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Shoulder Muscle Activity While Swimming in Different Wetsuits and Across Different Paces

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ABSTRACT

International Journal of Exercise Science 16(1): 172-181, 2023. A triathlon wetsuit is an important piece of equipment during the swim portion of the triathlon for the benefits of thermoregulation and additional buoyancy. However, a lack of knowledge exists about whether or not shoulder muscle activity is influenced by wearing a wetsuit. The purpose of this study was to determine if there were changes in shoulder muscle activity during front crawl with four different wetsuit conditions: Full sleeve (FSW), Sleeveless (SLW), Buoyancy shorts (BS), No wetsuit (NWS) in three different subjective swimming paces (slow, medium, and fast). Eight subjects (5 males, 3 females: mean ± SD, age = 39.1 ± 12.5 years; height = 1.8 ± 0.1 m; mass = 74.6 ± 12.9 kg; percent body fat = 19.0 ± 7.8%) completed twelve total swim conditions (4 wetsuits x 3 swimming pace) in a 25-m indoor pool. Muscle activity in anterior deltoid (AD) and posterior deltoid (PD) were measured using a wireless waterproofed electromyography (EMG) system. Stroke rate (SR) was calculated using the time to complete five-stroke cycles. The AD, PD EMG, and SR were compared using ANOVA with repeated measures. None of the dependent variables showed the interaction between wetsuit conditions and swimming paces ($p > 0.05$). Both AD and PD muscle activity as well as SR were influenced by swimming pace ($p < 0.05$) but not wetsuit conditions ($p > 0.05$). In conclusion, shoulder muscle activity and SR were not influenced by types of wetsuits but influenced by swimming pace.

KEY WORDS: Triathlon wetsuit, front crawl, electromyograph (EMG)

INTRODUCTION

A triathlon wetsuit is a piece of vital equipment during training and race in open water (13, 21). Two popular wetsuit models are 'full sleeve' and 'sleeveless' (1). Triathletes can also select buoyancy shorts during pool swim practice and even race events because they are made of the same material (i.e., neoprene) and thickness as the wetsuits. When wetsuits are allowed for a triathlon, triathletes can choose different wetsuit styles based on their preferences and/or environmental conditions. Triathletes can expect potential performance benefits when wearing a wetsuit (5, 6). Specifically, previous studies have demonstrated that swimming velocity increased by approximately 3 ~ 10% with a concurrent increase in either stroke rate or stroke length while swimming with a wetsuit compared to a regular swimsuit (6, 20, 21). Additionally, less energy cost is needed to cover a given distance while swimming with a wetsuit vs. a regular swimsuit (5, 17, 21, 24). Inexperienced swimmers tend to have a greater performance benefit than experienced swimmers (21) and wearing a wetsuit seems to help mitigate the anxiety of open water swimming (19, 24). The reduction of physiological demands and changes in stroke patterns when wearing a wetsuit are generally attributed to the reduced resistive drag and increased hydrodynamic lift force vs. not wearing a wetsuit (22, 23).

Swimming performance is determined by a combination of generating propulsive force effectively and reducing resistive drag force (22, 23). The majority of propulsive forces are generated from the upper body movement during the front crawl (6, 14). Muscle groups that generate the propulsive forces during swimming include the pectoralis major, latissimus dorsi, and deltoid muscles (i.e., anterior, middle, and posterior) (18). Thus, it makes sense to investigate upper body muscle activity to understand factors better that influence swim performance (9, 10, 14).

Despite the research conducted to date regarding the biomechanics of swimming, it is not clear if shoulder muscle activity while swimming in water is influenced by different types of wetsuits. To date, there is no empirical evidence regarding shoulder muscle activity during swimming with different styles of wetsuits. However, there is some evidence that the wetsuit may influence shoulder muscle activity since it has been reported that both anterior deltoid (AD) and posterior deltoid (PD) muscle activity increased by 66.8% and 40%, respectively, during dry-land swimming while wearing a wetsuit compared to a regular swimsuit when resistive power was controlled using a swim trainer (1). However, there is a gap in research on muscle activity while swimming in a wetsuit in the water (vs. dry land).

