COMPARING SHOULDER, ELBOW, WRIST KINEMATICS AND ONSET OF FATIGUE IN RECREATIONAL MALE SURFERS WITH AND WITHOUT WETSUITS

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ABSTRACT

Background: Wetsuits are marketed to surfers to enhance performance due to their flexibility. However, there are no studies investigating shoulder joint motion of a surfer while wearing a wetsuit. **Aim**: The purpose of this study was to compare shoulder, elbow and wrist kinematics, and the onset of fatigue in subjects wearing a wetsuit (WS) and no wetsuit (NW). **Hypothesis**: The null hypothesis is that there will be no change in ROM, power output and onset of fatigue while wearing a wetsuit compared to not wearing a wetsuit. **Methods**: Subjects included 5 recreational surfers who participated in two trials on separate days. Motions were recorded with reflective markers and a motion tracking camera system. Subjects performed a paddling exercise on a swim bench ergometer at 100W until fatigue. Stroke rate and length variability and shoulder angle among subjects pre and post fatigue and WS and NW data were compared. **Results**: Average time spent paddling was 4.9 minutes WS and 4.6 minutes NW. 5.6 % increase in fatigue while wearing a WS compared to fresh stroke area at the wrist. 1.6 % change due to NW(fatigue) vs WS (fatigue) at the elbow. No significance in ROM of the shoulder angle between both conditions and exercise state (p=.456 wetsuit condition, p=.137 exercise state **Conclusion:** We

concluded that while wearing a wetsuit there is no performance kinematic difference compared to not wearing a wetsuit. However, there was a slight difference during the onset of fatigue.

INTRODUCTION

Surfing consists of sport activity that is characterized by periods of high-intensity, low-intensity, and rest periods [10]. While surfing is becoming more popular there is very little information on shoulder joint kinematics. Manufacturers market the use of wetsuits as performance enhancing and doesn't restrict movement. Research can help manufacturers improve their product design for surfing wetsuits that allow full range of motion (ROM) in the shoulder, leading to improved customer satisfaction and performance. Though, it is unknown whether shoulder joint kinematics or power output change while wearing a wetsuit compared to not wearing a wetsuit while paddling on a surfboard. Research has shown that wearing a wetsuit while swimming provides performance benefits [11]. Improved swimming performance while wearing a wetsuit can be partially attributed to increased stroke rate due to increased energy efficiency added from the buoyancy and reduced active drag [2, 4, 12]. Swimming performance has been previously measured through factors such as maximal oxygen uptake, VO2max, and maximal mechanical power output [2, 12].

Studies have shown that well trained surfers have higher upper body aerobic fitness scores of peak power output, and blood lactate concentration, which corresponds to exercise intensity [9]. Oliver et al. (2012), found that the majority of time spent during surf competitions (average 20 minute bouts) was spent paddling (mean 16.3 ± 4.5 min) and (mean 4.2 ± 0.8 min) was spent paddling for a wave, which suggests early fatigue in the shoulders of surfers would be detrimental to performance. Tomikawa et al. (2009), studied the effects on swimming with a swimsuit and wearing a wetsuit (WS). In their findings, experienced triathlete participants performed a continuous progressive test and submaximal steady state test in both swimsuit and WS trials while energy cost of swimming, rating of perceived exertion (RPE), stroke length (SL) and stroke rate (SR) were recorded for each. This study found that the energy cost of swimming with a WS was lower in both swimming trials than with a swimsuit. Also, there were no significant differences between conditions for recorded RPE. Wearing a WS did not affect SL but improved SR, showing that swimming performance was enhanced with WS. Although this study does not look at power output of the arms, with the resistance of water, wetsuits are found to be beneficial for swimmers by reducing resistance and improving overall velocity while the RPE remains constant.

