Upper Extremity Muscle Activity During Simulated Dryland Swimming While Wearing Wetsuit

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UPPER EXTREMITY MUSCLE ACTIVITY DURING SIMULATED DRYLAND SWIMMING WHILE WEARING WETSUIT

By

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Bachelor of Science - Exercise Science
University of Nevada, Las Vegas
2011

A thesis submitted in partial fulfillment of the requirements for the

Master of Science - Kinesiology

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University of Nevada, Las Vegas
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Ciro J. Agnelli

entitled

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Abstract

Triathletes typically wear a wetsuit during the swim portion of an event, but it is not clear if muscle activity is influenced by wearing a wetsuit. The purpose of this study was to investigate if shoulder muscle activity was influenced by wearing a full sleeved wetsuit vs. no wetsuit during simulated dryland swimming. Subjects (n=10 males; 179.07±13.18cm; 91.20±7.25 kg; 45.6±10.52 years) completed two dry land simulated swimming conditions (VASA Ergometer Trainer): No Wetsuit (NWS) and with Wetsuit (WS). Electromyography (EMG) of four upper extremity muscles was recorded (Noraxon telemetry EMG, sample rate = 1000 Hz) for each condition: Trapezius (TRAP), Triceps (TRI), Anterior Deltoid (AD) and Posterior Deltoid (PD). Each condition lasted 90 seconds with data collected during the last 60 seconds. Resistance setting was self-selected and remained constant for both conditions. Stroke rate was controlled at 60 strokes per minute pace controlled by metronome. Average (AVG) and Root Mean Square (RMS) EMG were calculated over 45 seconds and each were compared between conditions using a paired t-test (α=0.05). PD and AD AVG EMG and RMS EMG were each greater during WS vs. NWS (p<0.05). The wetsuit had no effect on the TRAP nor TRI AVG EMG or RMS EMG (p>0.05). The greater PD and AD muscle activity while wearing a wetsuit might affect swimming performance and /or stroke technique on long distance event.
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Chapter 1

Introduction

Wetsuits have been used among many water sport modalities from SCUBA diving to surfing, and open water swimming to triathlon competitions. Wetsuit design is often unique to the demands of the sport. For example, wetsuits designed for surfing tend to have a thick and rough material to account for how the surfer paddles the surf board. In contrast, a wetsuit designed for swim performance typically has a smooth surface and thickness needs to be within competition rules. The commonality between wetsuits is that water is trapped between the skin and the material of the wetsuit and heated by the body to insulate the body from the cold temperatures.

The thermoregulation benefits and performance enhancements of wearing wetsuits during swimming have been well documented (Cordain & Kopriva, 1991, Ulsemear et al, 2014). During the sport of triathlon, it is very common for athletes to wear a wetsuit to take advantage of both the thermoregulation properties as well as the potential performance benefits. However, although there are competition rules for triathlon wetsuit design, there are a variety of wetsuit design features that athletes can select. There is a lack of research on some aspects of wetsuit design from both human movement and performance perspectives.

In triathlons, there are two general categories of wetsuit design: full-sleeve (Figure 1) and sleeveless (Figure 2).
Anecdotally, a widely discussed topic in triathlon websites and forums is whether or not long sleeve wetsuits increase resistance of arm movements more so than sleeveless wetsuits (triathlon.competitor.com 2015; forum.slowtwitch.com). The debate is typically centered on whether or not a full sleeve wetsuit causes a possible additional resistance to movement vs. the benefit of additional flotation and/or surface area on the arm that would aid in thermal regulation.
and propulsion. Presently, there are no empirical data on the influence of a full sleeved wetsuit on either of these issues. However, Nessler, et al. (2015) investigated the influence of surfing wetsuit design on shoulder movement and muscle activity during simulated surf paddling. In this study, it was reported that shoulder movement pattern and muscle activity were affected by the use of a long sleeve wetsuit when compared to a traditional swimsuit while simulated surfing paddling (Nesser et al., 2015).

Regarding thermal regulation, Tipton, Franks, Gennser & Golden (1999) reported that lower water temperature exposure of the upper limbs can deteriorate swimming performance, suggesting that a full wetsuit would be more beneficial than a sleeveless wetsuit. However, no study has specifically investigated whether or not shoulder muscle activity is influenced by wearing a full sleeve wetsuit during swimming or dryland simulated swimming.

Purpose of the Study

Therefore, the purpose of this study was to investigate if shoulder muscle activity was influenced by wearing a full sleeved wetsuit vs. no wetsuit during simulated dryland swimming.

Research Question

- Is there a difference in shoulder muscle activity during simulated dryland swimming while wearing a full sleeved wetsuit and not wearing a wetsuit?

