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Muscular Activity of the Posterior Deltoid During Swimming vs. Resistance Exercises on Water and Dry Land

Xavier García Massó and Juan Carlos Colado

The purpose of this study was to compare muscular activity of the posterior deltoid muscle during three typical aquatic physical conditioning activities. This interpretative case study involved a 23-year-old elite swimmer and athlete. Muscular activity was measured with surface electromyography during swimming crawl at maximum speed, and also while performing horizontal shoulder abduction using elastic band and Hydro-Tone Bells resistance. During the maximum voluntary contraction, we observed what appeared to be meaningful differences between the percentage of muscular activation during the swimming activity and that observed during the elastic band and aquatic resistance exercises (18.72% vs. 74.84% and 65.46%, respectively). No meaningful differences were observed between the percentage of muscular activation for the elastic band and aquatic resistance exercises. Resistance exercises, both in and out of the water, produce more muscle activation and may be more efficient for improving muscular strength than sprint crawl swimming.

Prescribing physical exercise for health reasons is the process by which a medical professional recommends that an individual undertake a personal exercise regimen in a systematic and individualized manner. The main objective of exercise prescription is to encourage people to increase their level of physical activity in an individually appropriate manner maximizing the health benefits (e.g., increasing cardiorespiratory capacity, improving strength) and minimizing adverse effects (e.g., soreness, injuries). For an exercise prescription, the purposes, interests, needs, environment and health status of the individual are all taken into account to create a set of personal objectives (Jiménez, 2003). Many professional fields and organizations have highlighted the alarming rate of chronic degenerative cardiovascular disease in the more technologically advanced societies (Cabri, Annemans, & Clarys, 1988; Dishman, Washburn, & Heath, 2004). This is particularly true in Spain, where cardiovascular disease accounts for 60% of total deaths and is, in fact, the leading cause of death and disease in the country (NIS, 2002). Consequently, since the 1960s, prescriptive physical conditioning programs for healthy individuals almost exclusively have involved aerobic exercise while at the same time underestimating the importance of other essential physical factors, such as muscle strength (Zimmermann, 2004). Among others, this is one of the reasons

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why the 7th leading cause of disease in Spain (NIS, 2002) is related to changes in the osteomuscular system and in the connective tissue that manifests as functional disabilities preventing carrying out essential everyday tasks with the consequent reduction in the quality of life. On the other hand, it is known that having a well-functioning musculoskeletal system is linked to a reduction in one or more heart disease risk factors and that a suitable percentage of lean muscle mass enhances overall maintenance of appropriate body composition (Graves & Franklin, 2001).

One of the most important criteria for exercise training is that certain “demands” must exist to create the ideal conditions for the adaptation process to be carried out effectively. It is necessary to combine sufficient frequency, intensity, duration, and specific type of exercise modality to produce a suitable overload that results in an optimal adaptation or “training effect.” Creating an optimal overload depends on the amount (i.e., frequency, intensity, and duration) of the stimulus, which in turn should depend on the needs of the person exercising (ACSM, 1998).

The pressing need for this study emerges when advanced societies such as Spain’s begin taking up healthy physical activities in their leisure time (Sánchez, 1996). We know from works by Martínez (1999) that swimming is among the most widely practiced sports in Spain as a leisure activity especially when persons desire to improve their levels of physical fitness. Since Greek and Roman times, the water environment has been considered an ideal surrounding in which to improve one’s level of physical fitness. As a result, different swimming styles are usually recommended as a means of improving the general physical conditioning of the population. It is assumed that they are not only effective in improving aerobic capacity but also muscle strength. According to the basic guidelines for prescribing health-related physical exercise mentioned previously, it is worth asking if swimming activities are a suitable means for improving physical conditioning oriented toward muscular fitness. Alternatively, should we recommend that people follow new aquatic exercise criteria established for improving muscle performance and endurance such as those outlined by Koury (1998); Sova (2000); Sanders (2001); Colado and Moreno (2001); Colado, Moreno, and Baixauli (2002); and Colado (2002, 2003, 2004).

