and right rotation
15	(Kumar et al., 2001)	To determine the median frequency (MF) and mean power frequency (MPF) of the sternocleidomastoid, splenius capitis and trapezius in progressively and linearly increasing isometric cervical flexion and extension.	Resisted neck flexion and extension
16	(Ng et al., 2014)	To assess the activity levels of the sternocleidomastoid muscle and upper trapezius muscle during static postures under controlled and	Resisted neck rotation

		standardized conditions, and to determine whether the muscle activity differed between sexes.	
17	(Ferrario et al., 2006)	To analyze the standardized EMG characteristics of two elevator jaw muscles and one neck muscle during maximum voluntary teeth clench in healthy subjects.	Resisted neck rotation

However, Kendall et al. (19۹3) proposes anterolateral neck flexion as a strength test for the sternocleidomastoid. Anterolateral flexion is performed with the subject in a supine position with elbows bent and hands externally rotated beside the head. The head is rotated to the opposite side and then the subject tries to laterally flex his neck against resistance applied by an examiner against the temporal region of the head in an obliquely posterior direction. EMG recording from the sternocleidomastoid during anterolateral flexion showed activity levels of over 100% MVC when normalized according to MVC during neck flexion (Kumar et al., 2002). However no study has compared the efficacy of this technique in eliciting MVC to that of other common MVC techniques.

Thus, the following techniques were chosen for further investigation:

1- Resisted neck flexion

2- Resisted neck lateral bending

3- Resisted neck rotation

4- Resisted neck anterolateral flexion

CHAPTETR 3

METHODOLOGY

3.1 Participants

For time purposes, the experiment was divided into two sections. Each section contained three different muscles. The First section contained the Upper Trapezius (UT), Sternocleidomastoid (SCM), and the Posterior Deltoid (PD). The second section contained the Lumbar Erector Spinae (LES), the Thoracic Erector Spinae (TES), and the Latissimus Dorsi (LD). Fifteen healthy male subjects with no history of back pain were recruited to perform the MVC techniques for each of the two sections. The Physical Activity Readiness Questionnaire (PAR-Q, British Columbia Ministry of Health, Appendix A) was used to screen participants for cardiac and other health problems, such as dizziness, chest pain, or heart trouble (Hoeger et al., 2001). Any participant who answered "yes" to any of the questions on the PAR-Q was excluded.

Before the experimental sessions, the testing procedure was explained in detail to each participant and their signatures were obtained on informed consent forms approved by the institutional review board (IRB) at the American University of Beirut (AUB).

3.2 Apparatus

The Tringo wireless EMG system was used to record electrical activity from the chosen muscles. Six rectangular (37mm x 26mm x 15mm, 14g) Ag/AgCL sensors were used. The Tringo system does not require the use of a reference electrode.

3.3 Experimental Task

The literature review gave a total of 23 MVC techniques to be tested. The number of MVC techniques for each muscle ranged between four to five techniques. The following subsections describe each of the techniques in further detail for each of the muscles of interest.

Participants were asked to gradually exert to their maximum effort in 3 to 5 seconds, hold it for 3 seconds, and gradually decrease the force in 3 seconds (Konrad, 2005). Each MVC technique was repeated three times. The three repetitions of each technique were labeled as a set. To avoid muscular fatigue, repetitions were separated with 30 to 60 seconds of rest (Konrad, 2005) and sets were separated with 2 minutes of rest (Caldwell et al., 1974; Sparto et al., 1997; Hummel et al., 2005; Andersen et al., 2008).

3.3.1 Lumbar/Thoracic Erector Spinae MVC Techniques

The literature showed that both the lumbar and thoracic portions of the erector spinae have similar MVC techniques; therefore, they were grouped into one subsection.

Five lumbar/thoracic erector spinae MVC techniques were chosen for further investigation in this study. Due to the fact that both muscles are primarily responsible for keeping the upper trunk in an erect position, all five techniques were essentially resisted extension of the upper trunk, with one resisted lower trunk extension test. The five MVC techniques are:

1- Trunk holding with a starting position of (-60^o): this test is performed with participants lying prone on an examination table and the hips aligned with the edge of the table top. The upper body is resting on a movable support forming a negative angle of 60^0 with the horizontal. The arms are positioned parallel to the trunk and the legs and thighs are secured to the table with two straps (Plamondon et al., 1999). At the signal, participants try to raise their upper trunk so it does not touch the movable support while resistance is provided through a belt attached around the shoulders. Figure 6 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

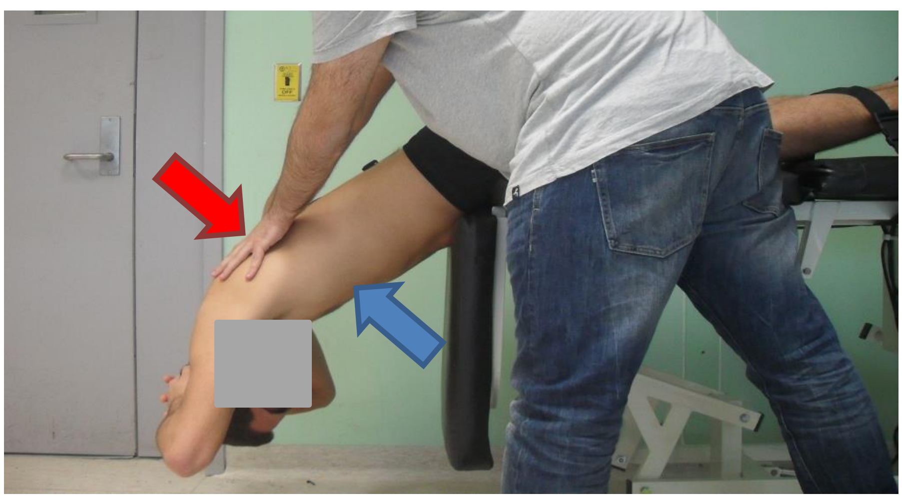

Figure 6: Trunk holding with a starting position of (-60^o)

2- Resisted upper trunk extension in a prone position: this test is performed while participants lying prone on an examination table with their legs straight and strapped with a belt. The hands are placed on the neck. Participants are asked to lift the head, shoulders and elbows just off the examination table while resistance is applied at the shoulders (O'Sullivan et al., 2006). Figure 7 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

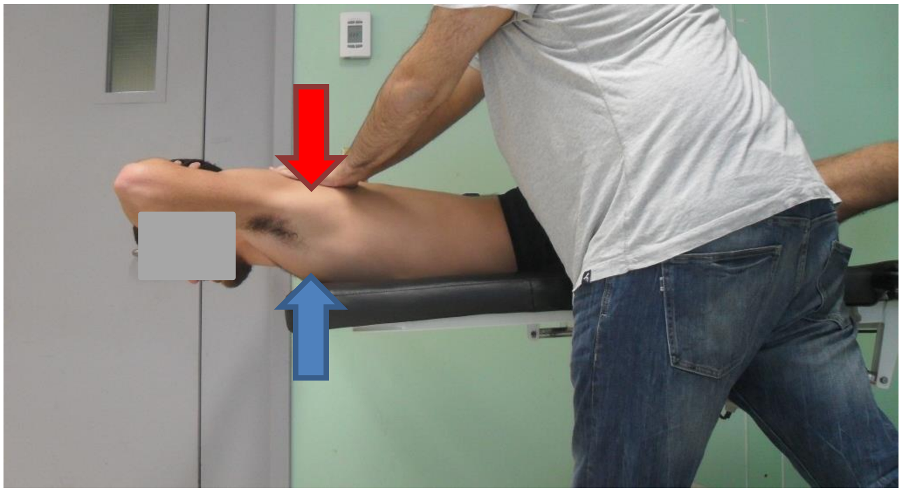

Figure 7: Resisted upper trunk extension in a prone position

3- Resisted upper trunk extension in a standing position: this test is performed with participants standing facing a wall with the shoulder strapped to the wall with the pelvis supported. At the signal maximal attempted backward extension is performed (JØrgensen & Nicolaisen, 1986). Figure 8 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

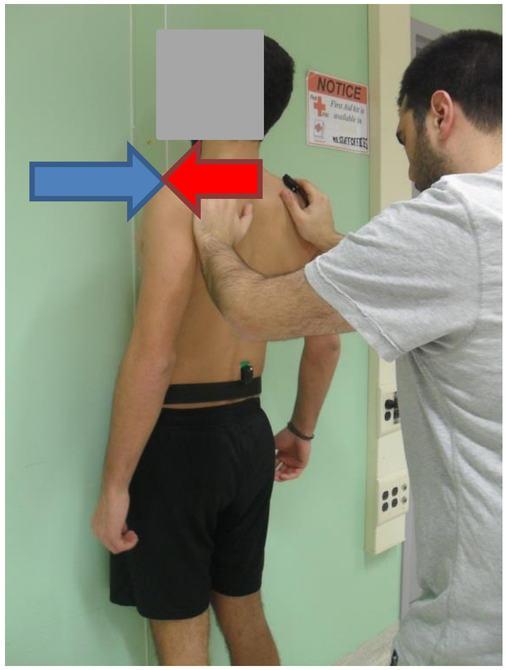

Figure 8: **Resisted upper trunk extension in a standing position**

4- Lower trunk extension: this test is performed with participants in a prone position with their upper trunk strapped to an examination table while the legs are horizontally cantilevered over the end of the table. At the signal, participants attempt to extend the lower trunk and the hips against manual resistance applied to the knees (Vera-Garcia et al., 2010). Figure 9 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

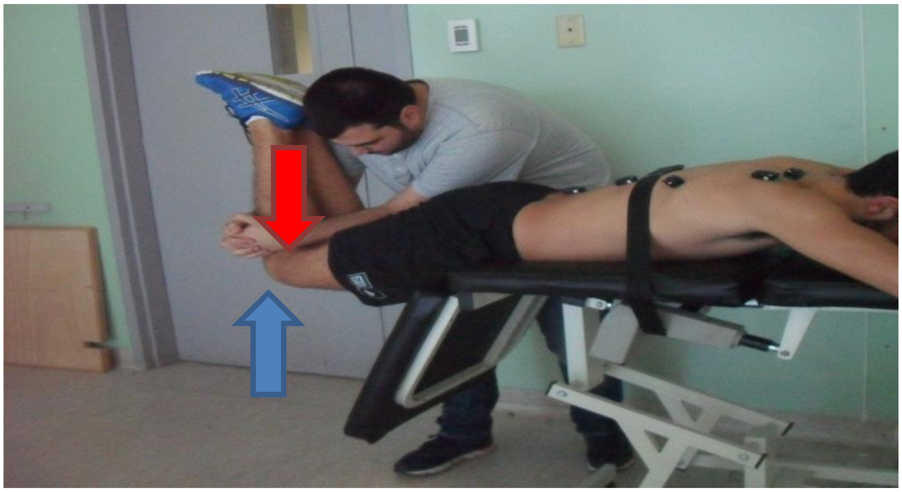

Figure 9: Lower trunk extension

5- The arch test: this test is performed with participants lying prone with both hands under the forehead. At the signal, participants attempt to raise the head, hands, and legs until the vertical height cannot be increased. This position is held for 5 seconds (Ng & Richardson, 1994). Figure 10 illustrates the starting position and the direction force production (blue arrow) in this test.