Therefore, the purpose of the study was to determine if shoulder muscle activity and stroke rate during front crawl were influenced by wearing a wetsuit. Specifically, AD and PD muscle activity were determined during swimming at three different subjective paces (i.e., slow, medium, and fast) with four wetsuit conditions: No wetsuit (NWS), Buoyancy shorts (BS), Sleeveless (SLW), and Full sleeve (FSW). We hypothesized that both AD and PD muscle activities would be affected by wetsuit conditions across swimming paces.

METHODS

Participants

Eight participants (five males and three females) volunteered for this study (age = 39.1 ± 12.5 years; height = 1.8 ± 0.1 m; mass = 74.6 ± 12.9 kg; percent body fat = 19.0 ± 7.8%). All participants were triathletes without any injuries. As part of the inclusion criteria, participants had to be able to swim a minimum of 3000 meters comfortably in a single workout load. Furthermore, they had experience swimming using a triathlon wetsuit in open water and pool settings. Participants provided written informed consent. The Institutional Review Board approved the research protocol by the host institution (ID# 1162924-8). Additionally, this research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (12).

Protocol

Participants visited the testing facility on a single day to complete four experimental sessions. The anthropometric data (i.e., height, weight, and body composition) was measured before the warm-up process. In addition, participants were provided the appropriate size of two types of wetsuits and buoyancy shorts. Four participants brought their own full-sleeve wetsuit, but they were also provided a sleeveless wetsuit and buoyancy shorts. Even though participants wore different brands of full-sleeve wetsuits, the wetsuit thickness was the same regardless of the wetsuit manufacturer and other wetsuit brands.

Participants performed a self-selected warm-up swim in a 25m indoor pool. The pool filtration system maintained water temperature at around 25 ~ 26.5°C. After the warm-up swim, EMG leads were placed on AD and PD muscles following the surface EMG for non-invasive assessment of muscles (SENIAM) guidelines (7). The right arm of all participants was used for instrument placement. The skin was prepared by first drying, shaving any visible hair, using a skin abrasion lotion, and then cleaning using alcohol wipes. The EMG transmitting sensors were connected to the electrodes and secured on the surface of the skin with double-sided tapes and adhesive patches.

All participants completed all four wetsuit conditions: no wetsuit (NWS), buoyancy short (BS), sleeveless (SLW), and full sleeve wetsuit (FSW). The order of wetsuit conditions was randomized order such that each order was unique.

For each wetsuit condition, participants swam at three subjective paces: slow, medium, and fast. The order of swimming paces was always slow, medium, and fast for each wetsuit condition. Each participant swam in total three lengths of the pool (75 m) for each wetsuit-pace combination. The time to complete each length (seconds) was recorded using a hand stopwatch to monitor and quantify swimming paces. Rest time was allotted between conditions as needed.

Participants were instructed to breathe only on the right side during the entire swimming session to minimize any possible influence of breathing patterns on muscle activity. All participants verbally reported they could comfortably breathe on either both sides or normally breath right side during their regular swim practice.

EMG was recorded during each swim length (25 m). After completing the three lengths for each wetsuit condition (i.e., three lengths for three paces for a total of nine lengths per wetsuit condition), participants exited the pool, and data were transmitted from the EMG sensor to the receiving unit.

Instrumentation: Body composition was measured using a bioelectrical impedance analysis device (570 Body Composition Analyzer, InBody USA, Cerritos, CA). In addition, muscle activity was measured (2000 Hz, 16-bits) for the AD and PD muscles using a telemetry electromyography (EMG) system (Mini-Wave, Cometa, Italy). This waterproofed EMG system allows the ability to record EMG data and 3-dimension acceleration data (ax, ay, az) of the transmitting sensor during swimming.