In the present study, our goal was to investigate the effects of wearing a wetsuit and no wetsuit during maximal exercise. Cordain et al. (1991), analyzed the effects of body composition on swimming performance with and without wetsuits. The subjects consisted of 14 intercollegiate female swimmers who swam 400 and 1500 meter trials. Their findings revealed that swim times were shorter with wetsuits than with no wetsuits. The results concluded that wetsuits increase buoyancy, which allows greater energy to be used in propulsion, rather than keeping a horizontal position. Tomikawa et al. (2009), investigated the effects of WS compared to not wearing a wetsuit (NW) on VO2max and power output in triathletes. There was no change in VO2max. Interestingly, they found no change in maximal mechanical power output (POmax) during a maximal 400m sprint in a swimming flume; however, they did find a positive correlation between WS and POmax, which was most likely due to technical factors, such as propulsion efficiency. Based on these findings, it is of interest to investigate the variability in stroke and power output caused by wearing a wetsuit during maximal paddling on a surfboard.

The primary purpose of this study was to compare kinematics at the shoulder, elbow, and wrist joints, as well as the onset of fatigue in subjects WS vs NW. The null hypothesis is there will be no change in ROM and onset of fatigue while wearing a wetsuit compared to not wearing a wetsuit. The alternative hypothesis is that there will be a difference between ROM, and onset of fatigue between subjects wearing a wetsuit and not wearing a wetsuit.

METHODS

Subjects

Nine male individuals participated in this study, while only 5 subject's data was used (mean $\pm$ stdev; age 28.3 $\pm$ 11.7 years, height 1.8 $\pm$ 0.03 m, weight 77.2 $\pm$ 6.7 kg and surfing experience 12.4 $\pm$ 11.8 years and 8.5 $\pm$ 4.7 hours per week. Subject data was not retrievable, so it was omitted from the results. Each participant signed a consent and medical history form, which included a description of prior injuries, surgeries etc. Subjects were excluded if prior injuries were listed to the back, arms, and shoulders to prevent and avoid further injury.

Equipment

A swim bench ergometer (Essex Junction, Vermont, USA) modified with a surfboard and hand paddles similar to that of Oliver et al., was used in the present study. Subjects were instructed to lie prone on an 8ft surfboard and to attempt to simulate a surfing specific paddling action. WS were made of 1mm neoprene and covered the torso and the arms to the wrist.

Procedure

All data was collected in a laboratory setting on two separate days with wetsuit condition randomized. One subject participated in another similar study. The other subjects were unfamiliar with the equipment, but were informed on the procedure. Three subjects performed their first trials with WS. The other two performed first trials with NW. Reflective markers were placed on the subjects' spine, elbow, shoulder and wrist joints while tracked with Vicon motion optical cameras (spinal process T1,T6, sacrum, lateral axillary border of the scapula below the acromion process, ulnar styloid process and lateral epicondyle).

The subjects were instructed to lie prone and paddle (alternating arms) on a swim ergometer. After a standardized warm-up (3 minutes of 30 Watts continuous paddling) each subject was given standardized encouragement to increase stroke rate 10 W every 10 seconds until 100 W is reached and continue until fatigue [6]. When subjects fell below 90 Watts for at least 30 seconds or stopped paddling, this was considered volitional fatigue.

Data Analysis

Motion data was recorded in a continuous interval of 2-minutes until fatigue. Power output (watts) data was collected every 10 seconds after the initial 3-minute warm-up at 30 watts. Time to fatigue was compared during both exercise state and WS conditions using the power output data. Stroke rate, stroke length, height and area of the wrist and elbow, average peak shoulder angle and average ROM at the shoulder in degrees among subjects pre and post-fatigue was also measured and compared among WS/fresh/fatigue and NW/fresh/fatigue. A 2-way repeated measures ANOVA was also used to determine whether there was a significant effect of WS on arm joint ROM. Significance will be determined with $p < .05$.

RESULTS

Average time spent paddling was WS 4.9 min, and NW 4.6 min. There was a 5.6 % increase in fatigue compared to fresh stroke area (mm^2) at the wrist for the NW trials (refer to Table 1). There was no significant difference in stroke area at the elbow when compared to WS/fatigue and NW/fatigue, respectively, with a 1.6 % difference (Table 2).

