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Electromyographic Study During Aquatic Training of the Trunk in Chest Wall Immersion

Chevutschi A*

Department of Sports and Health Science, France

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2. Keywords

Aquatic; exercise; EMG; Rotation; Trunk

1. Abstract

The objective of this study was to compare the activation of the muscles of the trunk during dynamic rotation exercises performed on dry land and in water. The EMG of 5 muscles of the trunk was studied on 16 female subjects. The selected muscles were: rectus abdominis (RA), obliquus externus abdominis (OE), obliquus internus abdominis (OI), erector spinae (ES) and iliocostalis lumborum (IC). Each subject performed an exercise of rotation of the trunk in a standing position at 2 frequencies (60 90 rep/mn) on land and in water and the same exercise at 60 rep/mn with a board. A repeated measures ANOVA was used for statistical analysis. For all 5 muscles tested, muscle activation was significantly greater in water compared to land at 90 rep/mn and at 60 rep/mn with a board

($p<0.01$). At 60 rep/mn there is only a significant difference ($p<0.05$) for ilio costalis lumborum in water compared to land. As an example the EMGi of the obliquus internus in water at 60 rep/mn with a board was approximately 51.0% of the MVC. These data suggest that the muscular activity of the muscles of the trunk increase with frequency and surface of the resistances during dynamic rotation exercises in water.

3. Introduction

Aquatic training concerns all age categories, from the youngest to the oldest and can be nefit healthy subjects as well as sick patients. Water is a unique setting reducing gravity and offering a wide array of therapeutic indications [1,2]. Thanks to the principle of Archimede, subjects immersed in water are lighter. For persons who cannot bear constraints on bones and joints it offers the possibilities to exercise in an ideal environment, considering that the more immersed in water the lighter the subjects are [3]. For these reasons, aquatic therapy is regularly used in rehabilitation or recreational programs. It is used to facilitate the return to function in the treatment of orthopedic upper and lower-extremity injuries [4]. Early activation of motion, improvement in joint mobility, muscle strength, proprioception and core strengthening, minimization of pain are factors support in aquatic physical therapy intervention for injuries [4]. In physical medicine aquatic therapy has been regularly used as the primary training technique or in addition to other exercises within a rehabilitation program [5]. During the initial rehabilitation stages aquatic training has often been used for early joint mobilization and muscle strengthening, when muscle exercises were either painful or difficult in normal gravity-based conditions. Despite the continued refinement of aquatic therapy techniques, there has been very little research evaluating muscle activity in analytic movements especially for trunk muscles. Furthermore, while aquatic training has been widely used yet, there is very little literature available regarding muscle evaluation in water. Most studies were conducted on healthy subjects and focused on the loco motor system. Fujisawa et al, [1] showed that sub-scapularismuscle activity in isometric exercises were decreased in water compared to similar exercises on dry land. Kelly et al [2] found significant differences favoring land training in a study on 6 shoulder muscles, in dynamic flexion movement and shoulder rotation. Very few authors have studied the therapeutic effects of aquatic rehabilitation training in patients after surgery [6]. Tovin et al [7] compared the effects of exercise in water and on land on patients after intra-particu-

***Corresponding Author (s):** *Alain Chevutschi, 235 avenue de la recherche 59120 LOOS, France, Tel: 0672366597, E-Mail: a.chevutschi@ifmknf-lille.fr*

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lar anterior cruciate ligament reconstructions. The only studies available focused on activity of the par vertebral and abdominal muscles during normal walking in water [8, 9]. The percentage of maximal voluntary contractions (%MVC) obtained from each of the tested muscles while walking in water, both with and without a water current, were all found to be lower than those obtained while walking on dry land at a level of heart rate response similar to that used when walking on dry land. Masumoto et al [8] found a decreased activity in the lower limbs and erector spinae muscles when walking in water compared to muscle activity while walking on dry land. This study was designed to describe and clarify muscle activity which occurs while walking in water. In order to calculate the % MVC, the measurement of maximal voluntary contraction (MVC) of each muscle was made before the gait analysis, thus facilitating a comparison of muscle activity while walking in water with those on dry land. In another study on backward walking in water, these same authors reported an increased activity for the par vertebral muscles and reduced activity in the lower limb muscles [9]. The only study we found on trunk muscle activity in water is from Bressel et al [10] who compared trunk muscles activity among a variety of therapeutic aquatic exercises designed for patients with low back pain. They concluded that abdominal bracing and Swiss ball exercises in water maximize trunk muscles activity. There is no comparison, in this study, of muscle activity in water versus on dry land. The muscles of the trunk are essential for several pathologies and regularly targeted in training or rehabilitation programs. For example, low back pain is a widespread problem affecting a number of people. Physical therapists and athletic trainers incorporate the use of aquatic therapy into their rehabilitation programs. Individuals predisposed to low back pain during standing exhibited altered neuromuscular strategies prior to pain development [11]. To our best knowledge, to date, no study has compared trunk rotation and trunk muscle activity between water and land conditions. Although physical principles and the thermodynamics of the fluids are well known, the level of muscle activity in the common exercises aquatic therapy is unknown.