Figure 10: The arch test

3.3.2 Latissimus Dorsi MVC Techniques

Five latissimus dorsi MVC techniques were chosen for further investigation. Two of these are internal rotation tests while the other three tests are two extension tests and an adduction test. The five MVC techniques chosen are:

1- Chest supported row contraction: participants flex their hips with feet on the floor, and place their torso prone on an examination table. Resistance is applied at the elbow against extension of the arm (Beaudette et al., 2014). Figure 11 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

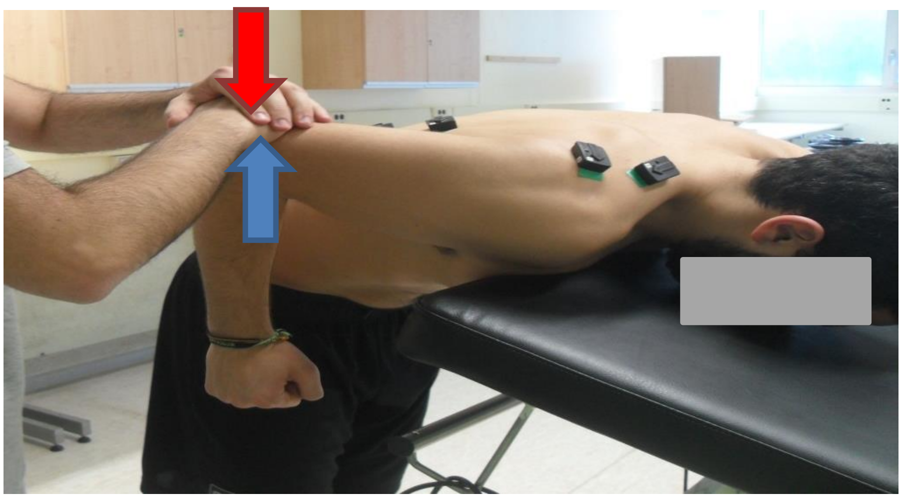

Figure 11: Chest supported row contraction

2- Internal rotation 90^o: in this test participants will try to internally rotate the arm against resistance applied at the wrist while the shoulder is in 90^o abduction in the plane of the scapula and the elbow is flexed 90^o (Boettcher et al., 2008). Figure 21 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

Figure 12: Internal rotation 90^0

3- Internal rotation 0^o: in this test participants will try to internally rotate the arm against resistance applied at the wrist while the arm is in a neutral position and the elbow is flexed 90^o (Boettcher et al., 2008). Figure 12 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

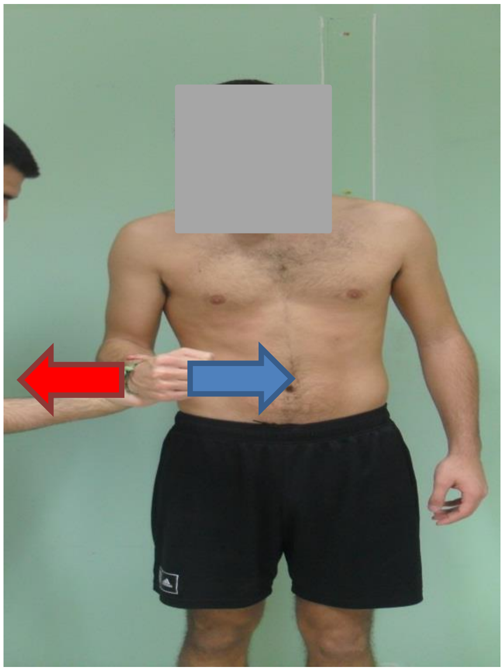

Figure 13: Internal rotation 0^o

4- Lat pull down: this test is performed with participants holding a fixed bar located above their heads while the two shoulders are in 90° abduction. At the signal, participants will try to pull the bar down while the examiner stabilized the participant by pressing downward on the shoulders to ensure that the contraction was isometric (Park et al., 2013). Figure 13 illustrates the starting position and the direction of resistance (red arrow) and force production (red arrow) in this test.

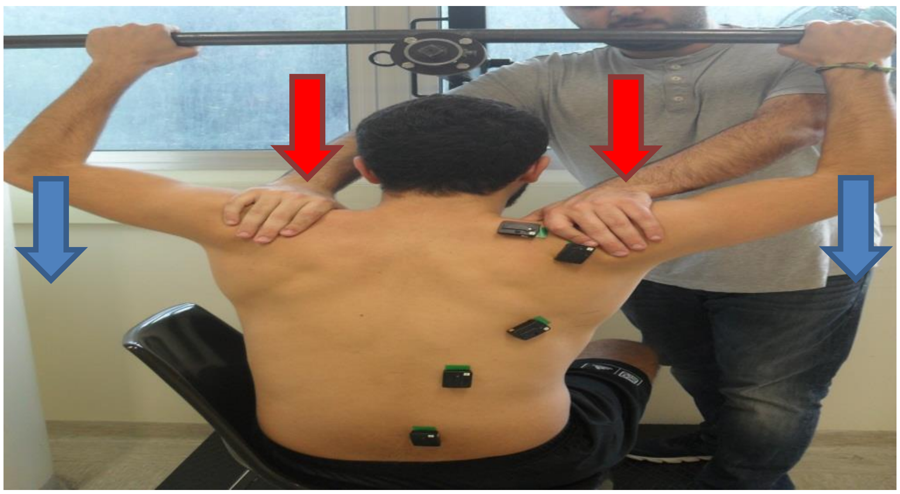

Figure 14: Lat pull down

5- Prone Extension: in this test participants lie prone on an examination table with their arms at the side and internally rotated. Participants will try to extend their arm against resistance applied at the forearm and pelvis (Park et al., 2013). Figure 15 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

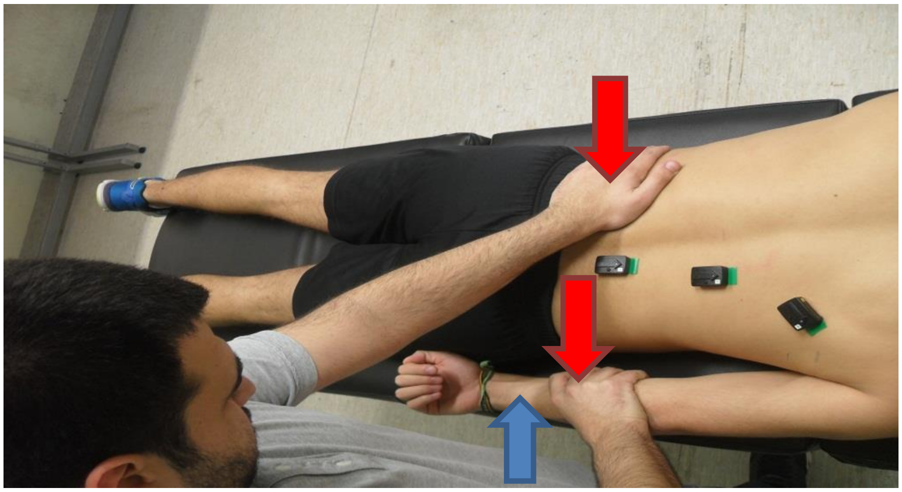

Figure 15: Prone extension

3.3.3 Posterior Deltoid MVC Techniques

Five posterior deltoid MVC techniques were chosen for further investigation. Three of these tests are abduction based tests. The five MVC techniques are:

1- Prone Elevation: in this test participants lie prone on the examination table raising their arm above head in line with lower trapezius muscle fibers. At the signal, participants will try to elevate the arm against resistance applied above the elbow (Boettcher et al., 2008). Figure 16 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

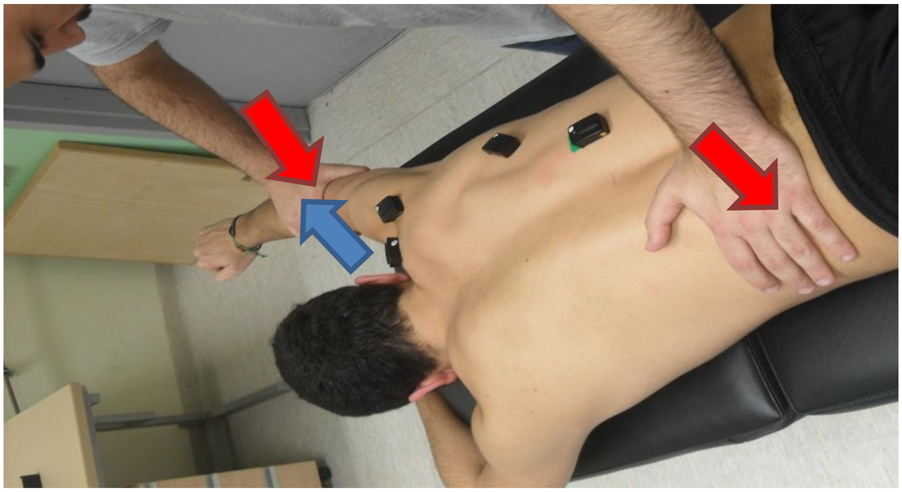

Figure 16: Prone elevation

2- Abduction 0º: participants stand with the arm in neutral position and the elbow flexed to 90º. Resistance is applied at the elbow against abduction of the arm (Boettcher et al., 2008). Figure 17 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

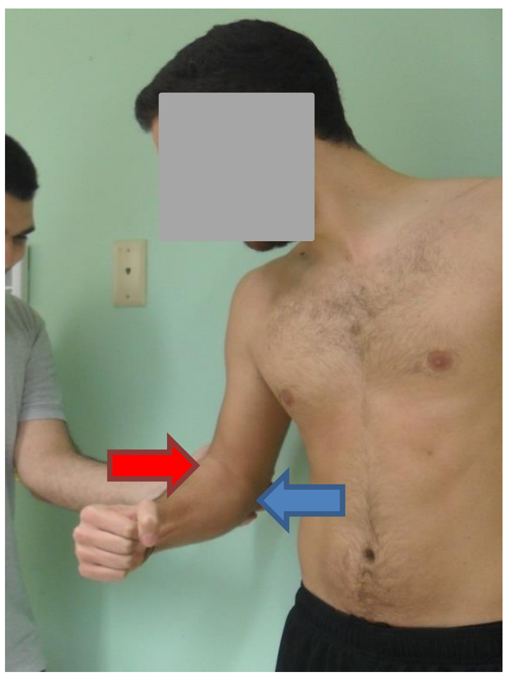

Figure 17: Abduction 0º

3- Empty can: in this test participants abduct their arm 90^{o} in the plane of the scapula while the elbow is extended and the arm internally rotated. Resistance is applied at the wrist against further abduction of the arm (Boettcher et al., 2008). Figure 18 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

Figure 18: Empty can

4- Transverse abduction: participants lie in a prone position with the arm is in 90^{o} abduction and the elbow in 90^{o} flexion. Resistance is applied against transverse abduction of the arm (Delagi & Perotto, 1980). Figure 19 illustrates the starting position and the direction of resistance and force production in this test.

Figure 19: Transverse abduction

5- Shoulder abduction in slight extension: in this test the elbow is in 90° flexion while the arm is in slight abduction (<90°) and slight internal rotation. Participants will try to abduct and extend the arm while resistance is applied at the shoulder and elbow in the direction of adduction and slight flexion (Kendall et al., 1993). Figure 20 illustrates the starting position and the direction of resistance and force production in this test.