There are relatively few electromyographic studies in water that have attempted to prove that swimming activities may be effective in creating sufficient stimuli for improving upper extremity strength and to discover if such strength actually applies broadly to all shoulder girdle muscle groups. Even scarcer are those studies that have evaluated the muscle response to exercises as common as those performed during aquatic resistance exercises. The lack of research is of great relevance since it is necessary to monitor that muscle conditioning practices being carried out within the normal population during their leisure activity to establish whether they are as safe as they are effective.

In view of the lack of research focused on swimming and muscular strength, this pilot study evaluated differences in shoulder muscle activity produced when swimming front crawl stroke compared with the change in strength of muscle groups producing horizontal shoulder abduction using Hydro-tone Bells in the water. In addition, we evaluated a similar dry-land exercise using an elastic band as a control group reference for interpreting muscle activity results. Finally, it must be pointed out that although case studies such as the current study do not normally lead to representative results, they are often appropriate for establishing hypotheses, corroborating methodological procedures, and, in short, they serve as a basis for initial debate and the development of subsequent larger scale studies (Heinemann, 2003; Thomas & Nelson, 2001).

Method

Participants

An elite level 23 year old athlete (1.79 m in height, 65kg in weight and with a body mass index of 20.29 kg/m^2) volunteered to take part in this case study. A regular swimmer since the age of 6 years, he typically combines competitive swimming training with water polo, triathlons, and long distance open water swimming. His competitive level is high, having won several national prizes over the past two years. He typically trains six weekly swimming sessions at an average to high level of intensity over a period of 1 hr and 30 min, plus seven more sessions in which he combines cycling, running, water polo, and resistance exercises. The participant had neither general cardiovascular nor osteomuscular contraindications nor general or local problems in scapulo-humeral and scapulo-thoracic joints at the time of the study. We should also point out that the participant was familiar with the proposed resistance exercise on dry land and with the front crawl stroke but not with the aquatic resistance exercise using Hydro-tone Bells employed in this study.

Exercise Protocol

First, it should be pointed out that it was not considered appropriate for the participant to take part in several sessions to become familiarized with the movements to be evaluated for these reasons: (a) Dry land exercises were callisthenic single joint movements with minimum psycho-motor demand and with which the subject was already familiar; (b) the swimming exercise consisted of performing front crawl, a stroke with which he has competed and won prizes; (c) although he had never used the “aqua gym,” the aim was for him to experience them just as many other new exercisers do during their first sessions. The idea of this was to check what type of stimulus such a novel movement creates despite the lack of familiarity, balance, and isolation that occurs in experienced performers, considering that when experienced on the “aqua gym” mechanism, the stimulus generated by the participant during exercise may be even higher. Intervals of approximately 10 min rest occurred between the three different exercise sessions performed. The temperature of the pool air environment was 31°C, 65% humidity level, and water temperature was 29°C.

Electromyography

We measured muscular activity using surface electromyography, model ME6000 of the Mega brand (Mega Electronics, Kupio, Finland). Self-adhesive electrodes were applied (Ag-AgC1) with conductor gel (Medicotest, M-00-S, Olstikke, Denmark). For the aquatic measurements, we employed a kit for aquatic use consisting of a waterproof cover with integrated electromyography (EMG) electrodes and a “Compact Flash” 256 MB capacity memory card. All data collected were analyzed with the software provided by the manufacturer (Mega Win v.2.3). To evaluate muscle activity, we recorded the gross signal using a sampling frequency of 1000

Hz and applied a quadratic mean (RMS) smoothing procedure at 0.05 s intervals. The signal was preamplified with a preamplifier placed 6cm from the electrodes (1µ V sensitivity, 305 gain, 8–500 Hz band). The data analyzed fit the peak amplitude obtained in a brief period during which the muscle reached its maximum contraction intensity during the concentric phase of the movement. We followed techniques employed by other authors both for the placing and securing of electrodes as well as for the treatment and analysis of the data (e.g., Hintermeister, Lange, Schultheis, Bey, & Hawkins, 1998; Kelly, Backus, Warren, & Williams, 2002; Kelly, Roskin, Kirkendall, & Speer, 2000; Pöyhönen, 2002; Soderberg & Knutson, 2000).