Data Reduction: Only the first length was used for data analysis. Since EMG leads were underneath the wetsuit material for two conditions, there was a high potential for movement artifact. EMG data were carefully inspected visually and any data set with obvious movement artifacts was removed from the analysis. This resulted in three data sets of AD and four data sets of PD being excluded from the analysis leaving an n=5 for the AD analysis and an n=4 for the PD analysis.

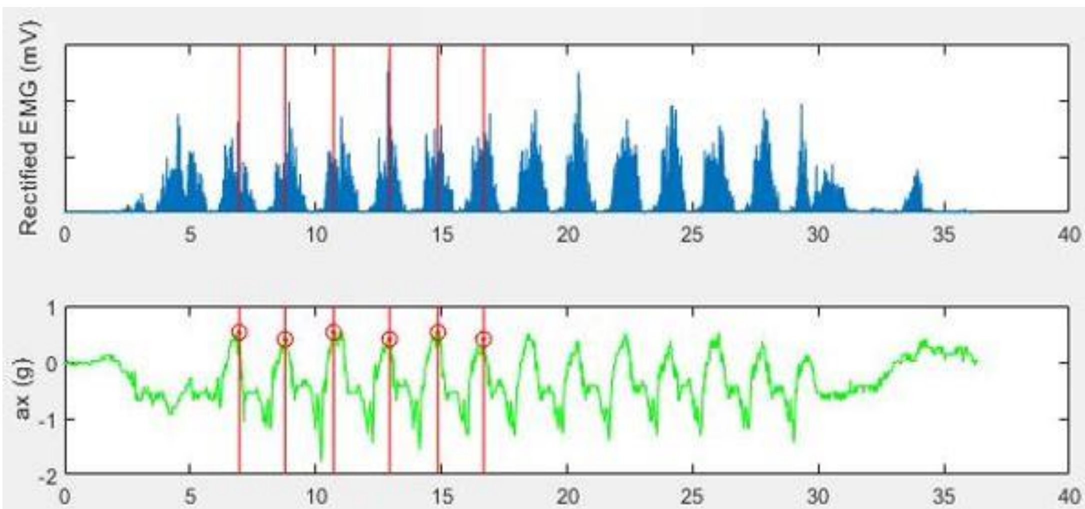

Figure 1. A sample data set from one subject illustrating rectified electromyography (EMG) data from the anterior deltoid (AD) muscle. Also illustrated are the acceleration (ax: g) data that was used to determine five stroke cycles.

The raw EMG data were processed by removing zero offsets and full-wave rectifying data. Five consecutive stroke cycles were then selected for further analysis based on the ax channel of the acceleration data of the AD transmitter. Specifically, local maximum values on the ax signal were used to identify the start/stop of a stroke cycle (Figure 1). The orientation of EMG transmitting sensors when attached to the right shoulder was set to align the x-axis vertically when standing in an anatomical position. Furthermore, the y and z axes were aligned with mediolateral and anteroposterior directions, respectively. After identifying the five cycles, EMG data for each muscle were then averaged.

Statistical Analysis

Statistical analyses were performed using SPSS 25 (IBM Corp, Armonk, NY). A 4 (wetsuit condition: NWS, BS, SLW, FSW) X 3 (pace: slow, medium, fast) repeated measures ANOVA was used for each dependent variable. Additionally, swim velocity (m/s) were calculated based on the time to complete 25m to determine whether or not the subjective swim paces (i.e., slow, medium, and fast) were different from each other using a 4 (wetsuit condition:) x 3 (swim velocity) repeated measure ANOVA. The alpha level was set as 0.05.

When Mauchly's Test of Sphericity was violated ($p < 0.05$), the F-ratio and p-value were adjusted by using the "Greenhouse-Geisser" correction instead of "Sphericity Assumed." Also, if there was a significant omnibus F-ratio for the interaction and main effect, post hoc analysis using pairwise comparison with a Bonferroni adjustment was performed to see which specific mean values differed. In addition, the effect sizes of different variables in the main effect were reported by the partial eta square (η_p^2). After data analysis, both AD and PD EMG data were normalized using the NWS condition at a slow pace as a 'base' condition for presentation purposes only.