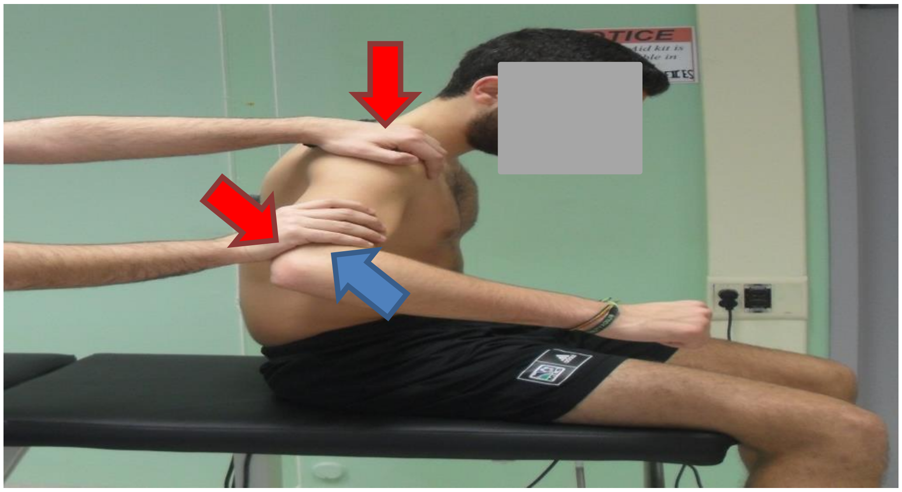

Figure 20: Shoulder abduction in slight extension

3.3.4 Upper Trapezius MVC Techniques

Five upper trapezius MVC techniques have been chosen for further investigation. These five techniques are all either flexion, elevation, or abduction based. The five MVC techniques are:

1- Abduction 90^o: the arm is stretched in 90^o abduction while the neck is side bent to the same side, rotated to the opposite site, and extended. Resistance is applied at the elbow against further arm abduction and at the head against further neck extension. Figure 21 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

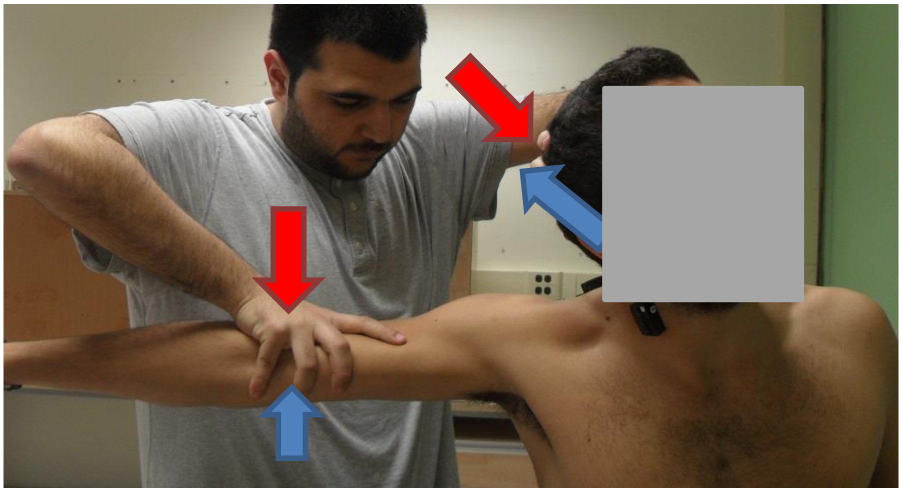

Figure 21: Abduction 90^0

2- Abduction 125^o: similar to the previous technique but with the arm in 125^o of abduction. Figure 22 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

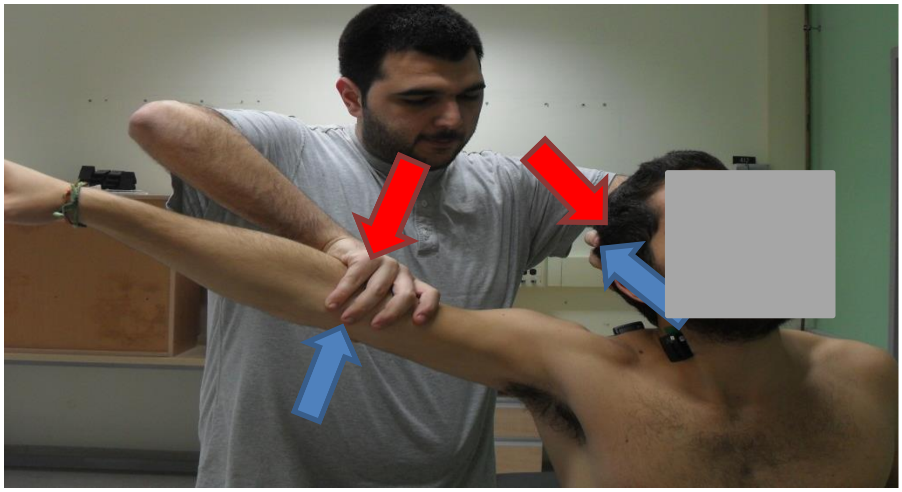

Figure 22: Abduction 125º

3- Flexion 125º: in this test the arm is placed in 125º flexion and the neck is side bent, rotated, and extended. Participants will try to flex the arm against resistance applied above elbow and at inferior angle of scapula attempting to de-rotate scapula (Boettcher et al., 2008). Figure 22 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

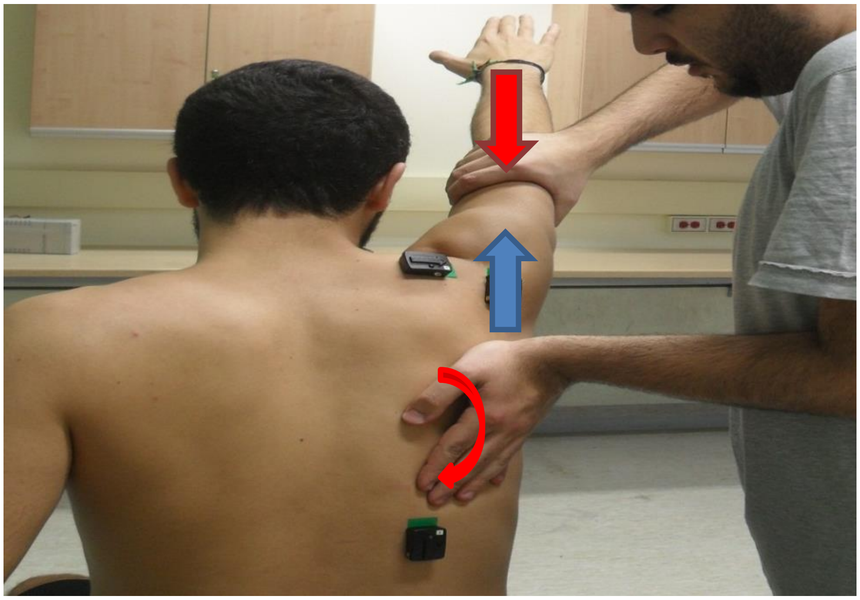

Figure 23: Flexion 125^0

4- Shoulder elevation: in a sitting position, participants will try elevate one of their shoulders while bringing the back of their head towards the elevated shoulder and turning the face to the other direction. Resistance is applied at shoulder and at the back of the head (Kendall et al., 1993). Figure 23 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

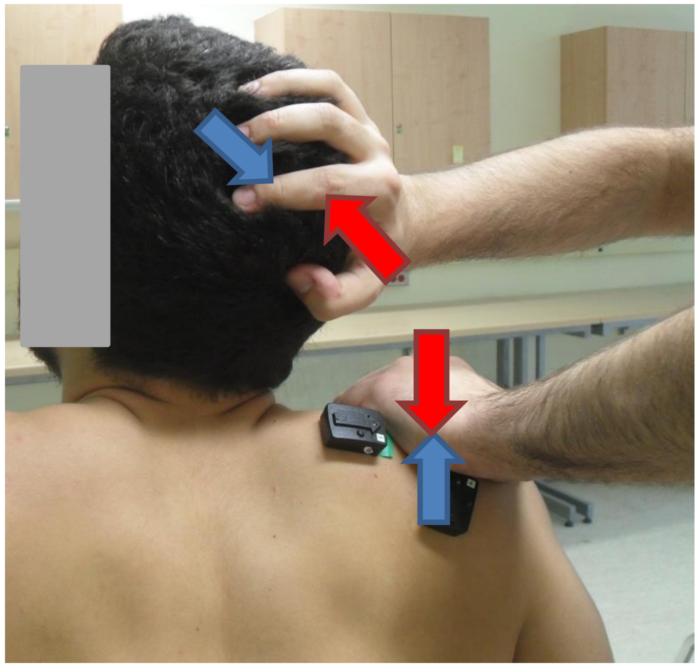

Figure 24: Shoulder elevation

5- Shoulder elevation and abduction: in a sitting position the participants will place their arm in 90° abduction while the neck is side bent, rotated, and extended. At the signal, the participants will try to elevate their shoulder, abduct the arm, and further extend the neck. Manual resistance is applied at the elbow against arm abduction and the shoulder against shoulder elevation. Figure 25 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

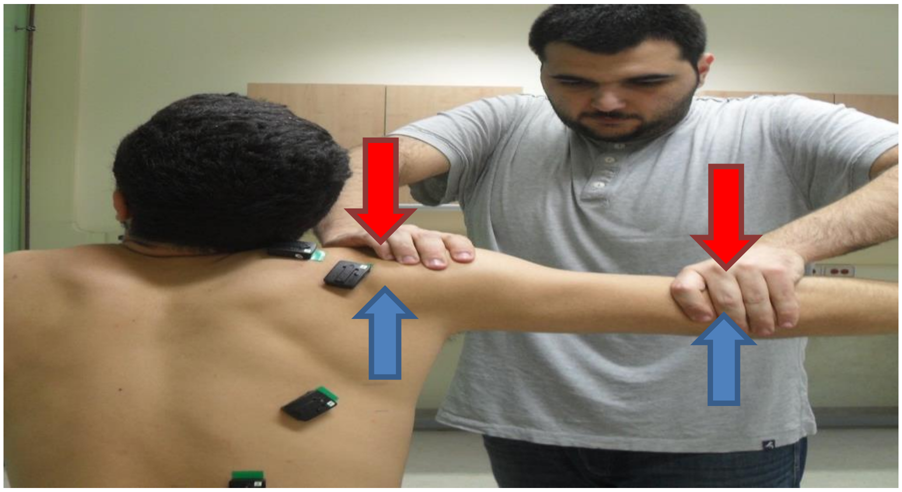

Figure 25: Combination of shoulder elevation and abduction

3.3.5 Sternocleidomastoid MVC Techniques

Four neck movements in different directions have been chosen as potential MVC techniques for the sternocleidomastoid. The four techniques are:

1- Resisted neck flexion: participants try to flex their neck against resistance applied at the forehead. Figure 24 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

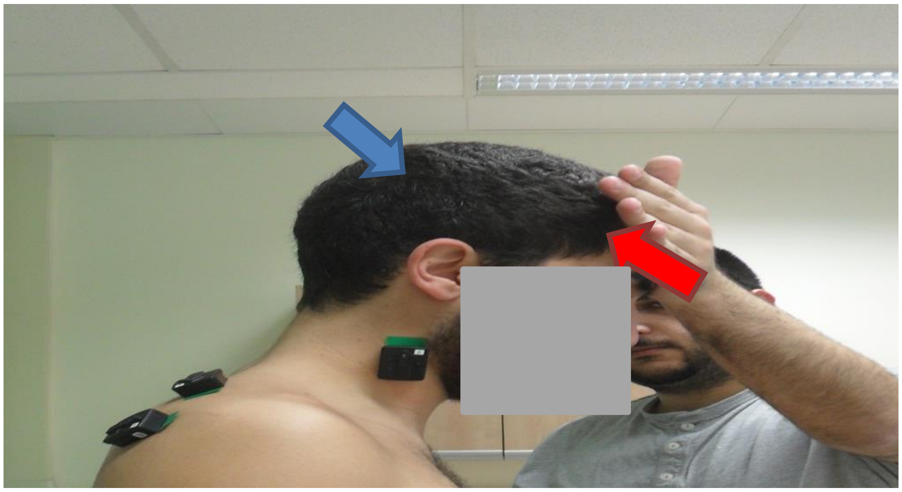

Figure 26: Resisted neck flexion

2- Resisted neck lateral bending: participants try to laterally bend their neck against resistance applied at the head. Figure 25 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

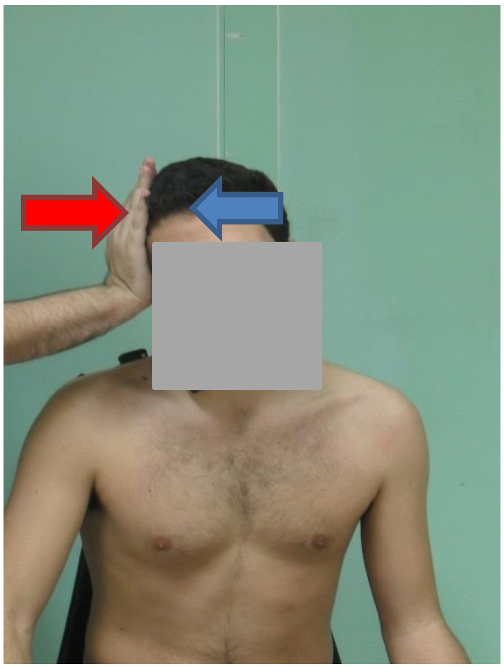

Figure 27: Resisted neck lateral bending

3- Resisted neck rotation: participants try to rotate their neck against resistance applied at the head. Figure 26 illustrates the starting position and the direction of resistance (red arrow) and force production (blue arrow) in this test.