Significance of the Study

The investigation of upper extremity muscle activity while wearing wetsuit can enable manufacturers and athletes alike to build and choose wetsuit models and sizes that will better fit their needs and provide safe protection and improve performance outcome.
Statistical Hypotheses

Null hypothesis - wetsuit does not have any effect on shoulder muscle activity during simulated dryland swimming.

Alternate hypothesis - wetsuit have an effect on shoulder muscle activity during dryland simulated swimming.

Limitations/Delimitations

1. Only one brand and model of wetsuit utilized.
2. The wetsuits available for testing were limited to four sizes.
3. All measurements were recorded during simulated dryland swimming vs. water.
4. Subject pool included swimmers and triathletes of different expertise levels.
5. Only male subjects.

Definitions

Electrogoniometer (Elgon) – a device used to measure joint angles.

Electromyography (EMG) – the study of the electrical signal associated with muscle contraction.

Stroke Rate (SR) – is the total number of cycles, from right hand water entry to left hand water entry one can complete in a 60-second count.

Stroke Cycle – defined as the cycle movement from the initial hand entry to underwater downward pull of one arm to recovery and back to its initial hand entry position.
Chapter 2

Literature Review

There is a strong body of literature examining the benefits of wetsuit use for human body thermoregulation protection and sports performance in open water competition. However, there is limited literature available on the impact of wetsuit on muscle activity. Part of the reason for this limited body of research is due to the challenges of recording electromyography (EMG) in water. This review puts together a collection of peer-reviewed studies that is available on the benefits associated with the use of wetsuits. In addition, challenges of surface EMG use in water will be reviewed.

Thermoregulation

Cold water immersion is a concern during open-water swimming events. Tipton et al. (1999) reported that cold water immersion in water temperatures at or below 18º C (64.4º F) showed that swim stroke length decreased, stroke rate increased and horizontal body alignment deteriorated. Since arms are more susceptible to cooling and eventual muscle fatigue, Tipton et al. (1999) stated that it might be a leading contributing factor to the decline in swimming ability. The changes reported by Tipton et al. (1999) can contribute to inefficient swimming technique and an increase in drag.

In US Triathlon sanctioned events, in order to protect participants when water temperature drops at or below 78º F, the use of wetsuits is legal and recommended (USAT, 2012). Furthermore, the water temperature range chart (Table 1) shows when to wear a wetsuit, when not to wear one (USA Triathlon leaves it to the athletes’ discretion whether to wear it or not, but makes it clear that if a wetsuit is worn, the athlete is not eligible for medal placement.
when water temperature is above minimum recommendation), and most importantly, when to cancel the swimming leg altogether.

Table 1. USAT Wetsuit Use Temperature Rules

<table>
<thead>
<tr>
<th>Distance in Meters</th>
<th>Temperature F</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 750 m</td>
<td>&lt; 50 50 - 54 55 -78 79 - 83 84 - 89 90 - 93 &gt;93</td>
</tr>
<tr>
<td>750 - 150 m</td>
<td>&lt; 51 51 - 55 56 - 78 79 - 83 84 - 87 88 - 90 &gt;90</td>
</tr>
<tr>
<td>&gt; 1500 m</td>
<td>&lt; 52 52 - 56 57 - 78 79 - 83 84 - 86 86 - 88 &gt;88</td>
</tr>
</tbody>
</table>

USAT Wetsuit Rules

<table>
<thead>
<tr>
<th>Cancel</th>
<th>Required</th>
<th>Allowed</th>
<th>No Awards</th>
<th>Not Allowed</th>
<th>Not Allowed</th>
<th>Cancel</th>
</tr>
</thead>
</table>

The Cancel rule requires the cancellation of the race. Required rule is for all athletes to use wetsuit; Allowed is optional wear; No Awards is left up to the athletes, but if wetsuit is worn, it will count towards award; Not allowed is no one can wear wetsuit. Source: http://www.athletesheart.org/wp-content/uploads/2013/11/TempGuidelines.png

The black temperatures per length of the race, indicates the water temperature is either too cold or too hot to allow the event to take place. The low range is dangerous because it increases the risk of hypothermia or the inability to keep the body’s core temperature high enough to avoid shock and potential death. On the other end of the spectrum, the high end includes the risk of overheating or hyperthermia, when the body temperature keeps rising and which can also lead to death. The horizontal lines range, the low end represents where the use of wetsuit is required for protection, where on the high end it is prohibited, in order to protect the athletes from overheating. In either instance, it is still safe for the event to take place. In the vertical lines range, in the low end, as described, the use of wetsuit is allowed. In the “No Award” middle range, it is allowed but swimmers are not eligible for awards as wetsuit use is mostly for the buoyance benefits. In the Banned upper range of the green, the use is banned to avoid any possible risk of hyperthermia.
There are different governing bodies for open water events, and each have studied the issues and developed their own guidelines for use in recent years. Below is a list of some of the most important organizations.