RESULTS

Observed swimming velocity (m/s) was not influenced by the interaction between subjective pace (i.e., slow, medium, and fast) and wetsuit conditions ($p > 0.05$). Swimming velocity (m/s) was different between subjective pace conditions ($F_{1.113, 7.793} = 55.431$, $p = 0.0001$, $\eta_p^2 = 0.888$, Figure 2). Furthermore, swimming velocity (m/s) was influenced by the wetsuit condition ($F_{3, 21} = 22.196$, $p = 0.0001$, $\eta_p^2 = 0.760$).

According to the pairwise comparison, swimming velocity was different between subjective paces (slow-medium; $p = 0.00001$, slow-fast; $p = 0.00001$, medium-fast; $p = 0.004$). Additionally, swimming velocity in the NWS condition was significantly slower than in other wetsuit conditions regardless of pace (NWS - BS; $p = 0.006$, NWS -SLW; $p = 0.0002$, NWS - FSW; $p = 0.004$). Swimming velocity was also different between BS and SLW ($p = 0.03$). However, there was no difference in velocities between SLW and FSW ($p > 0.05$) and between BS and FSW ($p > 0.05$).

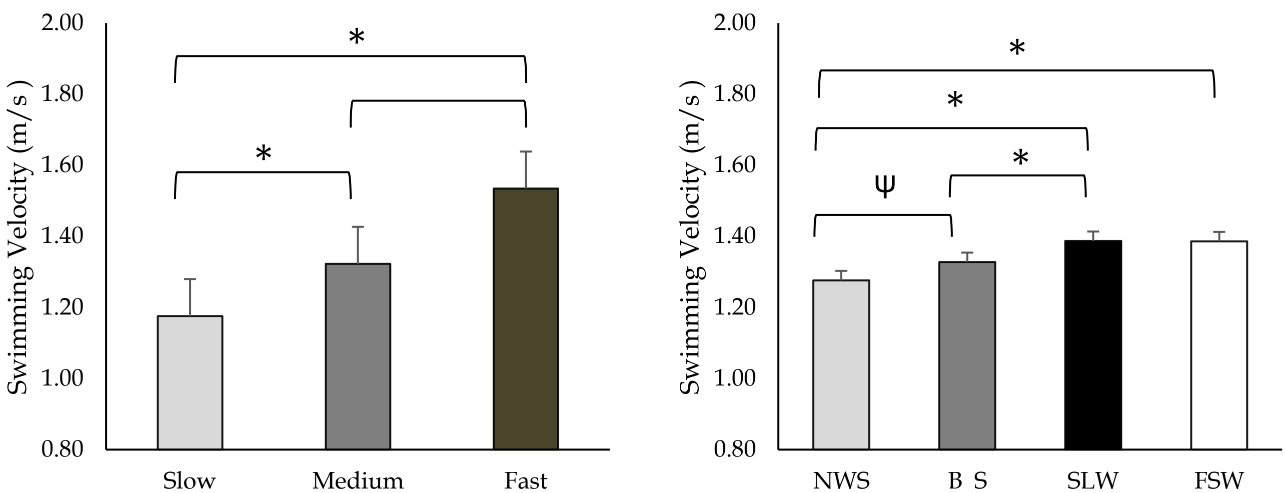

Figure 2. Swimming velocity and swimming pace by wetsuit conditions. Ψ denotes $p < 0.05$, * denotes $p < 0.01$.

AD and PD EMG were not influenced by the interaction between wetsuit condition and swim pace ($p > 0.05$). Both AD EMG ($p = 0.002$, $\eta_p^2 = 0.787$) and PD EMG ($p = 0.01$, $\eta_p^2 = 0.788$) were significantly influenced by swimming pace, but not by wetsuit condition ($p > 0.05$) (Figure 3).