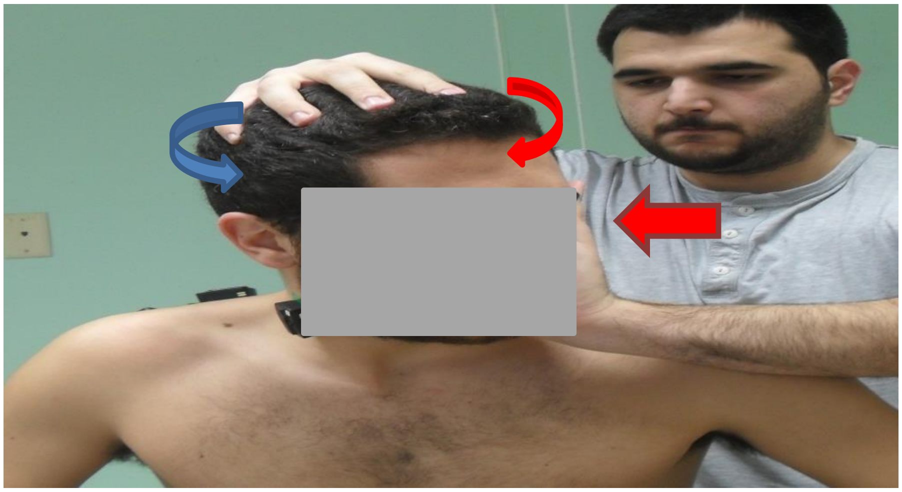

Figure 28: Resisted neck rotation

4- Resisted neck anterolateral flexion: participants lie in a supine position with their arm abducted (90^o), externally rotated, and the elbow flexed (90^o). The head is rotated to the opposite side and the participants will try to raise their head against resistance applied against the temporal region of the head in an obliquely posterior direction (Kendall et al., 1993). Figure 27 illustrates the starting position and the direction of resistance and force production in this test.

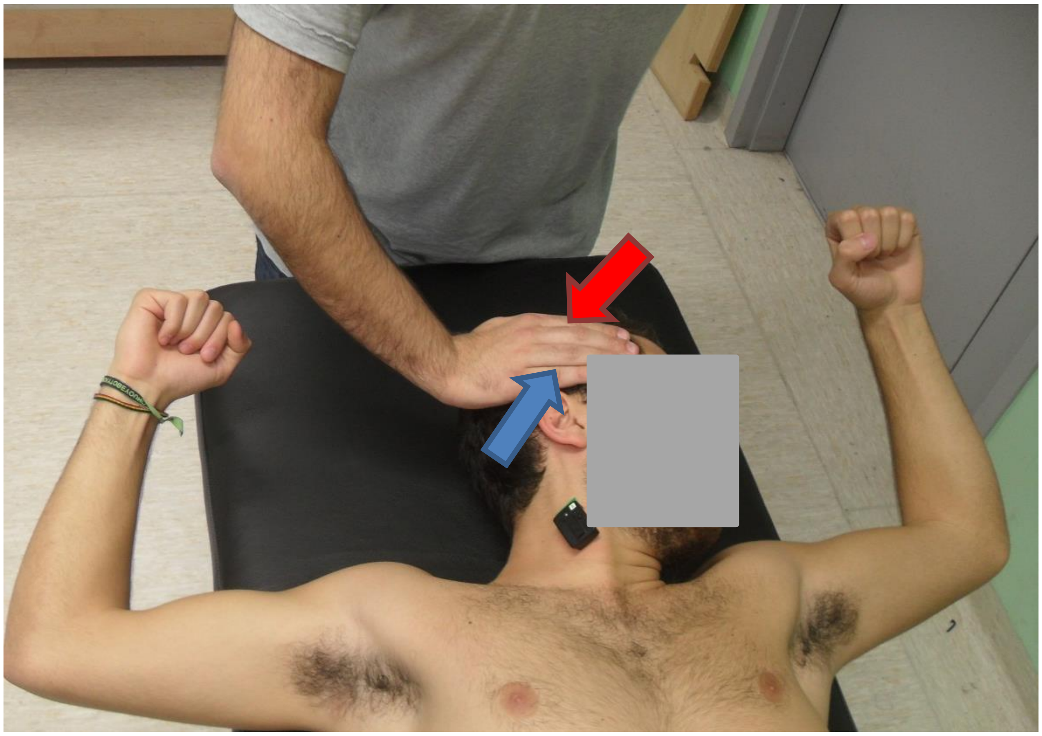

Figure 29: Figure 29: Resisted anterolateral neck flexion

3.4 Experimental design

Each muscle followed a single-factor repeated measures design. The dependent variables were the EMG signals. The independent variables were the MVC techniques. The independent variable was divided into four or five levels, depending on each muscle, each representing a MVC technique. The order of the MVC techniques was randomized for each participant.

3.5 Research Hypotheses

For each muscle, the following hypothesis was tested using the Kruskal-Wallis test:

- H0: The median EMG activities for all the MVC techniques are equal.

- H1: The median EMG activity of at least one MVC technique is significantly different than the remaining means.

3.6 Data Collection

3.6.1 Orientation

Each participant was given an orientation, introducing them to the equipment, data collection procedures, and specifics of the experimental tasks. After the orientation, they were asked to sign an informed consent form (the IRB form). Their demographic (age, height, weight, and gender) information were recorded. Then the participants underwent a five-minute warm-up session.

3.6.2 EMG Preparations

Subsequent to the warm-up session, preparations were made to ready the participants for EMG data acquisition. Any hair on the skin at the electrodes sites was removed. The same areas were cleaned with alcohol. The purpose of cleaning the skin is to get rid of dead skin cells, dirt, and sweat. Then the EMG surface electrodes were attached to the muscles of interest at the following positions:

- Upper Trapezius: electrode was placed 2 cm lateral to the midpoint of the lead line between the spinous process of C7 and the posterolateral border of the acromion (McLean et al., 2003)
- Posterior Deltoid: In the prone position with the head turned to the right side, the shoulder abducted to 90^o, the elbow flexed to 90^o, and the thumb pointing upwards, the electrode was placed 2 cm below the lateral border of the scapular spine in an oblique angle towards the arm (i.e. parallel to muscle fibers) (Cram et al., 1998).
- Lumbar Erector Spinae: electrode was placed 3 cm lateral to the L3 spinous process (McGill, 1991).
- Thoracic Erector Spinae: electrode was placed approximately 5 cm lateral to the T9 spinous process (McGill, 1991).
- Latissimus Dorsi: electrode was placed approximately 4 cm below the inferior tip of the scapula and midway between the spine and lateral edge of the torso (Cram et al., 1998).
- Sternocleidomastoid: electrode was placed at the lower $1/3^{rd}$ of the line connecting the sternal notch and the mastoid process (Cram et al., 1998).

Figures 28, 29, and 30 show the positions of the electrodes. After the preparations, participants performed the maximal voluntary contractions techniques described in section (3.3).

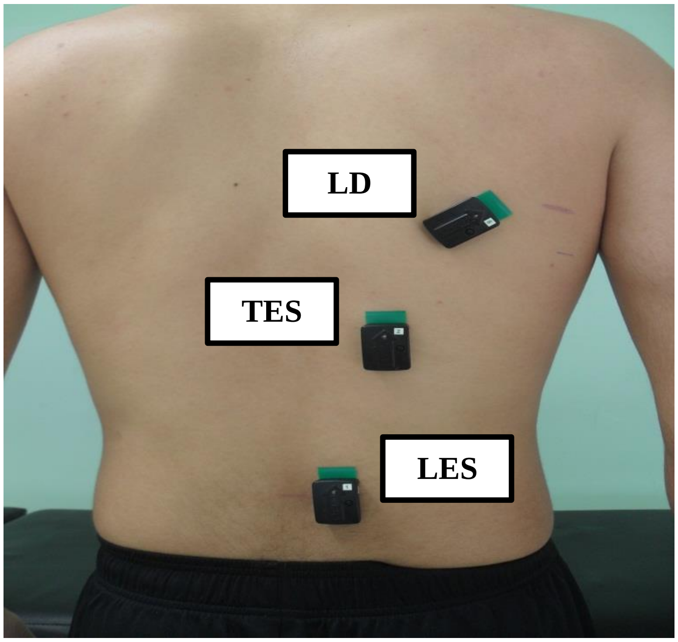

Figure 30: Electrodes locations for LES, TES, and LD muscles

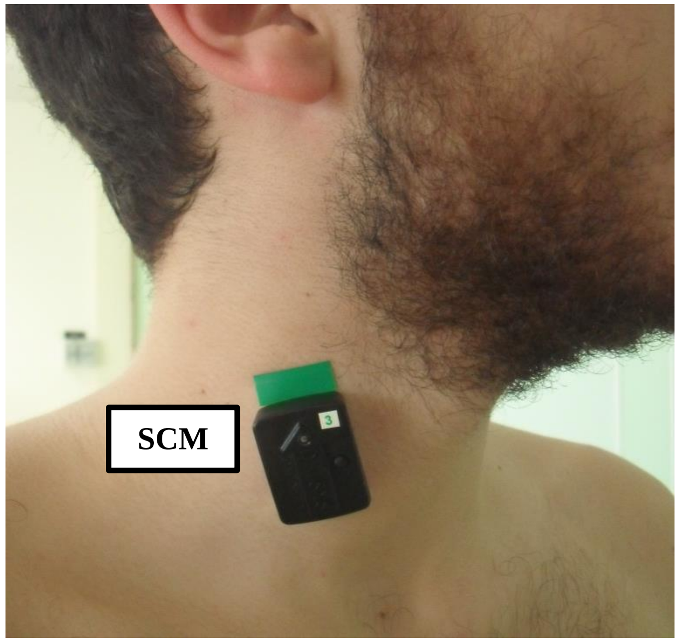

Figure 31: Electrode location for SCM muscle

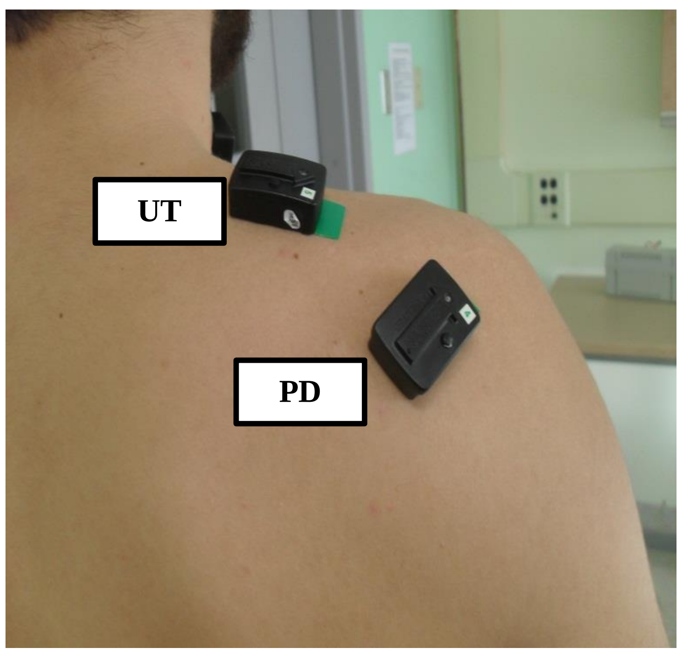

Figure 32: Electrodes locations for UT and PD muscles

3.6.3 Data Processing

During MVC exertions, EMG data was collected for a period of 15 seconds, giving participants enough time to reach their maximum exertion. The raw EMG activity from each electrode location was demeaned first and then full-wave rectified. The full wave rectified EMG activity were then be low pass filtered at 4 Hz, using a fourth-order dual pass Butterworth digital filter, to form a linear envelope (Burnett et al., 2007).

3.7 Statistical Analysis

For each muscle, the Kruskal-Wallis test was used to assess the effect of the MVC techniques on EMG activity. For all significant effects, post hoc analyses, in the form of the Mann-Whitney test was performed to determine the source(s) of the significant effect(s). The null and alternate hypotheses for the Mann-Whitney test in all muscles were as follows:

H0: Median "Test X" = Median "Test Y"

H1: Median "Test X" ≠ Median "Test Y"

The significance level (α) was set at 5%. Statistical significance was based on calculated p-values.