No significant difference was evident in average shoulder ROM angle between both conditions and exercise state (p=.456 wetsuit condition, p=.137 exercise state). Shoulder ROM degrees during fatigue increased 8.3 % in NW compared to WS (Table 3). During the WS trials, fresh vs fatigue, the average stroke area of the wrist increased 5.9 %. WS shoulder ROM increased by 3.7%.

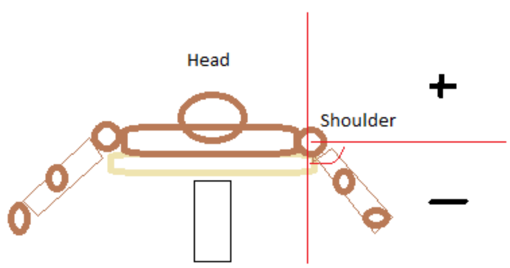


Figure 1. Surfer Position on ergometer Negative shoulder angle represents loss of ROM.

Table 1. NW vs. WS (Wrist Stroke) Fresh and Fatigue

	NW			WS		
Fresh	Stroke Area (mm^2)	Stroke Length (mm)	Stroke Height (mm)	Stroke Area (mm^2)	Stroke Length (mm)	Stroke Height (mm)
Mean ± SD	285105 ± 64405.9	952±99.9	444.2 ± 75.2	242911.5± 78252.7	926.6± 107.4	391±101.1
Fatigued						
Mean± SD	302308± 72104	980.5± 116.6	458.4± 56.4	258293.1± 94744	986.8±78.4	414.4±68.6

Table 2. NW vs. WS (Elbow Stroke) Fresh and Fatigue

	NW			WS		
Fresh	Stroke Area (mm^2)	Stroke Length (mm)	Stroke Height (mm)	Stroke Area (mm^2)	Stroke Length (mm)	Stroke Height (mm)
Mean± SD	1772.7± 1280.7	72.2±22.5	84.9±18	1529± 1053.8	60±16.7	83.8±23.9
Fatigued						
Mean± SD	16086.4± 27298.8	156.1± 125.8	152.7± 131.7	20686.5± 40482	161.2± 176.2	155.2± 158.8

Table 3. NW vs. WS ROM of the Shoulder (DEGREES)

Fresh	Ave ROM (NW)	Ave ROM (WS)
Mean± SD	87.9±12.5	89.6±22.6
Fatigue		
Mean± SD	101.4±14.2	93±14.5

Table 4. Average Peak Shoulder Angle - WS vs NW

	Fresh (NW)	Fatigue (NW)	Fresh (WS)	Fatigue (WS)
subject	Ave PEAK (deg)	Ave PEAK (deg)	Ave PEA (deg)	Ave PEAK (deg)
1	15.9	36.5	37.1	19.7
2	3.93	0.71	4.6	0.5
3	-15.2	9	-17.8	-15
4	0.7	5.3	-16.3	-3.8
5	-11.2	9.9	-7	16.6
Mean± SD	-1.2±12.45	12.3±14	0.12±22.5	3.6±14.5

Table 5. No Wetsuit (NW) Fresh (Left Arm)-Wrist

subjec t	Stroke Area (mm2)Wrist	Stroke Length (mm)	Stroke Height (mm)
1	283620.8	856.2	476.1
2	384796.1	1066.2	553.0
3	225964.02	882.6	372.1
4	230994.1	899.9	376.4
5	300150.1	1052.9	443.5
Mean	285105.0	952.0	444.2
SD	64405.9	99.9	75.2

Table 6. **No Wetsuit (NW)** Fatigue (Left arm) -Wrist

subject	Stroke Area (mm2)	Stroke Length (mm)	Stroke Height (mm)
1	219858.6	813.6	404.9
2	399852.5	1066.6	513.3
3	292792.0	100.0	511.6
4	252736.0	919.4	395.5
5	346298.4	1103.2	466.6
Mean	302308.0	980.5	458.4
SD	72104.0	116.6	56.4

Table 7. **No Wetsuit (NW)** Fresh (Left Arm)- Elbow

subjec	Stroke Area (mm2)	Stroke Length (mm)	Stroke Height (mm)

t			
1	971.3	65.1	97.03
2	1640.1	80.8	87.8
3	1636.5	42.4	71.1
4	678.5	68.7	62.4
5	3937.2	103.8	106.0
Mean	1772.7	72.2	84.9
SD	1280.7	22.5	18.0