Assessment of the Maximum Voluntary Contraction. Once we determined that the electrodes were in full working condition, we instructed the participant on the movement to be conducted for obtaining a maximum voluntary contraction (MVC). This involved pulling a nonelastic rope fixed to the wall in such a way that the upper extremities are positioned according to Kelly et al.'s (2002) description: 90° glenoid humerus abduction in the scapular plane with 45°external rotation of the humerus, 20° elbow flexion with no intervention by any other part of the body. A submaximal trial was performed followed by a 2 min rest, after which two maximum attempts were performed with a recovery interval of 3 min, with subsequent analysis of the highest recording.

Horizontal Shoulder Abduction With Elastic Band. Once the MVC had been determined, we instructed the participant about how to perform the movement for conducting the dry land trial. This consisted of a horizontal shoulder abduction movement with the glenoid humerus joint in the same position as that of the MVC trial. The subject held a light "Thera-Band" elastic band, measuring 1 m in length when not expanded, at a distance that enabled him to perform approximately 15 repetitions with an effort valued at between 7 and 9 according to the OMNI-RES scale (Robertson et al., 2003) or the qualitative equivalent of "hard." Held at this distance, he was to perform the movement without the elastic band losing its complete tension in the eccentric phase and completing the concentric phase to the pectoral level. Performance speed for exercisers at this level was that recommended by the ACSM (2002), that is, a fast speed. The performer completed two nonconsecutive submaximal phases during which we determined the relative percentage of MVC used, then rested for five minutes, and carried out a final series according to the criteria described previously.

Horizontal Shoulder Abduction With Hydro-Tone Bells. Once the exercise had been carried out on dry land with the elastic band, we showed the participant the movement to make for the aquatic exercise. This movement consisted of a horizontal shoulder abduction movement with the glenoid humerus and elbow position identical to that maintained in the MVC trial. The participant was to perform a sideways arm-raising movement described by Colado (2003, 2004) with the Hydro-Tone Bells (Aquatic Fitness Systems, Inc., Huntington Beach CA), material that increased the frontal and drag resistance. To guarantee greater stability during the movement and therefore increased performance speed and resistance, the participant positioned himself with one leg forward and the other leg resting on the pool wall. Both knees and hips were slightly flexed to guarantee better immobility of the spine and greater stability of the movement. The separation distance between the feet was slightly greater than that of the width of the hips.

Wrists were kept straight ahead of the forearm with resistance materials under water so that depth of immersion reached the acromion when hips and knees were slightly flexed. In the horizontal adduction movement, the hydrodynamic position of the Hydro-Tone Bells was not altered with regard to the abduction movement.

After both verbal and visual instructions the participant got into the water and performed some warm-up exercises for around three minutes. He then performed several movements according to the technique described, and we provided verbal corrections as appropriate. Immediately after he performed two nonconsecutive series of 15 repetitions to determine the speed at which the valid series should be performed according to his perception, he recovered for five minutes and performed the definitive trial. Intensity control was conducted according to the same criteria followed in the elastic band trial.

Performance of the Crawl Swimming Exercise at Maximum Speed. Given his competitive swimming history, as well the indications made by the trainers of the participant studied, it was not necessary to explain the technique of the sprint front crawl swimming stroke to him. Therefore, once he had recovered and the equipment was secured so that it ensured comfortable movement, we proceeded to evaluate the muscle response over a distance of 25 m at the maximum possible speed, using the above mentioned sprint crawl swimming stroke. After a warm up in the water, the participant performed a single 25 m trial.