The objective of the present study was to quantify and compare the level of electrical activity in trunk and spine muscles during rotary exercises in water and on dry land, at different frequencies and with and without resistance.

4. Methods

4.1. Subjects

The study was conducted on a group of 16 young women, students in Physiotherapy. The experiment was part of their study program. They all gave a written consent for the publication of these data. The subjects were healthy and had no affections of the loco motor system. During the interview we did not find any recent or older pathologies of the spine. No subject had cardio respiratory, muscle skeletal disorders or any contraindication to being immersed in water. For each subject, height was evaluated with a 0.5cm error margin and the percentage of body fat was estimated with a bio-impedance scale. Mean age, height, weight and body mass index values were respectively 21.8 +/- 1.4 years, 173.1 +/- 2.7 cm, 62.0 +/-3.9 kg and 26.1 +/- 5.2.

4.2. Electrodes and Electrodes Placement

Electromyographic recordings (raw EMG) of each muscle were collected using pre amplified bipolar surface electrodes (biometricsSX230), measuring 1cm in diameter and placed 2cm apart from one another. These pre amplified electrodes did not require any particular preparation; nevertheless before placing surface electrodes the skin was shaved, cleaned with alcohol and stripped with abrasive paper to facilitate electrode placement and adhesive properties for a better signal. The electrodes were fixed with double-face tape on the right side of the abdomen and the trunk on the rectus abdominis, obliquus extern us, and obliquus intern us (**Figure 1a**) and on two back muscles; erector spine and iliocostalislumborum pars thoracis (**Figure 1b**). The electrodes were oriented parallel to the muscle fibers for better quality EMG recordings [12]. For the rectus abdominis, the electrodes were placed 1cm above the umbilicus and 2 cm laterally according to the midline of the sternum. For the obliquus extern us abdominis the electrodes were placed alongside a line going from the lowest point of the chest wall to the tuberculum pubicum at 15 cm of the umbilicus. For the obliquus intern us abdominis the electrodes were placed at 1 cm above the anterior superior-iliac spine and under a line connecting the two anterior superior iliac spines. This electrode positioning had previously been validated as the most appropriate for muscle recruitment [13]. For the iliocostalislumborum the electrodes were placed at L2 level and oriented in parallel to a line going from the posterior-superior iliac spine and the lateral border of the muscle to the level of the 12th rib. For the erector spine the electrodes were placed at L5 level and aligned parallel to a line going from the posterior-superior iliac spine to the L1-L2 interspinous space. A reference electrode was placed on the temple of the subject, attached with an elastic band fixed by Velcro. Proper electrode positioning was then verified manually by conducting muscle testing for each subject on dry land. Before raw EMG recordings in water the electrodes were carefully covered with clear protective tape (Hypafix, BSN medical) (Figure 1a, 1b). This waterproof tape was especially suited for aquatic training so the electrodes are never in contact with water. We designed this particular waterproof electrode isolation system because no system had been designed for EMG recordings in water. We finalized during a previous study a system of insulation assuring the waterproofness of the electrodes [14].

Figure 1a: Placement and insulation of the electrodes on rectus abdominis (RA), obliquus externus (OE), and obliquus internus (OI).

Figure 1b: Placement and insulation of the electrodes on erector spinae (ES) and ilio-costalis lumborum pars thoracis (IL).