CHAPTER 4

RESULTS AND STATISTICAL ANALYSIS

4.1 Participants' Demographic Information

This study investigated the appropriate MVC techniques for six muscles. The muscles investigated were divided into two sections. Section 1 consisted of the posterior deltoid, sternocleidomastoid, and upper trapezius muscles, while section 2 consisted of the lumbar erector spinae, thoracic erector spinae, and latissimus dorsi muscles. Fifteen participants were recruited for each section of muscles. The average age, height, and weight of the participants are provided in Table 7.

Table 7: Participants' demographic information

Muscles	Number of Participants	Age (years)	Weight (kg)	Height (cm)
Posterior Deltoid Sternocleidomastoid Upper Trapezius	15	20.7	72.13	176.06
Lumbar Erector Spinae Thoracic Erector Spinae Latissimus Dorsi	15	20.79	75.57	179.36

4.2 EMG Results

4.2.1 Lumbar Erector Spinae

Table 8 shows the mean, median, minimum, maximum, first quartile, and the third quartile for the lumbar erector spinae EMG data. Figure 33 graphically represents the EMG results for the five MVC tests in box plots.

Table 8: EMG Results summary for lumbar erector spinae (Microvolts)

	Trunk Holding 60	Trunk Extension Prone	Trunk Extension Standing	Lower Trunk Extension	Arch
Mean	48.80	79.80	78.20	89.40	86.80
Median	36.00	81.00	80.40	83.10	88.80
Min	20.30	23.60	18.40	26.70	28.60
Max	117.00	181.00	176.00	221.00	146.00
1STQuartile	28.60	48.80	46.00	46.40	53.10
3rd Quartile	61.20	103.00	100.00	118.00	121.00
Standard Deviation	27.00	40.00	37.00	50.00	37.00

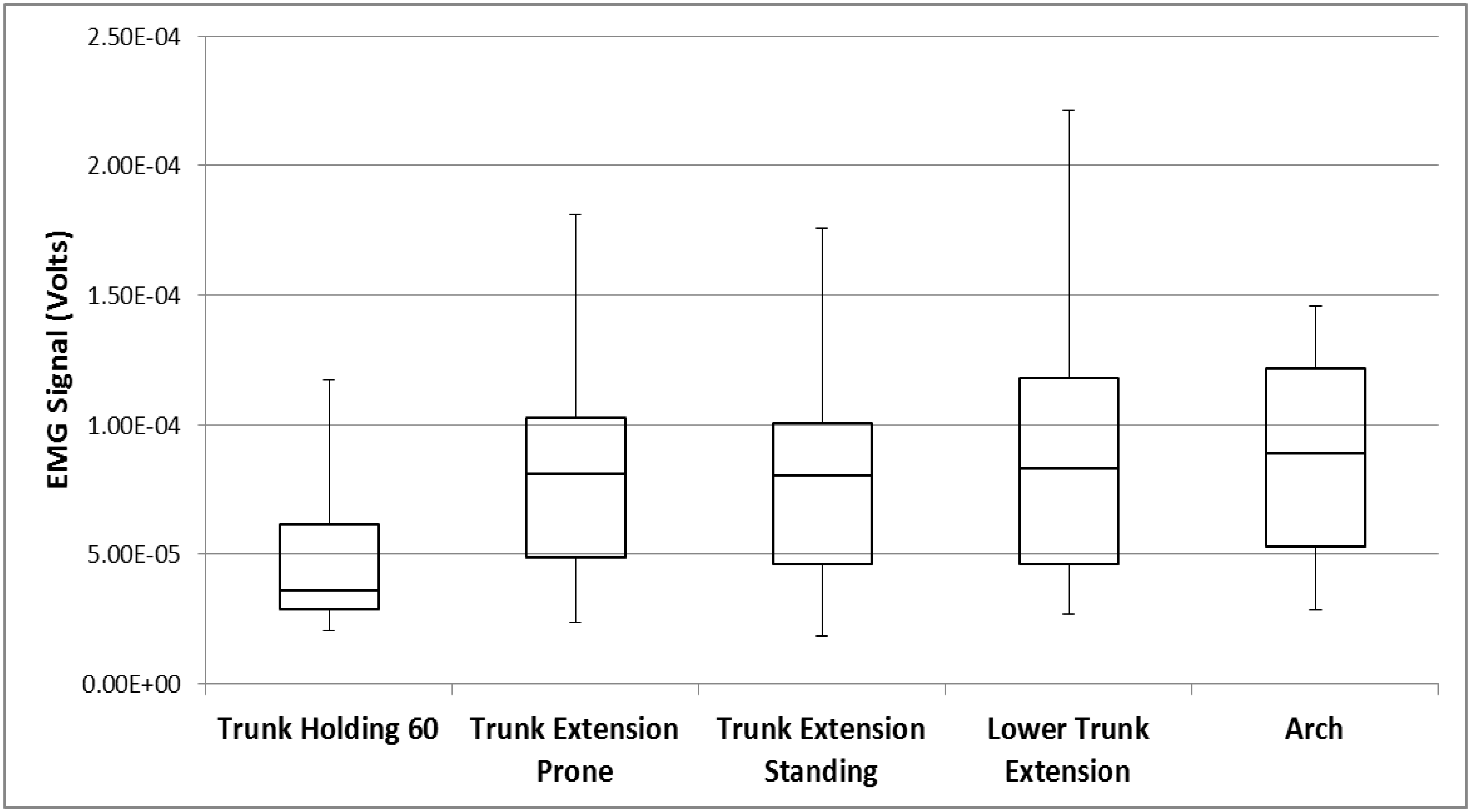

Figure 33: Box Plots of the five tests for the lumbar erector spinae

Post-hoc analysis was performed in the shape of a series of Mann-Whitney tests. Table 9 summarizes the results of the Mann-Whitney tests. The significance level was set at $\alpha = 5\%$. Therefore, P-values of less than 0.05 indicate a statistical difference between the two tests.

Table 9: P-values of Mann-Whitney tests for lumbar erector spinae (* indicates a significant difference)

	Trunk Holding 60	Trunk Extension Prone	Trunk Extension Standing	Lower Trunk Extension	Arch
Trunk Holding 60	-	-	-	-	-
Trunk Extension Prone	3.00E-04*	-	-	-	-
Trunk Extension Standing	1.00E-04*	9.87E-01	-	-	-
Lower Trunk Extension	0*	4.24E-01	3.97E-01	-	-
Arch	0*	3.25E-01	2.02E-01	7.35E-01	-

Four out of the ten pairs of exercises showed a statistical difference. Table 10 shows the medians of each of the aforementioned five pairs of exercises. These medians are compared in order to choose the more appropriate techniques.

Table 10: Medians of significantly different exercises for lumbar erector spinae (Microvolts)

Test X	Median	Test Y	Median
Arch	88.80	Trunk Holding 60	36.00
Lower Trunk Extension	83.10	Trunk Holding 60	36.00
Trunk Extension Prone	81.00	Trunk Holding 60	36.00
Trunk Extension Standing	80.40	Trunk Holding 60	36.00

The "Arch" test had the highest numerical median. However, there was not enough evidence to suggest a difference between the EMG signals generated by the "Arch" test and those generated by the "Lower Trunk Extension", "Trunk Extension Prone", and the "Trunk Extension Standing" tests. The results clearly showed that the EMG signal generated by the "Trunk Holding 60 test" is significantly lower than that generated by all other tests.

4.2.2 Thoracic Erector Spinae

Table 11 shows the mean, median, minimum, maximum, first quartile, and the third quartile for the thoracic erector spina EMG data. Figure 34 graphically represents the EMG results for the five tests in box plots.

Table 11: EMG results summary for thoracic erector spinae (Microvolts)

	Trunk Holding 60	Trunk Extension Prone	Trunk Extension Standing	Lower Trunk Extension	Arch
Mean	38.20	81.80	68.70	67.50	74.30
Median	29.20	60.50	67.90	53.30	70.70
Min	15.20	21.80	15.50	23.90	24.00
Max	106.00	182.00	162.00	142.00	130.00
1^{ST}Quartile	19.00	42.70	32.10	36.80	44.20
3^{rd} Quartile	53.20	134.00	96.30	99.40	104.00
Standard Deviation	24.00	50.00	37.00	34.00	33.00

The Kruskal-Wallis test was used to detect a significant difference between the five tests. The P-value for the Kruskal-Wallis test was equal to "0" which indicates that at least one of the five tests had an EMG signal that is statistically different from the other tests.

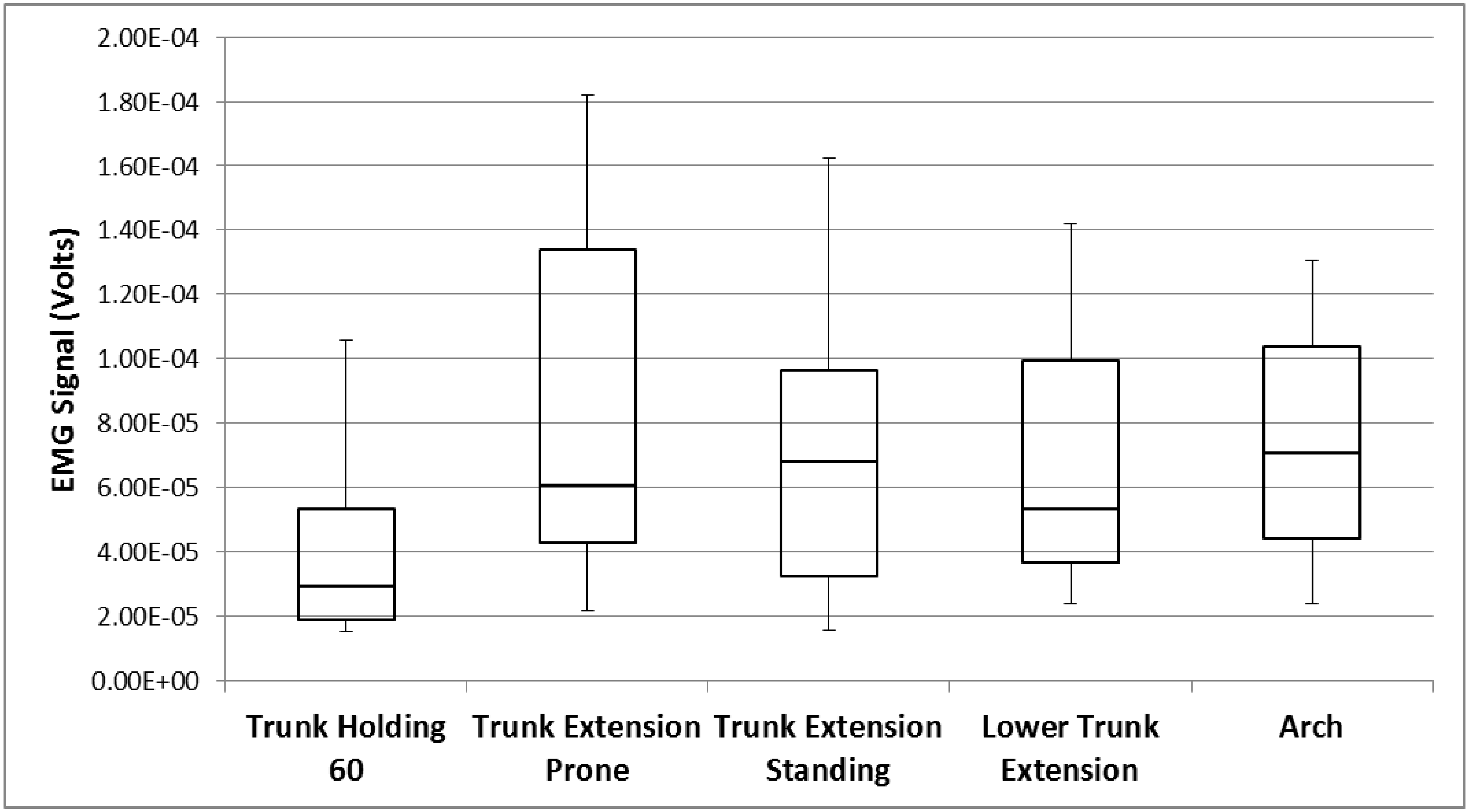

Figure 34: Box plots of the five tests for the thoracic erector spinae

Post-hoc analysis was performed in the shape of a series of Mann-Whitney tests. Table 12 summarizes the results of the Mann-Whitney tests. The significance level was set at α = 5%. Therefore, P-values of less than 0.05 indicate a statistical difference between the two tests.