USA Swimming 2013 Rulebook states, in short, that water temperature shall not be less than 16º C (60.8º F); in races >5K, the water must not exceed 29.45º C (85º F); and the total air and water temperatures shall not be less than 30º C (118º F) nor greater than 63º C (177.4º F).

The “Fédération Internationale de Natation” (FINA), was founded by eight national federations: Belgium, Denmark, Finland, France, Germany, Great Britain, Hungary and Sweden, during the 1908 Olympic Games in London. It has evolved into a federation with 207 national members and spans five continents. One of its principal objectives is to adopt necessary uniform rules and regulations for open-water swimming events in 5k, 10k, and 25k races. In its Open Water Rules book, article 5.5 it states:

“OWS 5.5 The water temperature should be a minimum of 16º C and a maximum of 31º C. It should be checked the day of the race, 2 hours before the start, in the middle of the course at a depth of 40 cm. This control should be done in the presence of a Commission made up of the following persons present: a Referee, a member of the Organising Committee and one coach from the teams present designated during the Technical Meeting.

OWS 5.5.1 The Safety Officer shall monitor temperature conditions periodically during the race.”

The International Triathlon Union, ITU prohibits the use of wetsuits in water temperatures above 22º C - 24º C and makes it mandatory when it is below 14º C – 16º C, on
race distances between 1500 m up to 4000 m, and swim distance may be shortened or even cancelled if the temperature drops below 14º C and cancelled below 13º C.

The World Triathlon Corporation (WTC), the owner of Ironman-branded events, adopted a 52º F to 88º F safety temperature range. If the temperature is outside this range, the swim event may be shortened or even cancelled. The use of a wetsuit is permitted in water temperatures up to 76.1º F (24.5º C) and prohibited if greater than 83.8º F (28.8º C). In addition, the wetsuit must not exceed 5mm in thickness and be non-rubber or neoprene material.

Tipton, & Bradford (2014) published a literature review of on cold and warm open-water swimming as part of their examination of exercise in extreme environments. They pointed out that how the body responds, in either hot or cold environment, is a continuous field of study. The understanding of how the body responds to exercise in extreme environments is far from complete, and the mechanisms involved are far too many to draw a simplified conclusion on the different body and psychological responses experienced by individual swimmers. The authors further offer a list of recommendations that although described as “weak/hypothetical,” provide a baseline of measurements to be considered when an athlete participates in an open water swimming event. Nevertheless, it is important to recognize that it is highly common for a triathlete to wear a wetsuit during events in part to maintain core body temperature during swim.

Performance

Wetsuits are not only used for thermoregulation. The material used to manufacture them helps swimmers in open water events by providing a buoyancy force in the water. This added force allows for a more streamlined body alignment and, therefore, an easier swim.

Cordain and Kopriva (1991) investigated wetsuit influence on swim performance. The objective of the study was to determine the influence of body composition upon swimming
performance with and without wetsuits. They reported that the 400 m and 1500 m swim times were significantly faster by -4.96% and -3.23%, respectively, when swimmers wore a wetsuit compared with swimsuit trials while not wearing a wetsuit. They also reported that lean swimmers benefited more from the use of a wetsuit than swimmers with higher percentage of body fat. Cordain and Kopriva (1991) attribute the benefit to the buoyancy wetsuits provide to leaner swimmers, allowing them to direct the energy preserved towards propulsion as opposed to trying to keep the body’s optimum horizontal position.

Ulsamer et al. (2014) studied swimming performances in long distance open-water events with and without wetsuits. They discovered that wearing wetsuits or not wearing them had no effect on an ultra-long distance open water race of 26.4 km. However, in the 3.8 km distance used in the full Ironman, when the top 10 male and female times were compared in a regression analysis and ANOVA, the top 10 males wearing wetsuits (51.7 ± 2.5 min), were faster (13.2%, p < 0.01), than the top 10 females wearing wetsuits (58.5 ± 3.2 min). The top 10 males not wearing wetsuits (52.1 ± 2.4 min) were also faster (19.6%, p < 0.01) than the top 10 females not wearing wetsuits (62.3 ± 2.5 min). They noticed that the top 10 females wearing wetsuits (58.5 ± 3.2 min) were faster (6.5%, p < 0.01) than females not wearing wetsuits (62.3 ± 25 min), and, therefore benefited more from the use of wetsuits in long open water long-distance swimming than the males. Ulsamer et. al. study reports agree with Cordain and Kopriva’s report which indicated that leaner swimmers gain greater benefit from using wetsuit over higher body fat swimmers.