Results

In this section we compare descriptively the values obtained in each assessment. Muscular activity of the posterior deltoid was higher in the horizontal shoulder abduction (dry-land—3001.73 µV ± 450.11- and aquatic medium –2643.18 µV ± 317.89) than in swimming crawl at maximum speed (750.82 µV ± 141.58). These values correspond to 74.84%, 65.46%, and 18.72% of the MVC, respectively; however, there was not a large difference between the percentage of muscular activation for the elastic band exercise and the aquatic resistance exercise.

We also observed that in the last repetitions of the set performance in the aquatic medium, a major variability appeared in the level of muscular activation in a different manner than the values of the dry land exercise. This variation corresponded with the moment at which it was possible to observe a minor stabilization of the body during the performance of the aquatic movement. Apparently what happened was that while the participant was adjusting his body position while also trying to generate a rapid horizontal shoulder abduction movement may have increased the resistance associated with aquatic drag forces, which caused the high variability between repetitions (i.e.,: #12 rept (3401 µV), #13 rept (2801 µV), #14 rept (3200 µV), #15 rept (2208 µV).

Discussion

According to Zimmermann (2004), the minimum intensity of strength training that produces a training effect, at least in untrained or scarcely trained muscles, should be around 40% of MVC. Therefore, those exercises prescribed for such a purpose must at least exceed this threshold. Clarys (1988) studied muscle activity in crawl swimmers performing at maximum speed. To do so, he recorded 25 muscle groups over the whole body, finding that only two of these muscle groups managed to clearly exceed 40% MVC activity. Paradoxically, the 40% threshold appeared in stabilizing rather than dynamic muscles, such as the toe and wrist flexors (43.10% of the MVC) and the lower abdominal muscles (48.33% of the MVC), which registered the highest activity. Cabri et al. (1988) specifically analyzed the activity of the driving agonist muscles during the crawl motion and found that, except at maximum speed, in which the percentage regarding MVC was close to 40% ± 3, at the other speeds (85 and 75% of maximum speed) activity fluctuated mainly between 30 and 35% of MVC. These results coincide with those obtained by Bollens, Annemans, Vaes, and Clarys (1988). Considering that these records are for maximum speeds in experienced and skilled swimmers, it would be expected that people with less aquatic experience who wish to improve their strength by means of continued movements in the water environment crawl stroke swimming would be unlikely to achieve the desired strength gain benefits especially in dynamically contracting muscle groups such as the horizontal shoulder abductors.

From the data obtained in the current case study, we examined the mean activity of the posterior deltoid muscle produced by motion at maximum speed in crawl stroke swimming. Descriptively, the EMG values observed were not enough to generate a local training effect to improve muscular strength, since the recording obtained indicated that mean muscular activation activity achieved was quite low, representing only 18.72% of MVC. Similar results were obtained in other studies such as the Clarys study (1988) that used participants with similar characteristics to our case study, where neither competitive swimmers nor novice swimmers reached a minimum threshold for improving strength.

Therefore, we conclude from our case study that prescribing exercises for improving muscle strength based solely on crawl swimming strokes is a mistake, since, in healthy people, activity levels sufficient for bringing about the desired training changes for strength in agonist or synergist muscles are not achieved. On the other hand, not all muscle groups are exercised when practicing a swimming stroke (Miyashita, 1997). This limitation could therefore oblige those who practice swimming to practice and master several swimming strokes to activate, albeit insufficiently, a greater number of muscle groups so that in doing so, the minimum stimulus created by training is shared across the majority of joints. This is the reason why we must identify other types of water activities that fulfill the dual mission of reaching an optimum training threshold for improving strength, regardless of the level of physical aptitude of the exerciser, as well as be able to create changes in the most important muscle groups for good osteomuscular health with a few easy movements (Colado, 2004; Sanders, 2001).