Table 12: P-values of Mann-Whitney tests for thoracic erector spinae (* indicates a significant difference)

	Trunk Holding 60	Trunk Extension Prone	Trunk Extension Standing	Lower Trunk Extension	Arch
Trunk Holding 60	-	-	-	-	-
Trunk Extension Prone	0*	-	-	-	-
Trunk Extension Standing	1.00E-04*	3.33E-01	-	-	-
Lower Trunk Extension	0*	2.20E-01	9.39E-01	-	-
Arch	0*	9.17E-01	3.25E-01	3.05E-01	-

Four out of the ten pairs of exercises showed a statistical difference. Table 13 shows the medians of each of the aforementioned five pairs of exercises. These medians are compared in order to choose the more appropriate techniques.

Table 13: Medians of significantly different exercises for thoracic erector spinae (Microvolts)

Test X	Median	Test Y	Median
Arch	70.70	Trunk Holding 60	29.20
Trunk Extension Standing	67.90	Trunk Holding 60	29.20
Trunk Extension Prone	60.50	Trunk Holding 60	29.20
Lower Trunk Extension	53.30	Trunk Holding 60	29.20

The "Arch" test had the highest numerical median. However, there was not enough evidence to suggest a difference between the EMG signals generated by the "Arch" test and those generated by the "Lower Trunk Extension", "Trunk Extension Prone", and the "Trunk Extension Standing" tests. The results clearly indicate that the EMG signal generated by the "Trunk Holding 60 test" is significantly lower than that generated by all other tests.

4.2.3 Latissimus Dorsi

Table 14 shows the mean, median, minimum, maximum, first quartile, and the third quartile for the latissimus dorsi's EMG data. Figure 35 graphically represents the EMG results for the five tests in box plots.

Table 14: EMG results summary for latissimus dorsi (Microvolts)

	Chest Supported Row	Internal Rotation 90	Internal Rotation 0	Lat Pull Down	Prone Extension
Mean	227.00	44.00	100.00	79.60	198.00
Median	236.00	38.20	79.50	55.80	225.00
Min	47.40	25.50	30.50	27.80	56.50
Max	597.00	119.00	197.00	254.00	430.00
1STQuartile	102.00	26.50	39.20	42.70	95.70
3rd Quartile	295.00	46.90	163.00	95.10	258.00
Standard Deviation	145.00	23.00	60.00	58.00	96.00

The Kruskal-Wallis test was used to detect a significant difference between the five tests. The P-value for the Kruskal-Wallis test was equal to “0” which indicates that at least one of the five tests had an EMG signal that is statistically different from the other tests.

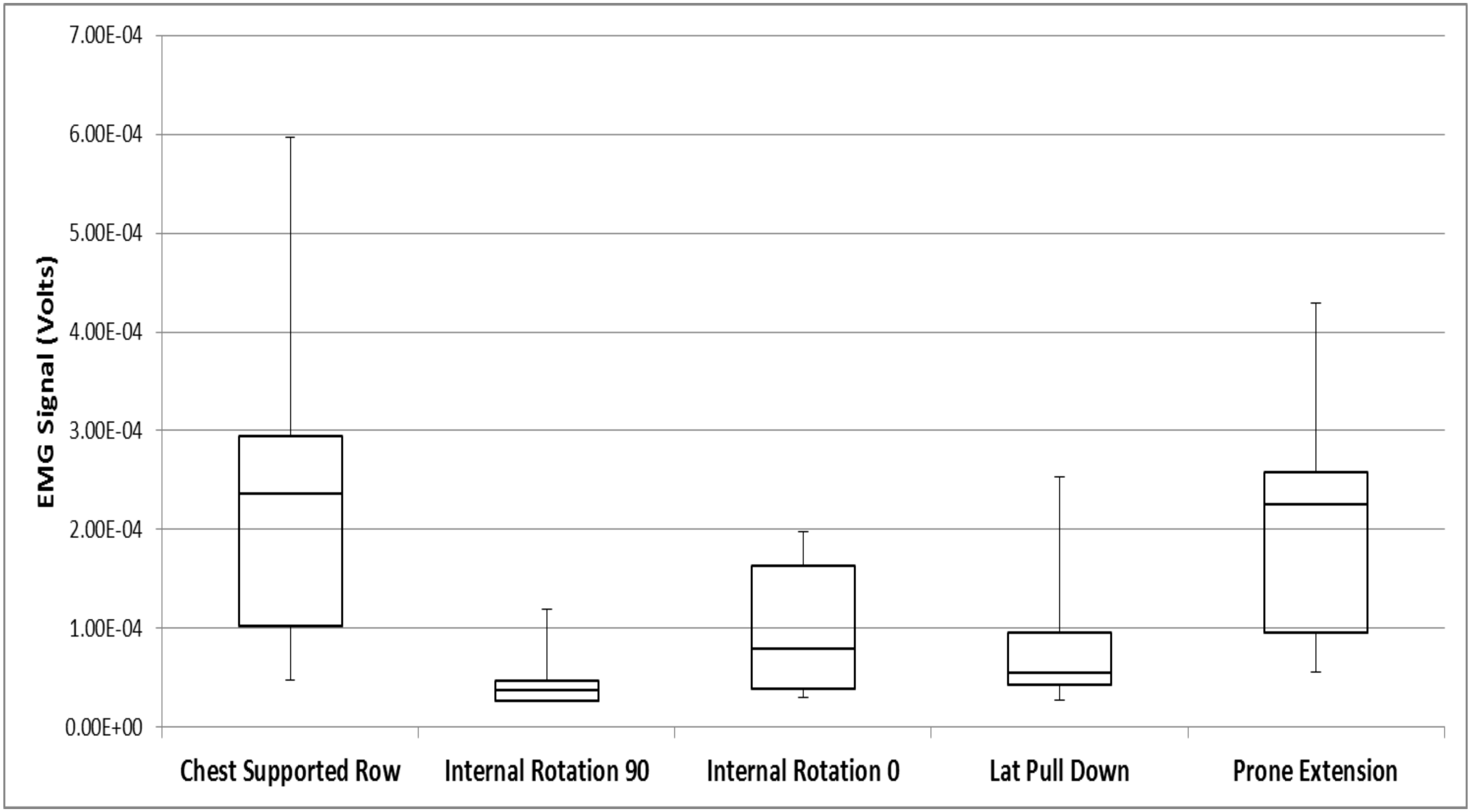

Figure 35: Box plots of the five tests for the latissimus dorsi

Post-hoc analysis was performed in the shape of a series of Mann-Whitney tests. Table 15 summarizes the results of the Mann-Whitney tests. The significance level was set at α = 5%. Therefore, P-values of less than 0.05 indicate a statistical difference between the two tests.

Table 15: P-values of the Mann-Whitney tests for latissimus dorsi (* indicates a significant difference)

	Chest Supported Row	Internal Rotation 90	Internal Rotation 0	Lat Pull Down	Prone Extension
Chest Supported Row	-	-	-	-	-
Internal Rotation90	0*	-	-	-	-
Internal Rotation 0	0*	0*	-	-	-
Lat Pull Down	0*	0*	8.71E-02	-	-
Prone Extension	3.29E-01	0*	0*	0*	-

Eight out of the ten pairs of exercises showed a statistical difference. Table 16 shows the medians of each of the aforementioned eight pairs of exercises. These medians are compared in order to choose the more appropriate techniques.

The EMG signal generated by the "Chest Supported ROW" test had the highest numerical median. However, there was not enough evidence to suggest any statistical difference between the EMG signals generated by the "Prone Extension" test and the "Chest Supported Row" test. The EMG signals generated by the aforementioned two tests were statistically higher than all other tests. The "Internal Rotation 90" test had the lowest numerical median and had an EMG signal that is statistically lower than those generated by the "Internal Rotation 0" and the "Lat Pull Down" tests.

Table 16: Medians of significantly different exercises for latissimus dorsi (Microvolts)

Test X	Median	Test Y	Median
Chest Supported Row	236.00	Internal Rotation 0	79.50
Chest Supported Row	236.00	Lat Pull Down	55.80
Chest Supported Row	236.00	Internal Rotation 90	38.20
Prone Extension	225.00	Internal Rotation 0	79.50
Prone Extension	225.00	Lat Pull Down	55.80
Prone Extension	225.00	Internal Rotation 90	38.20
Internal Rotation 0	79.50	Internal Rotation 90	38.20
Lat Pull Down	55.80	Internal Rotation 90	38.20

4.2.4 Posterior Deltoid

Table 17 shows the mean, median, minimum, maximum, first quartile, and the third quartile for the posterior deltoid's EMG data. Figure 36 graphically represents the EMG results for the five tests in box plot.

Table 17: EMG results summary for posterior deltoid (|Microvolts)

	Prone Elevation	Abduction 0°	Empty Can	Transvers Abduction	Shoulder Abduction in Slight Extension
Mean	504.00	392.00	324.00	610.00	531.00
Median	418.00	347.00	306.00	572.00	518.00
Min	171.00	50.40	50.90	220.00	156.00
Max	1250.00	1010.00	668.00	1240.00	1290.00
1STQuartile	338.00	158.00	173.00	420.00	383.00
3rd Quartile	698.00	535.00	490.00	747.00	646.00
Standard Deviation	241.00	263.00	177.00	248.00	215.00

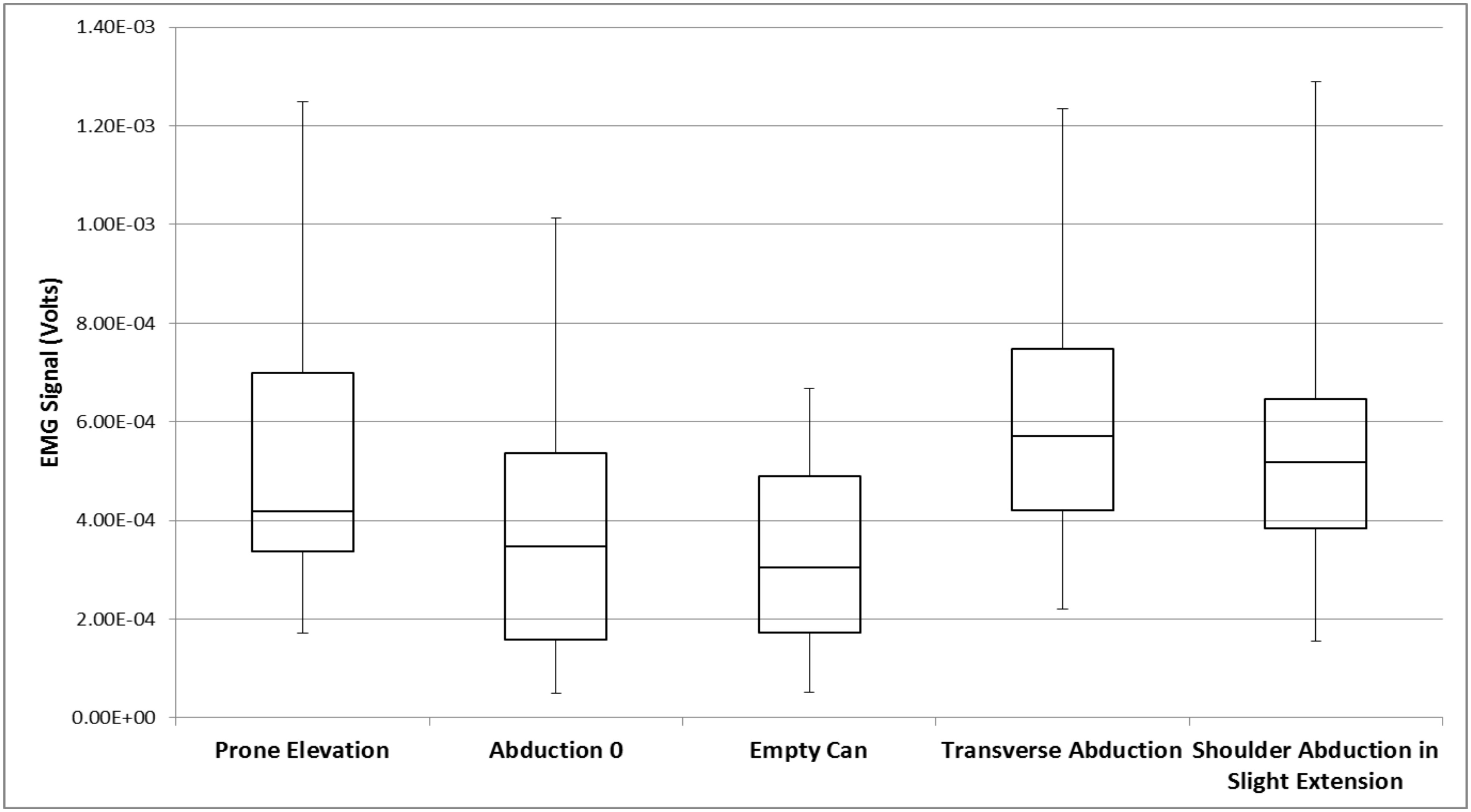

Figure 36: Box plots of the five tests for the posterior deltoid

The Kruskal-Wallis test was used to detect a significant difference between the five tests. The P-value for the Kruskal-Wallis test was equal to "0" which indicates that at least one of the five tests had an EMG signal that is statistically different from the other tests.