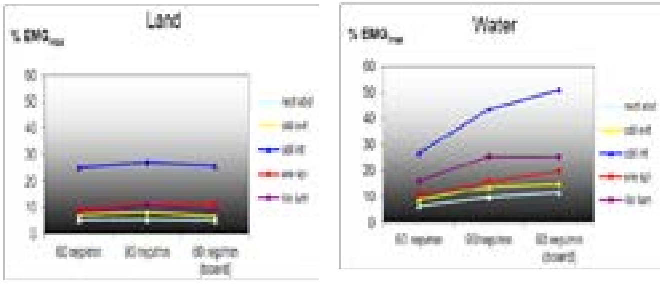

Figure 2: Percentage (%) of EMG max for the 16 subjects and for the 5 muscles studied: rectus abdominis, obliquus externus, obliquus internus, erector spinae, and iliocostalislumborum at 60, 90 repetitions per minute and 60 repetitions per minute with a board, on land and in water.

4.3. Measurement of Maximal Voluntary Contraction (MVC)

Maximal voluntary contraction (MVC) was used to normalize EMG magnitude. MVC measurements on abdominal and par vertebral muscles, essentially following the method described by his lop and Montgomery [15], conducted on land before performing water exercises in order to calculate the percentage of MVC (%MVC), to facilitate a comparison between normalized muscle activity evaluated while performing aquatic exercises and those evaluated on land during each experimental session. The entire EMG activity for the five muscles was expressed as percentage of MVC. The duration of the MVC test was set at 5 seconds for each muscle tested. The subjects were carefully introduced to the testing procedure and trained to produce the maximal force output before each measurement session. Raw EMG signal was obtained using an 8-channel recording system (Data LOG P3X8, Biometrics Ltd Cwmfach, Gwent NP11 7HZ, United Kingdom). Raw EMG was recorded at the sampling frequency of 1000 Hz and analyzed with the Origin Pro software. We used, to compare the activity in the water and on dry ground the integrated EMG (IEMG) obtained from the raw EMG. For each test, the first cycles were not kept for muscle activity measures since they were not representative of the activity [16]. For each subject and each muscle, in water as well as on dry land, the IEMG (mV. s) of the five consecutive cycles from the three recordings were divided by the time required to complete each cycle. The activity of each muscle during the exercises was then normalized according to the activity during this isometric training phase and expressed in % EMG max. Then all IEMG data were averaged in order to yield each IEMG per cycle.

4.4. Procedure

Recordings were first conducted on land then in water with full chest wall immersion, in a 6m x 6m and 1.3m deep rehabilitation pool with water temperature at 30°C. Before proceeding with the recordings, each subject was trained to correctly perform trunk rotary exercises. For proper electrode placements, all exercises were conducted in the same order of subjects on dry land and in water. For the exercises we chose two frequencies, 60 and 90 repetitions per minute (rep/mn) set by a metronome. These frequencies were chosen because60 rep/mn corresponds to a comfortable frequency of movement and because some of our subject found very difficult to perform the movements at a frequency higher than 90 rep/mn. Between each series the subjects could rest for 2 to 3 minutes. All recordings for a same patient were collected on the same day. Two tags were placed at 45° on the right and left side of the subject, according to the sagittal plane, both on land and in water in order to have an identical joint range of movement (ROM). The two series included at least 10 cycles for one exercise. The analysis was based on 5 consecutive cycles after discarding the first cycles not representative of the activity.

4.5. Training exercises

Exercise 1: Trunk rotation at 60 rep/mn. The subject is standing up, feet pelvis-width apart, arms alongside the body, elbows flexed at 90° and forearms in the intermediatepro-supination position. Fingers are extended and tight together, thumb pushed upwards. From this position, the subject performs alternate rotating movements on the right and left sides at 45° joint ROM on both sides. The metronome, set at 60 rep/mn, gives the rhythm.

Exercise 2: Same exercise as the first one but at a frequency of 90 rep/mn.

Exercise 3 : Trunk rotation with a board at 60 rep/mn. The subject is standing up, feet pelvis-width apart. The subject holds against his or her chest a foam board lengthwise(48 x 28 x 4.5cm). The right hand holds the proximal border of the board flat against the chest. The other hand, upper limb in extension, holds the other extremity of the board. The board is half immersed in water. From this position the subject performs alternative trunk rotations on the right and left sides with joint ROM at 45° on both sides. The frequency sets by the metronome is 60 rep/mn.

4.6. Statistical Analysis

Means and standard deviations (SD) percentage of maximal voluntary contraction are presented for all variables. The Shapiro-Wilks test was used for normal distributions. A two-way ANOVA (2 environments (water/land), 2 frequencies (60/90 rep/mn)) with repeated measures was done. In order to identify the differences between the various rotation conditions we used a Turkey post hoc test. The significance threshold was set at $p<0.05$. To perform the statistical analysis we used the STATISTICA 6.0 software. The same statistical analysis procedure was used to compare both frequencies and modalities60 board/60 rep/mn and 60 board/90 rep/mn.