Some new aquatic muscle training programs initially offer both of these advantages. Studies conducted in young, healthy, and physically active men, such as those by Colado and Llana (2003) and Colado (2003), have demonstrated the efficiency and safety of some of these activities using a photographic and video study. These same studies have produced an evaluation of the changes in muscle mass and maximum dynamic muscular strength when using a systematic strength improvement program in water. These types of aquatic programs are based on energetic and controlled performance of movements with surface devices that increase both frontal and drag resistance. These aquatic exercise programs also have the benefits of producing a minimum eccentric muscle activity that reduces the risk of injuries, muscle overloading, and subsequent muscle soreness and inflammation, employing shorter sessions so that in a single exercise both agonist and antagonist muscles are exercised in such a way that with only four exercises the majority of muscle groups can be trained and requiring little prior psychomotor experience and demand for their performance. This last requirement means that almost everyone is able to perform them regardless of their mobility and proficiency in the water. Furthermore, because the head is above water at all times, it enhances the leisure and social components of exercise, which can be important in maintaining compliance with these types of programs.

To avoid such basic mistakes as mistaken prescription of lap swimming as a primary means to improve muscular strength in healthy populations, one should also evaluate the efficiency and safety of aquatic exercises to guarantee evidenced-based professional guidance. Therefore, studies such as this current case study may be a step toward analyzing the adequacy of water-based muscle training activities. Our case study data suggested that there were no meaningful differences between the EMG responses created by the performance of dry land and water callisthenic exercises for strength training, as long as they are conducted with the methodology we have described in this paper. We also did observe that dry land and water callisthenic activities appeared to produce a much greater percentage of MVC as compared with maximal speed front crawl swimming.

As we mentioned earlier in this paper, several other studies involving electromyographic recordings that were based on callisthenic aquatic exercises aimed at dynamically improving strength , provide similar results to our case study findings. For example, Pöyhönen, Keskinen, Hautala, Savolainen, and Mälkiä (1999) and Pöyhönen, Heikki, Keskinen, Hautala, Savolainen, and Mälkiä (2001) found similar results with knee flexor-extensor muscles. More specifically Kelly et al. (2000) discovered the same effect using shoulder abductor muscles. Both authors even compared their results with those obtained from equivalent dry land movements, as we did in this case study. Kelly et al. (2000) conducted a study in which the dynamic muscle activity of several abductor muscles of the scapulo-humeral joint was evaluated both on dry land and in the water. A relevant conclusion of that study was that as the speed of movement increased, muscle activity in the water was similar to that achieved on dry land. At slow speeds, muscular activity was not nearly as high as the levels stimulated on dry land. That is, no statistically significant differences existed when employing gravity and water as stimuli creating a training effect. Even the mean intragroup muscle activity in water was higher than that achieved on dry land.

The level of activity achieved with shoulder abduction activation during stroke swimming was insufficient to bring about changes in healthy populations since the previously mentioned values of 30–40% were not reached, apparently owing to the fact that the water resistance created was not sufficient to increase the frontal and drag resistance produced in aquatic movements (Colado, 2004). Similarly, Pöyhönen (2002) and Pöyhönen et al. (2002) showed that, by using large enough equipment and a high rate of movement speed, a similar muscle activity could be achieved in knee flexors performing maximum exercise with an isokinetic machine and another conducted with hydro-boots in the water.

Practical Applications

Data from our case study strongly supports other findings that stroke swimming may serve as a source for improving muscle strength is a myth. We did observe that, unlike performing swimming strokes, aquatic resistance exercises potentially could be effective for strength training since they exceeded muscle activation levels of 40%. As long as aquatic resistance exercises use large surface devices, high movement speeds, and maintain core stability, then the muscle activity produced may reach thresholds similar to those of exercises performed on dry land. These findings may also be applied to physical exercise programs in prevention and functional rehabilitation as well as sports training.

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