SR was not influenced by the interaction between wetsuit condition and swimming pace ($p > 0.05$, Figure 4). However, SR was significantly influenced by swimming pace regardless of wetsuit condition ($p < 0.01$, $\eta_p^2 = 0.91$). Based on the post hoc test, SR differed between each pace condition (slow-medium; $p = 0.008$, medium-fast; $p = 0.001$, fast-slow, $p = 0.0003$). However, SR was not significantly influenced by wetsuit conditions ($p > 0.05$).

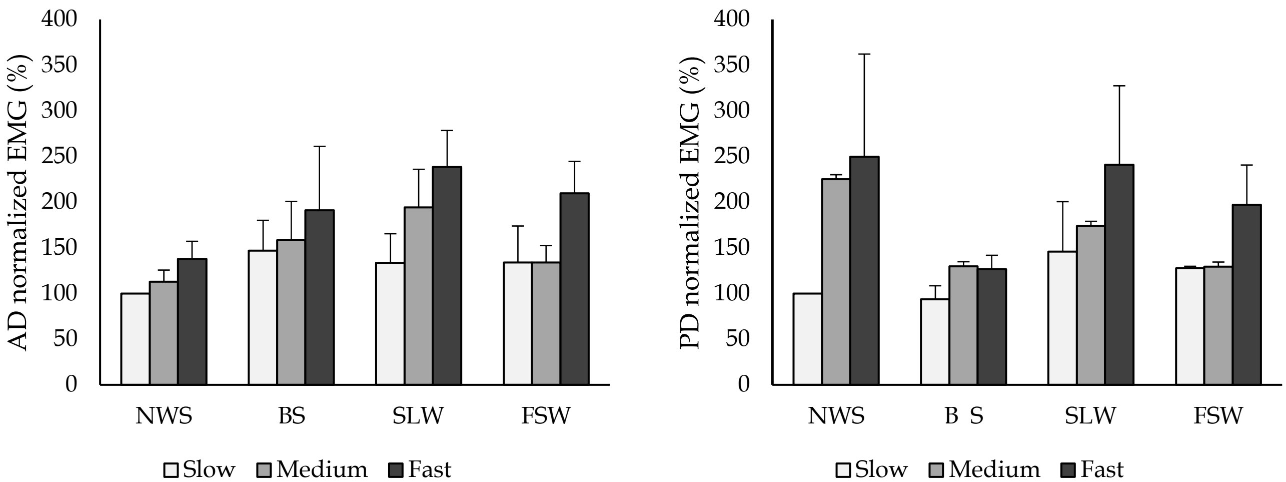

Figure 3. Illustration of normalized EMG data of both anterior deltoid (AD) and posterior deltoid (PD) for each wetsuit condition and swimming pace. EMG increased across swimming pace ($p < 0.05$).

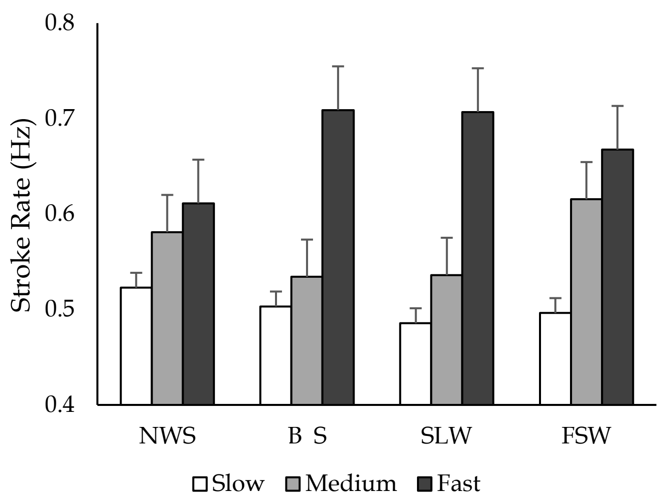

Figure 4. Illustration of stroke rate for each wetsuit condition and swimming pace.