Table 8. **No Wetsuit (NW)** Fatigue in the Elbow

Subject	Stroke Area (mm2)	Stroke Length (mm)	Stroke Height (mm)
1	64437.6	369.4	382.7
2	2671.4	97.8	91.6
3	2032.2	56.9	66.3
4	769.7	89.6	80.4
5	10520.7	167.1	142.7
Mean	16086.4	156.1	152.7
SD	27298.8	125.8	131.7

Table 9. **No Wetsuit (NW)** vs. **Wetsuit (WS)** Fresh vs. Fatigue in the shoulder (DEGREES)

	NW-Fresh	NW-Fatigue	WS-Fresh	WS-Fatigue

subject	Ave ROM Shoulder	Ave ROM Shoulder	Ave ROM Shoulder	Ave ROM Shoulder
1	104.6	126.1	126.7	109.0
2	93.6	90.3	94.2	90.1
3	74.5	98.4	71.6	74.2
4	90.2	94.4	73.2	85.5
5	76.7	98.0	82.1	106.0
Mean	87.9	101.4	89.6	93.0
SD	12.5	14.2	22.6	14.5

Table 10. **Wetsuit (WS)** Fresh Wrist and Elbow

Subject	Stroke Area (mm2) wrist	Stroke Length (mm) wrist	Stroke Height (mm) wrist	Stroke Area (mm2) Elbow	Stroke Length (mm) Elbow	Stroke Height (mm) Elbow
1	327257.2	929.9	559.0	1395.02	72.5	112.4
2	274553.9	1017.2	360.0	2888.0	75.9	104.6
3	149174.3	949.3	312.6	779.4	36.2	55.8
4	171187.7	744.6	317.8	315.9	49.5	70.1
5	292384.4	991.8	405.6	2266.6	65.8	76.2
Mean	242911.5	926.6	391.0	1529.0	60.0	83.8
SD	78252.7	107.4	101.1	1053.8	16.7	23.9

Table 11. **Wetsuit (WS)** Fatigue Wrist and Elbow

Subject	Stroke Area (mm2) Wrist	Stroke Length (mm) Wrist	Stroke Height (mm) Wrist	Stroke Area (mm2) Elbow	Stroke Length (mm) Elbow	Stroke Height (mm) Elbow
1	326353.1	942.9	521.4	93002.6	472.2	436.3
2	271232.2	1012.0	377.9	2732.7	89.0	107.3
3	111371.5	1049.0	381.5	1284.5	52.4	48.5
4	230643.0	871.6	349.5	407.1	64.6	82.9
5	351860	1059.0	441.6	6005.5	128.1	100.9
Mean	258293.1	986.8	414.4	20686.5	161.2	155.2
SD	94744.0	78.4	68.6	40482.0	176.2	158.8

Table 12. **Wetsuit (WS)**- Fresh vs. Fatigue in the shoulder

	Fresh	Fatigue
subject	Ave ROM Shoulder Angle (deg)	Ave ROM Shoulder (deg)
1	126.7	109.0
2	94.2	90.1
3	71.6	74.2
4	73.2	85.5
5	82.1	106.0
Mean	89.6	93.0
SD	22.6	14.5

Table 13. Average Peak Shoulder Angle - WS vs NW

	Fresh (NW)	Fatigue (NW)	Fresh (WS)	Fatigue (WS)
subjec t	Ave PEAK (deg)	Ave PEAK (deg)	Ave PEA (deg)	Ave PEAK (deg)
1	15.9	36.5	37.1	19.7
2	3.93	0.71	4.6	0.5
3	-15.2	9.0	-17.8	-15.0
4	0.7	5.3	-16.3	-3.8
5	-11.2	9.9	-7.0	16.6
Mean	-1.2	12.3	0.12	3.6
SD	12.45	14.0	22.5	14.5