Dryland swimming exercises have also been an area of interest for researchers. The focus of such studies, however, has been to examine shoulder muscles activity and the potential transfer of benefits swimmers could experience from dryland training into the water environment using time trials at race speed with a control group having access to traditional water training and
an experiment group having the added dryland practice along with the water training (Hogg, J.M., 1972, Glenn, G., 1977 & Hessburg, F.C. 1972-73).

Wetsuit Effect

Among the growing concern of sudden cardiac deaths (SCD) during the swimming leg of triathlons, some studies are starting to emerge exploring the potential risk factors that could be contributing to SCD cases. Physiologically, a small wetsuit seemed to have an effect on physiological parameters. Prado et al. (2014) investigated the influence of wearing a wetsuit on heart rate, blood pressure, and heart rate variability. Although the heart rate was not significantly affected, blood pressure and heart rate variability were different between no wetsuit compared to wearing a small wetsuit, and a large wetsuit compared to a small wetsuit. A limitation of this work is that measurements were taken in a resting state. The subjects were in a prone position, which simulated the swimmers’ body position; it did not involve any physical activity.

Challenges of Electromyography

The purpose of electromyography (EMG) in previous studies was to find out if a swimmer’s ability to mimic strengthening and conditioning on dryland could transfer and benefit swimmers in the water. Time trials were used to compare whether or not competition speeds were improved by strengthening and conditioning dryland training.

The fine wire EMG used to compare dryland and water muscle activity in Nuber et al. (1986), stated that when the maximal voluntary isometric contraction (MVIC) baseline used to compare dryland to water EMG signals, the water condition made it difficult, causing signal loss and noise. In their study, the objective was to use MVIC of each studied muscle: biceps,
pectoralis major, supraspinatus, subscapularis, infraspinatus, middle deltoid, serratus anterior, lower trapezius, and latissimus dorsi. The authors described the supraspinatus, infraspinatus, and middle deltoid primarily as recovery phase muscles. Another muscle worth pointing out during recovery is the serratus anterior. Although its activity in water was irregular, the serratus anterior was active during the whole recovery phase and was mostly active in its early and late part of the recovery. When compared to dryland exercise, the serratus anterior had the peak activity also at hand entry at the early pull-through phase of swimming. This indicates how important this muscle is in the scapular rotation when arm is fully abducted.

There is limited use of surface EMG to measure muscle activity during swimming due to the challenge of waterproofing the sensors. Another approach was used in the present study; it was surface EMG during simulated swimming on dryland. This approach allowed us to investigate the muscle activity of more superficial swimming muscle groups, Trapezius, Anterior and Posterior Deltoids, and Triceps, during simulated dryland swimming on an ergometer trainer.

Anecdotal Debates

Anecdotally, a main topic in triathlon forums and discussion groups has been: Should a swimmer wear a wetsuit during a triathlon even if the water temperature does not require it? If so, what size and type? The wetsuits come in three main different types: full suit with leg and arm coverage, Farmer John/Jane wetsuits (sleeveless and mid-calf coverage) (Figure 3), and “short john” wetsuits as the name suggests short (mid-thigh and sleeveless) (Figure 4).
The most frequently used and most recommended type of wetsuit in extreme water temperature is the full suit for total temperature protection. However, in most events where the water temperature is not as cold and the wetsuit is optional, full sleeves and leg wetsuits are still the preferred type due to the buoyance benefit (https://www.onetri.com/Triathlon-Wetsuit-
Although the choice is mostly personal and financial, as high-end wetsuits with high technological designs and material can be in the hundreds of dollars, the biggest concern is the constriction effect of a long sleeve wetsuit. That is, it may be that having sleeves on the arms could provide resistance to move the arms and therefore require more muscle activity vs. a wetsuit with no arms (i.e., farmer-john style or sleeveless).

As for sizing, certain manufacturers offer size charts based on height and weight to help athletes choose on their personal preference. Anecdotally, it is common to read that if a wetsuit does not feel too tight, then it is too big. However, there are no empirical data on the influence of wetsuit size on physiological or biomechanical parameters. It would be helpful to know if wetsuit size influences shoulder muscle activity. Nesser, et al. (2015) reported that shoulder range of motion pattern and muscle activity is indeed affected by the use of a long-sleeve wetsuit when compared to a traditional swimsuit on simulated surfing paddling. However, there is not a published study reporting shoulder muscle activity differences on swimming using long-sleeve wetsuit and no wetsuit, in-water or simulated swimming.