5. Results

Muscle activity (%MVC) during rotary exercises at 60 and 90 rep/mn and 60 rep/mn with the board, on land and in water is shown in (**Table I**). The percentages of EMG max for the16 subjects and for the 5 muscles studied (RA, OE, OI, ES, IL) at 60, 90 rep/mn, and 60rep/mn with a board, on land and in water are represented in the (**Figure 2**). In the first exercise there was no significant activity difference for the rectus abdominis, obliquus externus, obliquus internus and erector spinae muscles for exercises on dry land and in water. Only the muscle activity of the iliocostalislumborum (pars thoracis) was increased in water for this first exercise. In the second exercise, at 90 rep/mn, muscle activity increased in water for all the muscles studied vs. on dry land. It was 1.8 times higher for the rectus abdominis and obliquus externus and corresponded respectively to 10% and 14% of the MVC. It was 1.6 times higher for the obliquus internus (44% MVC), 1.3 for the erector spinae(16% MVC) and 2.2 for the iliocostalislumborum (pars thoracis) (26% MVC). This increase was found and amplified on all muscle groups for the rotation exercises at 60rep/mn with the foam board. In the third exercise the increases were 2.3 times higher for the rectus abdominis and obliquus extern us (11.5% and 15% MVC), 2 times higher for the obliquus internus (51% MVC), 1.7 times higher for the erector spinae (19.8% MVC) and 2.8times higher for the iliocostalislumborum (pars thoracis) (25.3% MVC). On land no difference in muscle activity was noted for all groups of muscles, regardless of the exercise.

Table I: Means and standard deviation of percentage of maximal voluntary contraction for rectus abdominis,obliquus externus, obliquus internus, erector spinae and iliocostalislumborum muscles on land and in water at60 and 90 repetitions per minute and at 60 repetitions per minute with a board.

Muscle	Test Condition	60 rep.mn^{-1}	90 rep. mn^{-1}	60 rep.mn^{-1}board
Rectus abdominis	Land	5.3 ±3.1	5.4 ± 3.2	5.0 ± 3.1
	Water	6.5 ±3.1	9.8 ± 6.1**	11.5 ± 7.2**
Obliquus externus abdominis	Land	7.0 ±3.4	8.0 ± 5.0	6.5 ± 2.9
	Water	8.8 ±5.1	13.9 ± 7.6**	15.0 ± 10.5**
Obliquus internus abdominis	Land	25.2 ±15.6	26.9 ± 19.6	25.8 ± 12.8
	Water	26.8 ±16.4	43.7 ± 24.2**	51.0 ± 26.7**
Erector spinae	Land	9.8 ±3.4	11.4 ± 6.0	11.5 ± 4.3
	Water	10.7 ±4.3	15.9 ± 7.7**	19.8 ± 9.6**
Iliocostalislumborum	Land	8.4 ±5.1	11.1 ± 5.7	9.1 ± 3.6
	Water	16.1 ±10.8*	25.5 ± 15.5**	25.3 ± 10.6**