Figure 2. Area of Stroke for WS and NW conditions

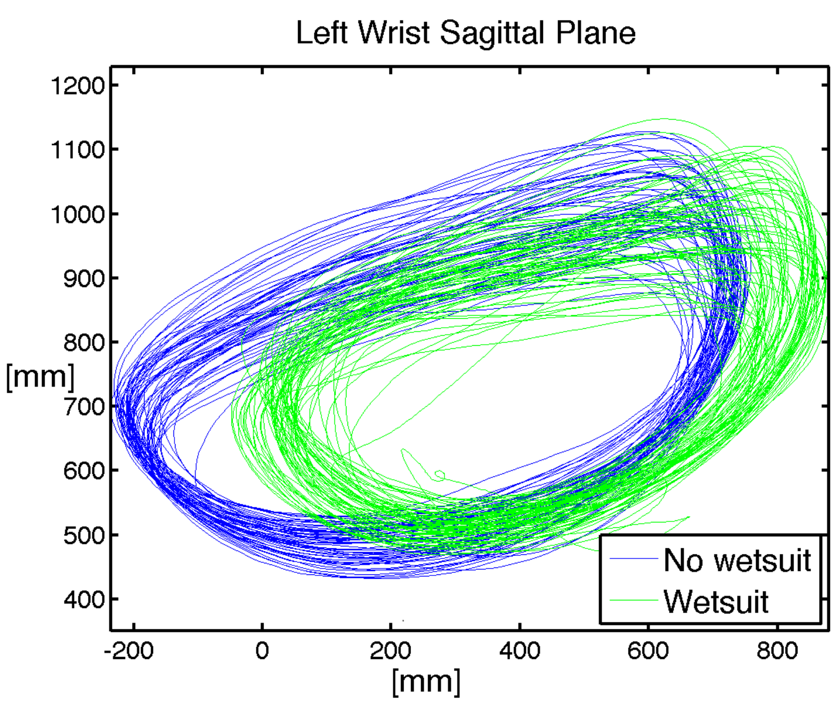
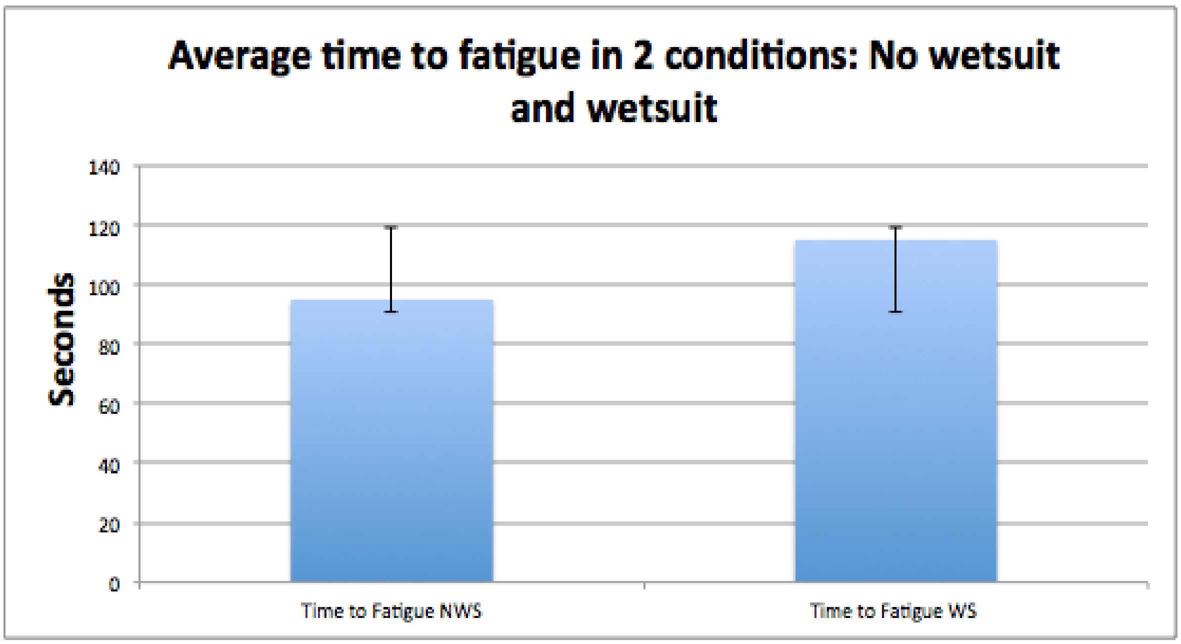