**Stroke Rate**

Stroke rate is defined as the time it takes a swimmer to complete two arm cycles, right and left, from the start of one arm to the finish of the opposite arm. The optima stroke is referred to as the “sweet spot” of 60 strokes per minute (swimsMOOTH.com). At this rate, it is believed that the swimmer is capable of optimized stroke cycles per minutes and distance coverage to achieve the best time possible for the distance swam. In the McLean et al. (2010) study, the authors noticed the VO2, HR, and RPE suffered a significant increase whenever stroke rate dropped but
were not affected when the stroke rate increased. McLean’s study, based on RPE, reported that swimmers chose to keep the slowest stroke rate such that VO2 was not increased.

Upper Extremity Muscles

Anterior Deltoid’s function is adduction of shoulder joint, performed chiefly by the middle fibers with stabilization by the anterior fibers. In addition, the posterior fibers extend and laterally rotate. These functions show higher muscle activity as part of the front crawl’s late pull-through phase through early to mid-recovery phase, and mild activity all the way to hand water entry (Pink et al., 1991).

Posterior Deltoid’s function, with the origin fixed, is stabilization of the adduction of the scapula and rotation of the scapula so the glenoid cavity faces cranially. In addition, the descending fibers elevate the scapula. In the front crawl, the posterior deltoid action has a higher muscle activity at mid to end of the pull-through phase, and mild activity through early to beginning of late recovery phase (Pink et al., 1991)

Trapezius’ function includes shoulder retraction (adduction) and elevation (upward rotation) of the scapula. These functions are part of the front crawl’s late pull-through to beginning of early recovery phase (Pink et a., 1991)

Triceps’ function is extension of the elbow joint and the long head is also responsible for shoulder adduction and assistance in shoulder extension. In the front crawl that is the final phase of the pull through and very beginning of the recovery phase.
Conclusion

The benefits of wearing wetsuit in open water swimming events have helped athletes endure extreme water temperatures as well as providing better body streamline during long distance events. The data available on wetsuit benefits indicate that its use is, in extreme water temperature, a necessity. However, there is a need of empirical data on wetsuit effect on biomechanics. The investigation of upper extremity muscle activity while wearing wetsuits can enable manufacturers and athletes alike to build and choose wetsuit models and sizes that will better fit their needs, provide protection and improve performance outcome.
Chapter 3

Methods

Subject Characteristics

Subjects (n=10 males; height 179.07±13.18cm; mass: 91.20±7.25 kg; age: 45.6±10.52 years) gave written informed consent to participate in the study. In order to be included in the study subjects had to fit in at least one of the wetsuit sizes as per manufacturer recommendations. Subjects also had to have swum in a wetsuit and be familiar with the front crawl swimming stroke, but not be necessarily seasoned swimmers. The subjects’ level of swimming expertise varied from novice to elite. In additional, subjects were free of any medical conditions that could be aggravated by exercise, and free of any acute or chronic shoulder injury.

Instrumentation

Wetsuit

Four sizes of the same model of wetsuit were used in this study (HUUB Design Limited, size-SMT, M, MT, ML, Aerious model 4 mm:4 mm thickness, Derby, UK). The manufacturer recommended weight and height that correspond to each size presented in Table 2. Wetsuit sizes were selected using the chart below, with subjects fitted with the smallest wetsuits within the size recommendation chosen.
Table 2. HUUB wetsuit size recommendation base on height and weight ranges. SMT: small medium tall, M: medium, MT: medium tall, ML: medium- large.

<table>
<thead>
<tr>
<th>Size</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMT</td>
<td>5’8” – 6’0”</td>
<td>160-179 lbs.</td>
</tr>
<tr>
<td>M</td>
<td>5’7” – 6’1”</td>
<td>159-187 lbs.</td>
</tr>
<tr>
<td>MT</td>
<td>5’11” – 6’3”</td>
<td>161-190 lbs.</td>
</tr>
<tr>
<td>ML</td>
<td>5’10”-6’4”</td>
<td>177-198 lbs.</td>
</tr>
</tbody>
</table>

Heart Rate
Heart rate was recorded using Polar Heart Rate Monitor F4 model. The main purpose was to track rest period in between conditions.

Electromyography
An 8-channel telemetry EMG system (Noraxon) was used to collect muscle activity of 4 different muscles on the right arm. An Electrogoniometer (Elgon) was attached to the right elbow joint to track arm flexion and extension.

Simulated Dryland Swimming
The VASA Inc., Essex Junction, VT bench was used to simulate the prone position dryland front crawl swimming (Figure 5).
Figure 5. The VASA Ergometer Trainer is equipped with a digital metronome that helps keep stroke rate and a resistance vent (at the base of the cable box on the left of the picture) that allows to regulate the amount of air been pulled at every stroke. The wider the opening the greater is the resistance, therefore slowing the stroke rate.