DISCUSSION

The main observation of this study was that neither AD nor PD muscle activity was influenced by wearing a wetsuit. However, we did notice a large variability in how each subject responded to each wetsuit condition. That is, some participants appeared to have greater muscle activity in the FSW while other participants had a greater muscle activity in the SLW condition. In a group statistical design, we recognize that there is the potential to mask individual responses. Furthermore, we recognize that different swimming styles may interact differently with each wetsuit condition. Nevertheless, we believe that sharing the observations we have made is important to advance the research in the area of wetsuit development.

We did not observe any changes in SR during swimming in any of the wetsuit conditions, but SR did increase when participants increased their swim pace. Based on the results, AD and PD muscle activities increased as the swimming pace increased (Figure 3). Since the AD muscle is active in the early recovery phase of a swim stroke (18), participants may reduce the time in the recovery phase to achieve a faster pace with a concurrent increase in AD muscle activity. Furthermore, a previous study reported that participants activated more PD muscle during the pull phase to swim faster (18). Taken together, it seems that our observations of increasing SR with a concurrent increase in AD and PD muscle activities are similar to previous research (18).

A benefit of wetsuits or buoyancy shorts allows for achieving a lower coefficient of drag and reduced resistive drag (i.e., $F_{drag} = ½\rho C_d A v^2$) due to the smoothness of the material (22, 23). Resistive drag force is determined by the fluid density (ρ), coefficient of drag (C_d), frontal area (A), and the velocity of the fluid moving over the object (v) using the equation $½\rho C_d A v^2$. The smoothness and buoyance provided by the wetsuit materials can influence Cd and A. Therefore, wearing a wetsuit reduces resistive drag force, allowing for a more effective propulsive force from a biomechanics perspective. Previous research also observed an increased hydrostatic lift of approximately 39N when swimming with a wetsuit (3). Based on our laboratory pilot work, the average value of buoyancy force shows a somewhat similar value (i.e., 33.68 ± 1.63N) to the previous study.

In the present study, we were focused on deltoid muscle activity and we do not know if other muscles (e.g., latissimus dorsi, pectoralis major, rhomboids, upper trapezius, serratus anterior) were influenced by wetsuits and/or buoyancy short. Nevertheless, the importance of the present work is that we were able to determine the surface EMG of two key shoulder muscles (AD and PD). Future research is needed to analyze other muscle groups and EMG data during different phases of the stroke.

As expected, the swimming velocity during swimming without a wetsuit (i.e., NWS condition; 1.28 ± 0.17 m/s) was slower than in the velocity used for other wetsuit conditions. Specifically, in our experiment, NWS velocity was 3.8% slower on average than BS condition (1.33 ± 0.16 m/s) as well as 7.9% slower than SLW (1.39 ± 0.18 m/s) and FSW conditions (1.39 ± 0.21 m/s). Since SR did not change between wetsuit conditions and participants swam faster when wearing either a wetsuit or buoyancy shorts at each swim pace, participants took a longer stroke. These observations are consistent with previous research which swimming velocity was about 3 ~ 7% faster when wearing a wetsuit and this faster velocity was largely achieved by increasing the stroke length (4, 6, 15).

The importance of the experimental approach used in this study was that we controlled subjective rating of pace; slow, medium, and fast. Even though we confirmed participants swam at a different pace between slow, medium, and fast subjective paces, we recognized that the study results might differ if a different experimental model was used. For example, another approach would be to control velocity for each wetsuit condition. In that case, the subjective rating of pace for a matched velocity would be lower for the wetsuit conditions vs. the no wetsuit condition. Likewise, if heart rate or rate of oxygen consumption were controlled, it would be likely that the subjective rating and velocity measures would be different between conditions. Finally, another approach would be to control swim power between conditions – which has been done using a dry-land swim bench (18) but not in the water. Nevertheless, these alternative experimental designs should be completed to understand muscle activity better while swimming in triathlon wetsuits.