Figure 3. Average time to fatigue for WS and NW conditions



DISCUSSION

The primary aim of the study was to compare the kinematics of the shoulder, elbow, and wrist joints, as well as the onset of fatigue in subjects wearing a WS vs NW. It was hypothesized that wearing a wetsuit would have no effect on the ROM and onset of fatigue compared to not wearing a wetsuit. However, after analyzing our data, we accept the null hypothesis first mentioned and conclude that wearing a WS does not have an effect on the ROM, and onset of fatigue.

In our study, we investigated 5 recreational surfers and measured their fatigue and change in shoulder and wrist angles over 2-minute trials of paddling on a modified swim ergometer. We set out to discover the effects of WS compared to NW paddling conditions. Although we did not find any significant changes for each condition and exercise state, more subjects might have revealed significant differences.

Although, significant data was not found, a few trends were noticed. For example, the peak shoulder angle in fatigue state of the participants was more than 3 times greater in NW than in WS conditions, indicating that the WS was somewhat restrictive (Table 4). When fatigued, the average stroke area about the wrist increased for both conditions, but the WS trials remained smaller than the NW trials. The elbow stroke area dramatically increased when fatigued for both WS and NW trials. There is also a decrease in average stroke area in the wrist and in the elbow at the fresh period of the trial with the wetsuit compared to without.

The present study was analyzing a novel topic, therefore, we were very limited in previous research. Locating previous research data and learning from their results made designing the study more difficult. Along with no comparison data, some limitations were encountered. The subjects had to learn how to use the ergometer. The average time spent paddling in the present study (WS 4.9 min NW 4.6 min) which was in agreement with Oliver et al., (12) who found the average time spent paddling out to a wave was (mean 4.2 ± 0.8 min). These numbers represent how wearing a WS added to the power of each subject and allowed them to paddle for longer periods of time than with NW. This may be attributed to the surfers comfort in wearing wetsuits, since all typically wear wetsuits for 9.2 ± 1.79 months out of the year. After analyzing the plotted data, the change in stroke length of the left wrist in the sagittal plane also shows the effect of the WS on ROM of the subjects.

Several other limitations of our current study were also observed, however, would not alter our results and conclusion. One limitation of the present study was the small sample size of 5 subjects. A larger sample size might have led to a significant difference in some of the variables we tested for. Another limitation included the effects of wet vs dry land swimming which made a difference in the arm cycle executions while air resistance does not realistically resemble water resistance. Although we did not measure EMG, according to previous research, muscle activation is not the same without propelling of the body forward in the water [11]. Third, the height and weight of the subjects were self reported in the consent forms, as well as any previous injuries. These few limitations however had no effect on the overall study and the outcome was fairly similar between all 5 subjects.

The main concern before conducting each test was whether we would get an accurate and similar stroke from the subjects due to the fact of using the hand paddles. Some of the subjects would start in a "doggy paddle" form and would need to be cued to alter their form to the correct position. However, once fatigue approached, we noticed a return to the "doggy paddle" form again. Another concern we had was whether the suit should be wet or dry when worn; eventually, it was decided to be kept dry and freshly cleaned for all subjects to keep the results as accurate and similar as possible. Collectively, the results of our study came to not support our null hypothesis but instead rejected it and proved that wearing a WS does in fact have a positive effect on the ROM in the shoulder and wrist kinematics and the amount of time it takes to reach full fatigue.

While the main focus of this study was to compare the change in shoulder and wrist kinematics, future studies should look into testing expert surfer joint motions to find commonalities in the paddle stroke. After establishing a norm range of angles, different and new wetsuit materials can be compared to decide which has the greater potential to increase performance. Comparing how fast these different materials help or do not help the surfers move, which material slows down fatigue, or even which option (WS or NS) allows for better and longer endurance for surfers.