Post-hoc analysis was performed in the shape of a series of Mann-Whitney tests. Table 18 summarizes the results of the Mann-Whitney tests. The significance level was set at $\alpha = 5\%$. Therefore, P-values less than 0.05 indicate a statistical difference between the two tests.

Table 18: P-values of the Mann-Whitney tests for posterior deltoid (* indicates a significant difference)

	Prone Elevation	Abduction 0^o	Empty Can	Transvers Abduction	Shoulder Abduction in Slight Extension
Prone Elevation	-	-	-	-	-
Abduction 0^o	2.70E-02*	-	-	-	-
Empty Can	8.00E-04*	3.53E-01	-	-	-
Transvers Abduction	4.45E-02*	1.00E-04*	0*	-	-
Shoulder Abduction in Slight Extension	4.20E-01	3.50E-03*	0*	9.97E-02	-

Seven out of the ten pairs of exercises showed a statistical difference. Table 19 shows the medians of each of the aforementioned seven pairs of exercises. These medians are compared in order to choose the more appropriate techniques

The results indicate that the “Transvers Abduction” test had the highest numerical median. However, there was not enough evidence to suggest a statistical difference between the “Transvers Abduction” test and the “Shoulder Abduction in Slight Extension” test. The “Empty Can” test had the lowest numerical but was not statistically different than the “Abduction 0” test. The EMG signal generated by the “Prone Elevation” was statistically higher than those generated by the “Empty Can” and “Abduction 0” tests.

Table 19: Medians of significantly different exercises for posterior deltoid (Microvolts)

Test X	Median	Test Y	Median
Transvers Abduction	572.00	Prone Elevation	418.00
Transvers Abduction	572.00	Abduction 0	347.00
Transvers Abduction	572.00	Empty Can	306.00
Shoulder Abduction in Slight Extension	518.00	Abduction 0	347.00
Shoulder Abduction in Slight Extension	518.00	Empty Can	306.00
Prone Elevation	418.00	Abduction 0	347.00
Prone Elevation	418.00	Empty Can	306.00

4.2.5 Upper Trapezius

Table 20 shows the mean, median, minimum, maximum, first quartile, and the third quartile for the upper trapezius EMG data. Figure 37 graphically represents the EMG results for the five tests in box plots.

Table 20: EMG results summary for upper trapezius (Microvolts)

	Abduction 90	Abduction 125	Flexion 125	Elevation	Elevation + Abduction 90
Mean	541.00	586.00	487.00	316.00	641.00
Median	531.00	583.00	423.00	333.00	580.00
Min	16.60	18.20	18.00	15.00	17.20
Max	1310.00	1170.00	1020.00	734.00	1490.00
1STQuartile	378.00	400.00	338.00	238.00	462.00
3rd Quartile	620.00	765.00	649.00	403.00	840.00
Standard Deviation	293.00	295.00	259.00	143.00	353.00

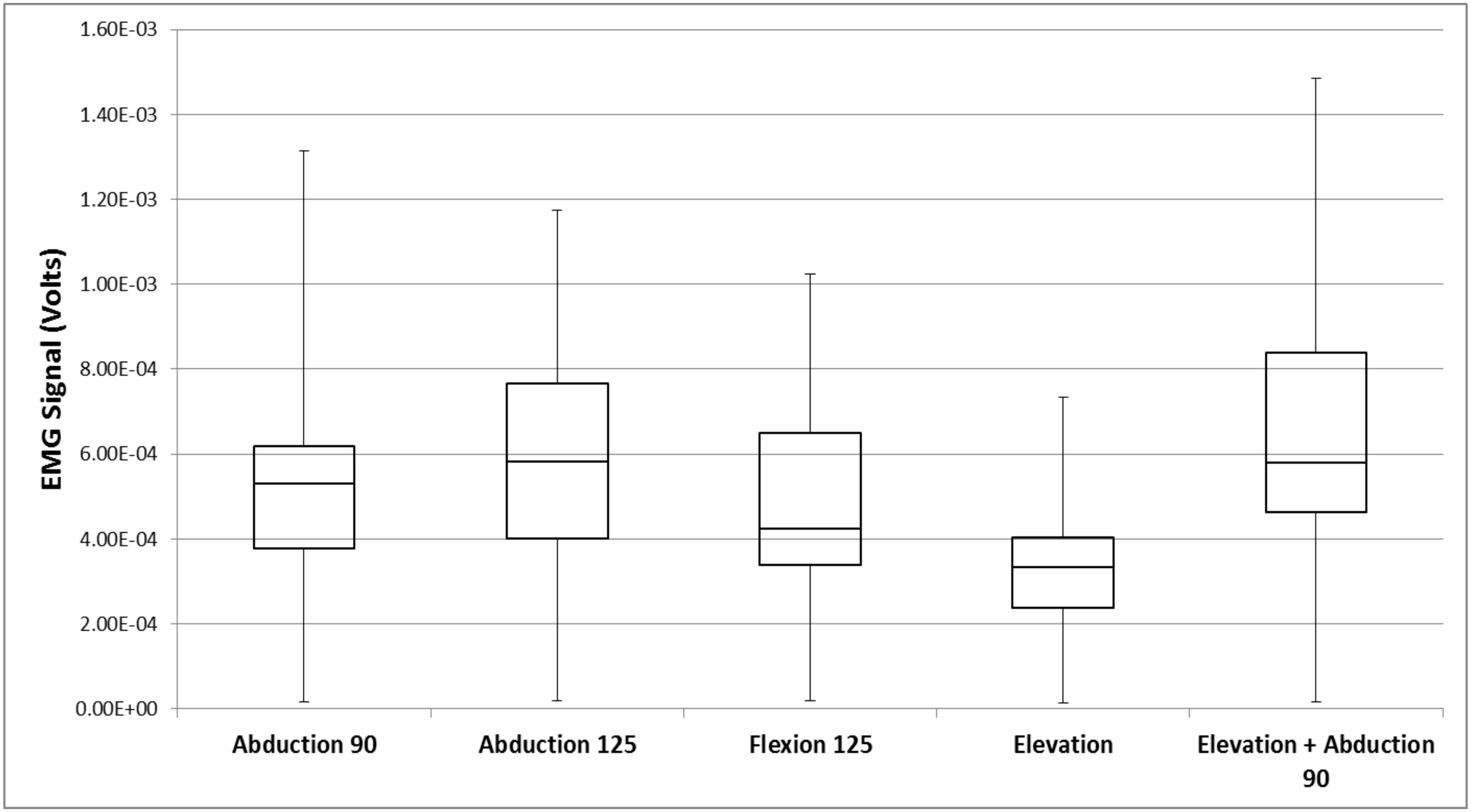

Figure 37: Box plots of the five tests for the upper trapezius

The Kruskal-Wallis test was used to detect a significant difference between the five tests. The P-value for the Kruskal-Wallis test was equal to "0" which indicates that at least one of the five tests had an EMG signal that is statistically different from the other tests.

Post-hoc analysis was performed in the shape of a series of Mann-Whitney tests. Table 21 summarizes the results of the Mann-Whitney tests. The significance level was set at $\alpha = 5\%$. Therefore, P-values of less than 0.05 indicate a statistical difference between the two tests.

Table 21: P-values of Mann-Whitney tests for upper trapezius (* indicates a significant difference)

	Abduction 90	Abduction 125	Flexion 125	Elevation	Elevation + Abduction 90
Abduction 90	-	-	-	-	-
Abduction 125	3.02E-01	-	-	-	-
Flexion 125	2.98E-01	6.58E-02	-	-	-
Elevation	0*	0*	5.00E-04*	-	-
Elevation Abduction 90	1.29E-01	5.94E-01	1.58E-02*	0*	-

Five out of the ten pairs of exercises showed a statistical difference. Table 22 shows the medians of each of the aforementioned five pairs of exercises. These medians are compared in order to choose the more appropriate techniques.

The results indicate that the “Abduction 125” test had the highest numerical median. However, there was not enough evidence to suggest statistical differences between the “Abduction 125” test and the “Abduction 90” and the “Elevation and Abduction 90” tests. EMG signal generated by the “Elevation” test is lower than that generated by all other tests. The “Elevation” test had the lowest numerical median and was statistically lower than all other tests.

Table 22: Medians of significantly different exercises for upper trapezius (Microvolts)

Test X	Median	Test Y	Median
Abduction 125	583.00	Elevation	333.00
Elevation Abduction 90	580.00	Flexion 125	423.00
Elevation Abduction 90	580.00	Elevation	333.00
Abduction 90	531.00	Elevation	333.00
Flexion 125	423.00	Elevation	333.00

4.2.5 Sternocleidomastoid

Table 23 shows the mean, median, minimum, maximum, first quartile, and the third quartile for the sternocleidomastoid EMG data. Figure 38 graphically represents the EMG results for the four tests in box plots.

Table 23: EMG Results summary for sternocleidomastoid (Microvolts)

	Flexion	Lateral Bending	Rotation	Anterolateral Flexion
Mean	195.00	150.00	213.00	339.00
Median	176.00	115.00	190.00	344.00
Min	15.10	13.90	13.80	13.70
Max	567.00	575.00	474.00	856.00
1^{ST}Quartile	94.10	61.00	132.00	206.00
3^{rd} Quartile	218.00	179.00	306.00	425.00
Standard Deviation	137.00	132.00	122.00	178.00

The Kruskal-Wallis test was used to detect a significant difference between the five tests. The P-value for the Kruskal-Wallis test was equal to “0” which indicates that at least one of the five tests had an EMG signal that is statistically different from the other tests.