**Procedures**

Subjects completed two conditions: simulated dryland swim activity with No Wetsuit (NW), and with wetsuit (SW). The NW served as the control condition. For each condition, stroke rate was controlled using a metronome. Subjects were instructed to maintain a rate of 60 strokes per minute. This stroke rate represents a typical rate that most swimmers should be able to maintain. ([http://triathlon.competitor.com/2015/08/training/what-is-the-ideal-stroke-rate_120831](http://triathlon.competitor.com/2015/08/training/what-is-the-ideal-stroke-rate_120831)).

All simulated dryland swim activities were performed in the prone position while on a swim ergometer (VASA Inc., Essex Junction). Each condition lasted 90 seconds. Subjects were queued to mimic swim technique that they would use while in the water. Subjects were introduced to the stroke rate using the metronome. Subjects were allowed to practice it so the
Resistance vent opening could be adjusted to match metronome stroke rate tempo. Resistance setting was consistent between conditions.

After practicing and being comfortable using the swim ergometer, the locations for the EMG leads were prepared by shaving, abrading and cleaning the sites where the EMG leads were placed.

EMG leads were placed on the right-side on the surface of the skin of the following muscles: Anterior Deltoid (AD), Posterior Deltoid (PD), Trapezius (TRAP), Triceps Brachii (TRI). An Elgon was placed ON the elbow joint to track elbow flexion on both phases of recovery and pulling.

Placement of the EMG leads followed the SENIAM guidelines (http://seniam.org/sensor_location.htm).

The EMG lead for the Anterior Deltoid was placed at about 2cm width distal and anterior to the acromion, in the direction of the line between the acromion and the thumb (Figure 6).

Figure 6. Anterior Deltoid Electromyography placement
The Posterior Deltoid lead was placed about 3.5cm behind the angle of the acromion. Its orientation was in the direction of the line between the acromion and the little finger (Figure 7).

Figure 7. Posterior Deltoid EMG Placement

The Descending Trapezius (upper) lead was placed at 50% on the line from the acromion to the spine on vertebra C7. Its orientation will be in the direction of the line between the acromion and the spine on vertebra C7 (Figure 8).

Figure 8. Descending Trapezius EMG Placement
The Triceps Brachii (long head) lead was placed at 50% on the line between the posterior crista of the acromion and the olecranon at 2 finger widths medial to the line. Its orientation was in the direction of the line between the posterior crista of the acromion and the olecranon (Figure 9).

Figure 9. Triceps Brachii EMG Placement

After instrumentation, subjects were asked to perform and maintain maximal voluntary isometric contraction (MVIC) against maximal scapula elevation load for the trapezius, and shoulder press for remaining muscles (anterior, posterior deltoids and triceps Brachii), for 5 second duration. EMG data recorded during conditions were normalized to the greatest 1-second average from the MVIC per muscle.

Subjects performed the following:

No wetsuit (NWS) - the subjects performed the front crawl in prone position on the VASA trainer for a 90-second bout while maintaining a 60 stroke per minute rate with the
assistance of the metronome. Data collection was during the last 60 seconds of the 90-second bout. Subjects rested for 3 to 5 minutes or until the heart rate was within 20 beats from resting heart rate.

Wetsuit (WS) - the subjects performed the front crawl in prone position on the VASA trainer for a 90-second bout while maintaining a 60 stroke per minute rate with the assistance of the metronome. Data collection was during the last 60 seconds of the 90-second bout. Subjects rested for 3 to 5 minutes or till the heart rate was within 20 beats from resting heart rate.

Condition order was set such the control condition NW was first and WS second. This was done to minimize the chance of EMG leads failure due to increased body temperature caused by the use of the wetsuit at room temperature and therefore skin moisture and perspiration, and/or accidentally pulling a lead off during wetsuit removal.

Data Reduction

EMG data were processed by first removing any zero offset and then full-wave rectifying data. Average (AVG) and Root Mean Square (RMS) EMG was calculated over 45 seconds

Statistical analysis

The dependent variables were the AVG and RMS EMG of each muscle (8 total dependent variables). The independent variable was the condition (NWS, WS). A paired t-test was used to test each dependent variable between conditions. Significance was set at $\alpha = 0.05$. 
Chapter 4

Results

Group means and standard deviations for each variable are presented in table AVG EMG and RMS EMG for each muscle, each condition are presented in Table 3 and illustrated in Figures 10 and 11.

Stroke rate was not different between conditions (t = -1.2459, p = 0.243). Average EMG for PD (t = -3.491, p = 0.013) and AD (t = -3.066, p = 0.007) were each different during NW vs. WS. Neither TRAP nor TRI AVG EMG were different between conditions (t = -0.079, p = 0.939) and (t = -0.885, p = 0.399) respectively.