*p< 0.05 land versus water

**p< 0.01 land versus water

6. Discussion

There is a lack of information on the levels activity of the muscles of the trunk during aquatic training. To our knowledge this study was the first attempt at comparing the activity of the rectus abdominis, obliquus externus, obliquus internus, erector spinae and iliocostalislumborum muscles during three dynamic rotary exercises on land and in water. This investigation was primarily set up to test for differences in the %MVC of each muscle when exercising in water, with increased frequency and resistance in water, vs. exercising on dry land. It is difficult to compare our results with other studies carried out on land because of the difference of gravity and also because we did not find anyone. Bressel et al [10] compare trunk muscle activity levels among a variety of therapeutic aquatic exercises designed for patients with low back pain. These exercises are performed in a pool but are not compared with the same exercises on land. In this study mean EMG values tended to be less than 25% of MVC for all muscles and exercises tested. Our results are similar excepted for the obliquus internus. There was no difference in EMG activity at 60 rep/mn for the two environments except for the iliocostalis muscle. The lack of difference could be explained by the reduced movement frequency and small surface of resistance in the water represented by the hand and forearm. The increased iliocostalis activity validates the rotary action of this muscle classically considered as having very little influence on the axial rotation because of the small distance between the ribs and the ilium. However in this situation, the controlateral rotation increases this distance and can trigger chest wall derotation. Dumas et al [17] reported the ipsilateralrotation activity of the iliocostalis muscle, also found in our study. At 90 rep/mn, the muscle activity was increased in all muscle groups studied. This increased muscle activity for all muscles in water was approximately 1.5 times higher than on land. In our study, the frequency went from 60 to 90 rep/mn corresponding to an angular velocity increase of 1.5. These results are in accordance with the biophysical properties of water. In fact, in a fluid the resistance varies with the square velocity according to the formula: $R= K.S \sin \alpha(v-v')^2$. R: resistance of the water, S:Surface of the moving body (m^2):α:Angle of approach, V:Velocity (m/s),V': Velocity of the fluid (m/s), K: Factor linked to the environment (viscosity, density, adhesive and cohesive forces). In water, at 60 rep/mn with the foam board we found a significant increase in muscle activity almost 2 to 2.5 higher than on land for the rectus abdominis, obliquus externus, obliquus internus and erector spinae muscles and 3 times higher for the iliocostalislumborum muscle. The increasing activity was related to the larger surface of resistance represented by the foam board. The highest activity was found on the obliquus internus, acting as prime mover of theipsilateral rotation with the obliquus externus acting as prime mover of the contralateral rotation. The rectus abdominis and erector spinae muscles do not have any known rotary effect on the trunk but are identified as stabilizing muscles. Their activity increases with frequency and resistance. The main results of this study clearly demonstrated that frequency and consequently velocity and surface of resistance in water increased muscle activity compared to measures conducted on dry land. On the land movement frequency and a greater surface of resistance had no impact on the activity of the studied muscles. Even though EMG activity increased in water, it remained quite low except for the obliquus internus muscle (51% MVC) and rarely went above 20% of MVC. It may be questioned that the rotation exercises in water lead to an effective muscular strengthening as they produced EMG values considerably less than 60% of MVC. Poyhonen et al [18] reported a significant decrease in the signals of the EMG amplitude during maximal isometric contractions of knee extensors in water vs. dry land without any reduction of force and with reproducibility over time. These authors debated that the reduced EMG activity in water could be explained by electromechanical and/or neurophysiologic underlying mechanisms. We compared muscle activity according to MVC for each muscle tested on dry land, because it was impossible to perform the tests described by his lop and Montgomery [15] with the same positions in water. Several hypotheses have been brought up to explain this decreased muscle activity in water, one of them could be the effect of weightlessness on muscle spindles and proprioceptivesystems within the neuromuscular system [19]. Poyhonen et al [18] reported that Dietz et al [20] showed that muscle proprioceptive mechanisms could not account for the effect observed under water but rather suggested that the EMG responses were mediated by reflexes activated by pressure receptors within the body. Similarly, Avela et al [21] found that during unexpected gravity conditions muscle spindle activity might be reduced. Poyhonen and Avela [19] concluded that the head-out immersion induced deterioration in neuromuscular functions, perhaps by triggering inhibitory mechanisms. Furthermore, the findings from micro-gravity simulations suggested that the decreased effect of gravity during immersion was associated to the reduced stimulation of the gravireceptors of the muscles, the vestibular system and the skin [19,22]. Accordingly, the mechanism behind these decreased muscle activity could revolve around the effects of partial weightlessness, although hydrostatic pressure might need to be considered [19].

7. Conclusion

The results of this study highlight an increase in the activity of muscles of the trunk during dynamic rotation exercises in water versus dry land. Muscle activity, expressed in percentage of MVC increases with the frequency and resistance to movement in water. These results are in accordance with the biophysical properties of water. This increased muscle activity affects the muscles that are prime movers of the rotation, i.e. obliquus internus and obliquus externus but also the stabilizing muscles: rectus abdominis, erector spinae and iliocostalislumborum. Our study shows that it is possible to increase vertebral muscle activity in water versus. dry land while benefiting from reduced constraints especially on a vertebral level and promoting the inclusion of these types of exercises in Physical Medicine and rehabilitation programs. It is informative for the design of aquatic therapies. The rate of exercise (rep/mn) and use of props such as boards appear to be important factors to determine the impact the exercise will have on muscle activation for performing in the air versus water.

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