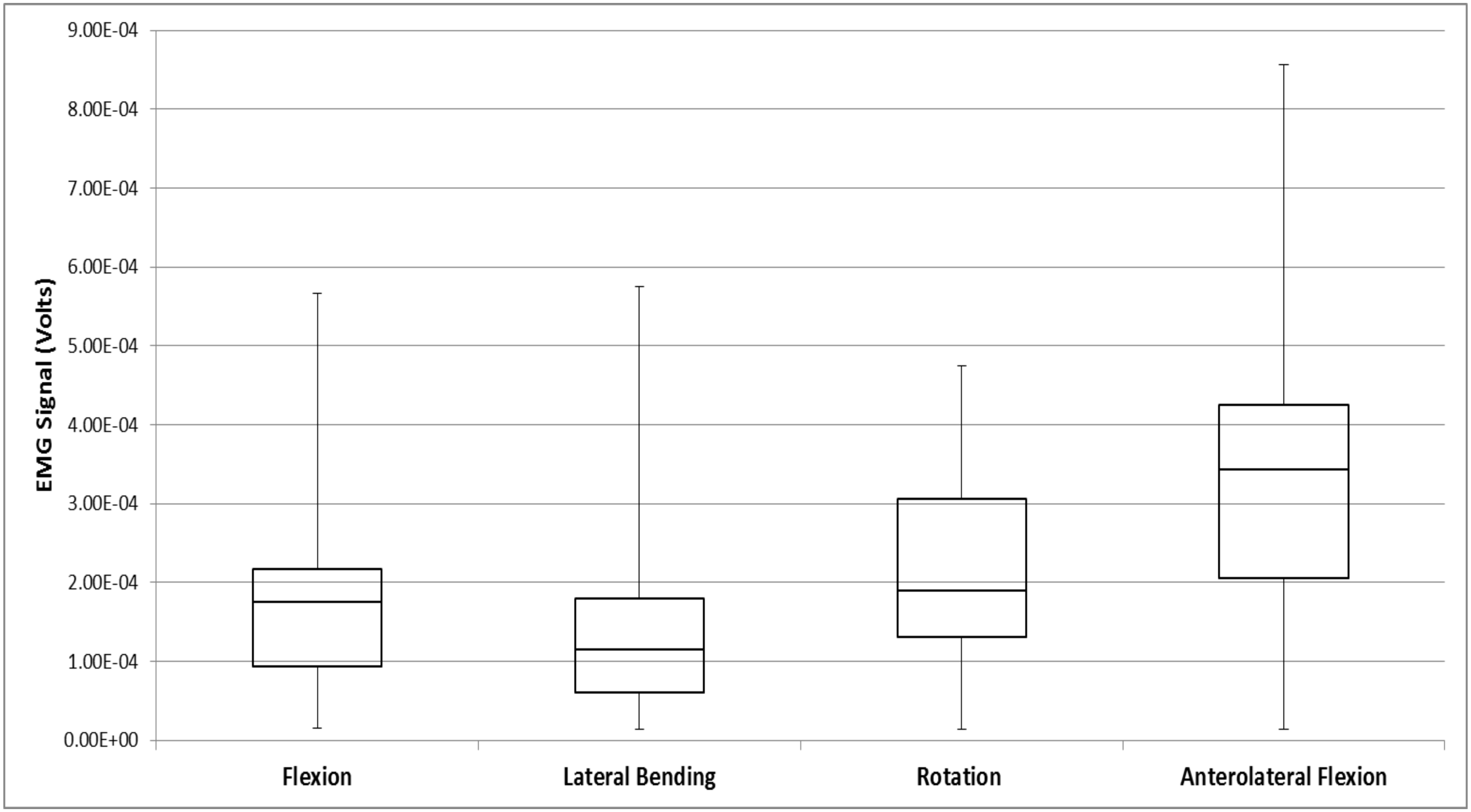

Figure 38: Box plots of the four tests for the sternocleidomastoid

Post-hoc analysis was performed in the shape of a series of Mann-Whitney tests. Table 24 summarizes the results of the Mann-Whitney tests. The significance level was set at $\alpha = 5\%$. Therefore, P-values of less than 0.05 indicate a statistical difference between the two tests.

Table 24: P-values of Mann-Whitney tests of sternocleidomastoid (* indicates a significant difference)

	Flexion	Lateral Bending	Rotation	Anterolateral Flexion
Flexion	-	-	-	-
Lateral Bending	2.59E-02*	-	-	-
Rotation	3.58E-01	1.70E-03*	-	-
Anterolateral Flexion	0*	0*	2.00E-04*	-

Five out of the six pairs of exercises showed a statistical difference. Table 25 shows the medians of each of the aforementioned five pairs of exercises. These medians are compared in order to choose the more appropriate techniques.

Table 25: Medians of significantly different exercises for sternocleidomastoid (Microvolts)

Test X	Median	Test Y	Median
Anterolateral Flexion	344.00	Rotation	190.00
Anterolateral Flexion	344.00	Flexion	176.00
Anterolateral Flexion	344.00	Lateral Bending	115.00
Rotation	190.00	Lateral Bending	115.00
Flexion	176.00	Lateral Bending	115.00

The EMG signal generated by the "Anterolateral Flexion" test was statistically higher than that generated by all other tests. While the "Lateral Bending" test had an EMG signal statistically lower than all other tests.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Lumbar and Thoracic Erector Spinae

There are no previous studies that had directly compared any of the five tests that were tested in this research. The literature regarding the MVC technique for lumbar and thoracic erector spinae did not present any evidence to suggest that both subdivisions of the erector spinae are maximally activated by the same technique. However, the results of this study indicate that both sections of the erector spinae muscle are maximally activated by the same set of tests. The arch test generated the highest numerical median of EMG signal in both lumbar and thoracic erector spinae. However, there was not enough evidence to suggest a statistical difference between the arch test and the “Trunk Extension Prone” test, the “Trunk Extension Standing” test, and the “Lower Trunk Extension” test. These results, contradict those of Plamondon et al. (1999) wich indicated that the trunk holding exercise with a starting position of 60^o provides a more adequate MVC technique.

Additionally, the arch test showed the least value of standard deviation in both subdivisions of the erector spinae. In the lumbar erector spinae, the “Trunk Extension Standing” test showed the second least value of standard deviation. While the “Lower Trunk Extension” test showed the second least standard deviation in the thoracic erector spinae.

Therefore, either one of the following tests can be used as a MVC technique for both the lumbar and thoracic erector spinae:

- The Arch Test
- Trunk Extension Standing
- Lower Trunk Extension
- Trunk Extension Prone

5.2 Latissimus Dorsi

The literature regarding the MVC technique of the latissimus dorsi presents two sets of MVC techniques. Internal rotation techniques have been dominant in electromyographic studies until recent years (Boettcher et al., 2008; Kelly et al., 1996). However, recent studies have recommended the use of different techniques (Chest Supported Row Contraction, Lat Pull Down, and Prone Extension) without directly comparing the EMG signal generated by those techniques to that generated by internal rotation techniques (Park et al., 2013; Beaudette et al., 2014).

The results of this research show that the “Chest Supported ROW” test and the “Prone Extension” test generated levels of EMG signals that were not statistically different from each other. The “Prone Extension” test showed a lesser value of standard deviation than the “Chest Supported ROW” test. However, the EMG signals generated from the aforementioned two tests were statistically higher than those generated by the “Internal Rotation 90” test, “Internal Rotation 0” test, and the “Lat Pull Down” test. The “Lat Pull Down” test showed no statistical difference from the “Internal Rotation 0” test.

In conclusion, this research recommends using the “Prone Extension” test or the “Chest Supported ROW” test for normalizing EMG signals from the Latissimus Dorsi.

5.3 Posterior Deltoid

The literature presented five possible MVC techniques for the posterior deltoid. Three of these five techniques were drawn from a electromyographic study (Boettcher et al., 2008), while the other two were muscle strength testing techniques (Kendall et al., 1993; Perroto et al., 1980). None of the three techniques recommended by Boettcher et al. (2008) proved to be an appropriate MVC technique. This obviously indicates that muscle strength testing techniques, which are not properly investigated in electromyography studies, are possible appropriate normalization techniques.

The “Transvers Abduction” test did not show any statistical difference from the “Shoulder Abduction in Slight Extension” test but had a higher value of standard deviation. This indicates that the “Shoulder Abduction in Slight Extension” test is a more preferable MVC technique since it generates more consistent EMG signals between trials.

In conclusion, this research recommends using the “Shoulder Abduction in Slight Extension” test or the “Transvers Abduction” test for normalizing EMG signals from the posterior deltoid.

These results further prove the need to examine muscle strength testing techniques as possible MVC techniques.

5.4 Upper Trapezius

Arm abduction, arm flexion, and shoulder elevation techniques are the most dominant MVC techniques in the literature. The results indicated that the elevation test generates statistically lower EMG signals than all other tests which contradict the findings of Jensen et al. (1995) who reported that arm flexion techniques were not as effective in activating the upper trapezius as techniques with arm abduction or shoulder elevation. Therefore, it is clearly inefficient to use elevation based techniques to normalize EMG signals from the upper trapezius. Furthermore, there was not enough evidence to suggest a significant difference between the two abduction tests involved in the study (Abduction 90 and Abduction 125) and the “Flexion 125” test.

However, there was a significant difference when comparing the “Flexion 125” with the “Elevation and Abduction 90” test, which is a “combination test” devised by the authors of this study and not drawn from the literature. Thus, there is evidence to suggest that techniques that are based on a combination of the main movements of the upper trapezius might be more efficient MVC techniques than those currently used in the literature.

There was no statistical difference between the “Elevation and Abduction 90” test, the “Abduction 125” test, and the “Abduction 90” test. The “Abduction 90” test had the least value of standard deviation, followed by the “Abduction 125” test and the “Elevation and Abduction 90” respectively. This means that the “Abduction 90” test generates more consistent MVCs between trials.

Therefore, either one of the following tests can be used to normalize EMG signals from the upper trapezius:

- Abduction 90
- Abduction 125
- Elevation and Abduction 90

The “Abduction 125” test and the “Elevation and Abduction 90” test were not previously described in the literature but are developed by the research team. This shows that previous ergonomic research has not covered all possible MVC techniques and indicates the need to further explore such techniques in future research.

5.5 Sternocleidomastoid

Electromyography studies have usually used neck flexion, neck bending, or neck rotation to normalize EMG signals from the sternocleidomastoid. However, the results clearly indicate that the EMG signal generated by the “Anterolateral Flexion” test is statistically higher than that generated by all those tests. However, the “Anterolateral Flexion” test had also the highest value for standard deviation. The “Anterolateral Flexion” test is a test used for muscle strength testing purposes (Kendall et al, 19٩3) and is rarely used in electromyographic studies as a MVC technique.

In conclusion, this research recommends using the “Anterolateral Flexion” test for normalizing EMG signals from the sternocleidomastoid, since it was numerically the largest.

Table 26 summarizes the recommendations for each of the six muscles.

Table 26: Summary of recommendations

	Recommended MVC technique(s)
Lumbar Erector Spinae	• The Arch Test • Trunk Extension Standing • Trunk Extension Prone • Lower Trunk Extension
Thoracic Erector Spinae	• The Arch Test • Lower Trunk Extension • Trunk Extension Standing • Trunk Extension Prone
Latissimus Dorsi	• Prone Extension • Chest Supported ROW
Posterior Deltoid	• Shoulder Abduction in Slight Extension • Transvers Abduction
Upper Trapezius	• Abduction 90 • Abduction 125 • Elevation and Abduction 90
Sternocleidomastoid	• Anterolateral Flexion

5.6 Research Limitation and Future Work

Participant for this study were recruited through flyers distributed in the campus of the American University of Beirut. Therefore, the population of the study is mainly young male students between the ages of 18 and 25. Thus, caution must be taken before generalizing the results of this study.

In five out of the six muscles investigated, the results showed that one of the recommended MVC techniques was a muscle strength testing technique. Therefore, future research should look into muscle strength testing techniques as possible MVC techniques for data normalization purposes. Additionally, the results of this study indicated that a test combining shoulder arm abduction and shoulder elevation generated an EMG signal in the upper trapezius that showed no statistical difference to those generated by the appropriate MVC technique, the “Abduction 125”. Thus, further research may test EMG signals generated in the upper trapezius during tests that have a combination of movements.

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APPENDIX A

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

For most people physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

YES	NO	
☐	☐	1. Has your doctor ever said you have a heart trouble? Should only do physical activity recommended by a doctor?
☐	☐	2. Do you frequently suffer from chest pain?
☐	☐	3. Do you often faint or have spells of severe dizziness?
☐	☐	4. Has your doctor ever said your blood pressure was too high?
☐	☐	5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by, or might be made worse with exercise?
☐	☐	6. Is there any good physical reason why you should not follow an activity program even if you want to?
☐	☐	7. Are you 65 and not accustomed to vigorous exercise?

If you answer “yes” to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary. I have read this questionnaire, I understand it does not provide medical assessment in lieu of a physical examination by a physician.

Participant’s signature: __________________ Date: __________________

Investigator’s signature: __________________ Date: __________________

Adopted from PAR-Q validation report, British Columbia department of Health, June 1975. Reference: BQ Hafen, WWK Hoeger (1994), Wellness: Guidelines for a healthy lifestyle. Englewood, Colo.: Morton Pub. Co.