The RMS EMG for AD (t = -3.418, p = 0.008) and PD (t = -2.940, p = 0.016) were each different between conditions. Neither TRAP (t = -0.239, p = 0.817) nor TRI (t = 0.587, p = 0.572) were different between conditions.

Table 3. Means and standard deviation per condition. Stroke Rate (SR), Average EMG (AVG EMG) and Root Mean Square EMG (RMS EMG) for Trapezius (TRAP), Anterior Deltoid (AD), Posterior Deltoid (PD), and Triceps (TRI). EMG data are presented as normalized to Maximal Voluntary Isometric Contraction (MVIC). The p-value (p=0.05) for each comparison is included.

<table>
<thead>
<tr>
<th>SR (Hz)</th>
<th>No Wetsuit</th>
<th>Wetsuit</th>
<th>Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.93 ±0.15</td>
<td>1.97±0.19</td>
<td>p=0.243</td>
<td></td>
</tr>
<tr>
<td>AVG EMG (%MVIC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRAP</td>
<td>58.22 ±45.08</td>
<td>59.49 ±35.28</td>
<td>p=0.939</td>
</tr>
<tr>
<td>AD</td>
<td>20.87 ±13.08</td>
<td>34.80 ±10.73</td>
<td>p=0.007</td>
</tr>
<tr>
<td>PD</td>
<td>55.59 ±29.01</td>
<td>77.82 ±27.40</td>
<td>p=0.013</td>
</tr>
<tr>
<td>TRI</td>
<td>46.39 ±18.28</td>
<td>50.74 ±21.26</td>
<td>p=0.399</td>
</tr>
<tr>
<td>RMS EMG (%MVIC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRAP</td>
<td>90.83 ±64.63</td>
<td>96.69 ±59.46</td>
<td>p=0.817</td>
</tr>
<tr>
<td>AD</td>
<td>39.88 ±24.18</td>
<td>65.69 ±22.16</td>
<td>p=0.008</td>
</tr>
<tr>
<td>PD</td>
<td>85.52 ±42.35</td>
<td>120.48 ±39.57</td>
<td>p=0.016</td>
</tr>
<tr>
<td>TRI</td>
<td>82.21 ±27.80</td>
<td>88.30 ±37.22</td>
<td>p=0.572</td>
</tr>
</tbody>
</table>
Figure 10. Illustration of electromyography (EMG) for each muscle and condition.

Mean EMG and standard deviation for Trapezius (TRAP), Anterior Deltoid (AD), Posterior Deltoid (PD), and Triceps (TRI) muscles for both conditions no wetsuit (NWS) and Wetsuit (WS). Note: * denotes significance between conditions (p < 0.05).

Figure 11. Illustration of mean root mean square (RMS) and Standard Deviation.
Mean RMS and standard deviations for Trapezius (TRAP), Anterior Deltoid (AD), Posterior Deltoid (PD), and Triceps (TRI) muscles for both conditions no wetsuit (NWS) and Wetsuit (WS). Note: * denotes significance between conditions (p=0.05).
Chapter 5

Discussion

The most important observation of this study was that muscle activity of the PD and AD were each greater while wearing a wetsuit vs. not wearing a wetsuit when simulating swimming on dryland at equivalent stroke rates. The null hypothesis that a wetsuit does not have any effect on shoulder muscle activity during simulated dryland swimming was refuted for the PD and AD. In contrast, there was no influence of wearing a wetsuit on the muscle activity of the TRAP and TRI muscles. Therefore, the null hypothesis for these muscles was retained.

The observation of greater muscle activity of the PD and AD during simulated swimming while wearing a wetsuit compared to not wearing a wetsuit is similar to what was observed by Nessler, et al. (2015). Although in that study, the muscle investigated was the middle deltoid and the exercise was simulated surf paddling with and without wetsuit. Even though a wetsuit designed for surfing is different than a triathlon wetsuit, Nessler et al. (2015) also reported greater middle deltoid muscle activity while wearing the wetsuit. Although the middle deltoid was not studied in the present study, both Nessler et al. (2015) and the present study are consistent in that wearing a wetsuit influences shoulder muscle activity.

These observations are reasonable given the function of the deltoid muscle as a whole during swimming. Pink et al. (1991) studied 12 muscles of the front crawl stroke in order to better understand muscle activity during each phase of the stroke. Predominately, the anterior, medial and posterior deltoids are recovery phase muscles with muscle activity peaking during late pulling phase to early recovery for PD, as well as a mild activity through mid-recovery for AD. The present study did not control for stroke pattern. However, based upon the observations reported by Pink et al. (1991), it is hypothesized that the difference in the muscle activity of the
PD and AD during simulated dryland swimming in a wetsuit was mostly during late pulling through late recovery. Additionally, this study also controlled for stroke rate, and the wetsuit intervention, like Nessler et al. (2015), did not have any effect on stroke rate.