It is not known how shoulder muscle activity is related to physiological demands when swimming with different wetsuits. Observations of physiological demand (e.g., the rate of oxygen consumption) in conjunction with muscle activity data would give a deeper understanding of the influence of wetsuits on swim performance. That being said, it is not clear specifically how changes in shoulder muscle activity might influence triathlon swimming performance. It does seem reasonable to suspect that more shoulder muscle activity would indicate generating more propulsive force to propel forward motion for any wetsuit condition. Alternatively, it also seems reasonable that muscle activity was similar across wetsuit conditions since pace was determined subjectively.

Although we included both males and females in this study, we did not have sufficient numbers of subjects to determine if there is any sex influence on muscle activity. However, previous studies have demonstrated that the effect of a wetsuit may differ between male and female swimmers (13, 22, 25). For instance, male swimmers generally had a heavier body density than females due to height, limb lengths, and fat-free mass. Furthermore, previous studies demonstrated that female swimmers might get more performance benefits while swimming with a wetsuit for longer than 10km, an ultra-distance open water swimming (13). Therefore, further research may need to recruit an equal number of participants between males and females to see gender differences.

The issue of wetsuit fit cannot be underestimated in research such as this. This issue is evident by simply looking at the number of available sizes per wetsuit model per manufacturer. Manufacturers not only make small, medium, large, etc. sized wetsuits, but they also provide sizes such as medium-tall and/or medium-long. Anecdotally, athletes will try different wetsuit models and/or manufacturers and select one that is most qualitatively comfortable. The obvious factors that influence comfort would include anthropometrics (e.g., height, trunk length, leg length, chest/waist circumference, etc.) but the less obvious factors that might also influence comfort is swimming style. The style of arm recovery, amount of rotation, kicking effectiveness, and so forth could all play a role in which wetsuit model/manufacturer is most comfortable let alone which wetsuit would provide the best influence on swim performance. In our study, we fully recognize the limitation of using a group statistical design and realize that individual responses may be masked. Given this, we did qualitatively inspect individual responses and note that participants did have subtle variable EMG responses to swim paces and wetsuit conditions. This seems to suggest that swimmers used different strategies of coordination for different conditions. However, since pace was selected subjectively, it may be that the pace selected was done so to yield similar muscle activity. Nevertheless, we feel this work represents an important foundation of understanding muscle activity while swimming in different wetsuits (i.e., full sleeve, sleeveless, buoyancy shorts).

In conclusion, the current study investigated whether the type of wetsuit influenced shoulder muscle activity and stroke rate during front crawl stroke. On average, AD or PD muscle activity was not influenced by the type of wetsuit worn when swim pace was subjectively selected. Our experiment could not discern any potential influence of individual swim style for a given wetsuit condition on muscle activity. However, both AD and PD shoulder muscle activities and stroke rate were increased when participants swam faster regardless of wetsuit type. Taking together, it seems important that triathletes choose a wetsuit for the swim portion of the triathlon that is comfortable based on their body size and swim style.

REFERENCES

1. Agnelli C, Mercer JA. Muscle activity during dryland swimming while wearing a triathlon wetsuit. Int J Kinesiol Sport Sci 6(1): 7-11, 2018.

2. Barbosa TM, Bragada JA, Reis VM, Marinho DA, Carvalho C, Silva AJ. Energetics and biomechanics as determining factors of swimming performance: updating the state of the art. J Sci Med Sport 13(2): 262-9, 2010.

3. Chatard JC, Senegas X, Selles M, Dreanot P, Geyssant A. Wet suit effect: A comparison between competitive swimmers and triathletes. Med Sci Sports Exerc 27(4): 580-6, 1995.