It is not clear if the increased muscle activity while wearing a wetsuit influences swim performance. Hawley et al. (1992), indicated the importance of arm power during swim distances longer than 400 m. The relationship of predicting front crawl swimming speed based on arm power production, was established based on the peak sustained workload and a 400-m swim comparison. Additionally, Hawley et al. (1992) noted that triathletes tend to use more upper body propulsion vs. nonelite swimmers who are using upper body and leg propulsion more evenly. Given the importance of upper body power generation and that triathlons swim segments are typically 750 m and longer, a greater muscle activity of the PD and AD may be an indication that swim performance could be negatively influenced. However, swim performance was not measured in the present study and future research is needed to determine if an increased muscle activity can influence swim performance.

It is important to recognize that a main limitation of this research is that all measurements were taken while simulating swimming vs. swimming in the water. Future instruments should be developed to allow the measurement of surface EMG during swimming in the water. This study is also limited in that only one brand of wetsuit (and one model) was tested. It may be that some wetsuit brands or models allow for less restricted shoulder movement. Future studies should explore other brands/models in order to develop wetsuit fit criteria based upon empirical data. Furthermore, only one intensity of exercise was tested at a controlled cadence. It would be helpful in future studies to repeat the experiment at different intensities, resistance setting, and cadences.
In addition, future simulated dryland swimming while wearing wetsuit studies may need to explore the influence of room temperature. In the current study, the room temperature was set at 72°F (22°C). Although exercise time was brief, wearing a wetsuit on land during simulated swimming could potentially influence core temperature. Anecdotally, subjects did often comment that they felt hot while wearing the wetsuit.

Equally important in future studies would be to include female subjects. This study chose to examine only male subjects due to the majority of SCD cases reported being male athletes. However, understanding the influence of wetsuit design on muscle activity as well as swim performance for females is important.

In this study, the stroke rate was controlled for both conditions. However, stroke pattern as tracked by elbow flexion via Electrogoniometer, did seem to demonstrate changes in arm pattern between conditions. Qualitatively, a lower and wider arm recovery was noted when subjects completed the wetsuit condition. Therefore, it is not clear if muscle activity was different because of the change in arm movement or if it was due to the wetsuit providing greater resistance to shoulder movement. For example, the wetsuit design might be creating greater resistance limiting elbow flexion and/or shoulder circumduction. Future studies should also add kinetic and kinematic analysis to track changes in both sagittal and frontal planes during the recovery phase of the stroke. These added modalities may help explain the possible changes in the stroke pattern more specifically, and the increased in muscle activity.

Practical Application

These findings may be useful to an athlete when making a wetsuit choice. For example, the athlete needs to consider the benefits of added buoyancy and better thermoregulation.
provided by a full sleeve wetsuit vs. sleeves vs. the risk of greater muscle activity. Furthermore, the athlete should likely discount anecdotal advice such as “if the wetsuit is not tight, it is too loose.” Instead, athletes should consider their choices of wetsuit brands and models. Although there are currently no empirical data on the risk vs. benefit of how tight a wetsuit is on muscle activity and/or swim performance and thermoregulation characteristics, it does make sense that the athlete finds a brand or model of the wetsuit that allows comfortable upper body movements. The athlete should also be aware of the influence of his/her body composition and swim ability may be factors that influence wetsuit brand/model selected.

These findings may also be useful for coaches. For example, if a coach, has a client who has a noticeable shoulder weakness and is aiming to participate on an open water race where the use of wetsuit is required, the coach would likely want to include a comprehensive shoulder muscle strengthening and endurance program. For example, if an athlete has an injury to the deltoid muscle, the coach should consider carefully how to integrate wetsuit use for that athlete. It may be important for coaches to recommend sleeveless wetsuit in situations where water temperature is appropriate.

Conclusion

This study yielded two important outcomes. First, the wetsuit effect was significant on the upper extremity muscle activity of the PD and the AD muscles. Secondly, the wetsuit had no effect on the upper extremity muscle activity of the TRAP or the TRI while simulating swimming at a controlled stroke rate. As a practical application, it would seem that a wetsuit should be selected that minimizes restrictions to shoulder movements. This could be related to wetsuit size, design, fit, and/or materials used. Manufacturers frequently use a more flexible
material on high end wetsuits. However, future research is needed to determine if swim performance is negatively influenced due to increased muscle activity while wearing a full sleeved wetsuit.
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