4. Cordain L, Kopriva R. Wetsuits, body density, and swimming performance. Br J Sports Med 25(1): 31-3, 1991.

5. de Lucas RD, Balikian P, Neiva CM, Greco CC, Denadai BS. The effects of wet suits on physiological and biomechanical indices during swimming. J Sci Med Sport 3(1): 1-8, 2000.

6. Gay A, López-Contreras G, Fernandes RJ, Arellano R. Is swimmers' performance influenced by wetsuit use? Int J Sports Physiol Perform 15(1): 46-51, 2020.

7. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 10(5): 361-74, 2000.

8. Hue O, Benavente H, Chollet D. The effect of wet suit use by triathletes: An analysis of the different phases of arm movement. J Sports Sci 21(12): 1025-30, 2003.

9. Martens J, Daly D, Deschamps K, Fernandes RJ, Staes F. Intra-individual variability of surface electromyography in front crawl swimming. PLoS One 10(12): e0144998, 2015.

10. Martens J, Daly D, Deschamps K, Staes F, Fernandes RJ. Inter-individual variability and pattern recognition of surface electromyography in front crawl swimming. J Electromyogr Kinesiol 31: 14-21, 2016

11. Millet GP, Chollet D, Chalies S, Chatard JC. Coordination in front crawl in elite triathletes and elite swimmers. Int J Sports Med 23(2): 99-104, 2002.

12. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2020.

13. Nikolaidis PT, Sousa CV, Knechtle B. The relationship of wearing a wetsuit in long-distance open-water swimming with sex, age, calendar year, performance, and nationality - crossing the "Strait of Gibraltar." Open Access J Sports Med 9: 27-36, 2018.

14. Nuber GW, Jobe FW, Perry J, Moynes DR, Antonelli D. Fine wire electromyography analysis of muscles of the shoulder during swimming. Am J Sports Med 14(1): 7-11, 1986.

15. Parsons L, Day S. Do wetsuits affect swimming speed? Br J Sports Med 20(3): 129–131, 1986.

16. Peeling PD, Bishop DJ, Landers GJ. Effect of swimming intensity on subsequent cycling and overall triathlon performance. Br J Sports Med 39(12): 960-4, 2005.

17. Perrier D, Monteil K. Triathlon wet suit and technical parameters at the start and end of a 1500-m swim. J Appl Biomech 20(1): 3–13, 2004.

18. Pink M, Perry J, Browne A, Scovazzo ML, Kerrigan J. The normal shoulder during freestyle swimming. An electromyographic and cinematographic analysis of twelve muscles. Am J Sports Med 19(6): 569-76, 1991.

19. Tipton M, Bradford C. Moving in extreme environments: Open water swimming in cold and warm water. Extrem Physiol 3(1): 1-11, 2014.

20. Tomikawa M, Shimoyama Y, Nomura T. Factors related to the advantageous effects of wearing a wetsuit during swimming at different submaximal velocity in triathletes. J Sci Med Sport 11(4): 417-23, 2008.

21. Tomikawa M, Nomura T. Relationships between swim performance, maximal oxygen uptake, and peak power output when wearing a wetsuit. J Sci Med Sport 12(2): 317-22, 2009.

22. Toussaint HM, Bruinink L, Coster R, De Looze M, Van Rossem B, Van Veenen R, De Groot G. Effect of a triathlon wet suit on drag during swimming. Med Sci Sports Exerc 21(3): 325-8, 1989.

23. Toussaint HM, Beek PJ. Biomechanics of competitive front crawl swimming. Sports Med 13(1): 8-24, 1992.

24. Trappe TA, Pease DL, Trappe SW, Troup JP, Burke ER. Physiological responses to swimming while wearing a wet suit. Int J Sports Med 17(2): 111-4, 1996.

25. Ulsamer S, Rüst CA, Rosemann T, Lepers R, Knechtle B. Swimming performances in long distance open-water events with and without wetsuit. BMC Sports Sci Med Rehabil 6(1): 1-13, 2014.