Another topic of interest would be to investigate benefits of wetsuit buoyancy while surfing, it remains unclear whether the added buoyancy while wearing a wetsuit would benefit a surfer paddling. Cordain et al. (1991), analyzed the effects of body composition on swimming performance with and without wetsuits. The subjects consisted of 14 intercollegiate female swimmers who swam 400 and 1500 meter trials. Their findings revealed that swim times were shorter with wetsuits than with no wetsuits. The results concluded that wetsuits increase buoyancy, which allows greater energy to be used in propulsion, rather than keeping a horizontal position. Again, although we did not test for buoyancy, these findings can be used for future studies that would analyze the effects on performance and fatigue depending on the wetsuit thickness.

Based on our limited results and subjects, further studies would need to investigate the shoulder kinematics of surfers while wearing wetsuits and while not in the fatigued state. These studies would be more applicable to wetsuit manufacturers to create superior products for increased customer satisfaction and revenue.

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Random Stuff (extra, not to print out)

Above is a rough representation of what nesseler discussed with me on Average Peak shoulder degrees. The shoulder abducts horizontally. So the larger the negative number, the greater fatigue.

Notes: Any Average peak shoulder angle that reads negative is when the upper arm goes under the shoulder joint (or the board level), any number above the shoulder joint will read a positive number on average peak shoulder angle. He wants us to analyze those results WS vs NW. I ‘ll create the “Ave Peak Shoulder” table soon. cool, for the tables below should we compare each individual participant instead of taking the average for the stroke area for all of them?

I was thinking comparing just the Mean's of each table… the last table that I got to finish is the Ave Peak shoulder .. That to follow; ….. what i was worried about is the fact that each person has a different arm length therefore the area of the stroke will be different.

Oh.. umm I got the data from nessler's findings. So the tables are based of what he concluded. oh ok, well maybe ill put that under our limitations, im not sure

Ok that works too.. I m at work til 5, so bare with me…. lol no prob :)

Limitations- Remember to state that these limitations did not affect our results.
Time differences between dry land and "wet" arm cycle executions.
Most muscles showed lower EMG peaks during dry land swimming and created a different pattern of movement.
"Hand palm shaped paddles disturb the muscle pattern and have to be avoided"
Aim is to find efficiency increasing factors…
Although we do not measure EMG according to previous research, muscle activation will not be the same without propelling of body forward in the water.
(Biomechanics and Medicine in Swimming VII By A.P. Hollander, D. Strass, J. Troup)

Only air resistance- does not realistically resemble water resistance
-Injuries, weight and height self reported
-small sample size

http://cc.csusm.edu/pluginfile.php/208136/mod_resource/content/1/Oscar%20US%20paper.pdf

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ANAEROBIC AND AEROBIC FITNESS PROFILING OF COMPETITIVE SURFERS
OLIVER FARLEY, NIGEL K. HARRIS, AND ANDREW E. KILDING
Sports Performance Research Institute New Zealand, AUT University, Auckland, New Zealand

Farley, O.R., Harris, N.K., Kilding, A.E. (2012). Physiological demands of competitive surfing. *Journal of Strength and Conditioning Research, 26*(7): 1887-1896.
Field testing^^^--12 nationally ranked surfers- average time paddling 16.3 +- 4.5 min and for a

wave 4.5 min. Gives us speed range for calculated intensity. Majority of time is spent paddling, so fatigue would be detrimental to performance.
(What was our subject average time paddling?)

Upper body aerobic fitness comparison between two groups of competitive surfboard riders
A Mendez-Villanueva 1,2, J Perez-Landaluce I, D Bishop 2, B Fernandez-Garcia 1,
R Ortolano 1, X Leibar 3 & N Terrados 1
Tested 2 different performance levels of competitive surfer's upper body aerobic fitness on a dry land paddling board. Mean peak power output was 154.71±36.82 W vs. 117.70±27.14 W. We had recreational surfers go to 100 W.

Physiological Profiles of Australian Surf Boat Rowers
James W Fell I & Philip T Gaffney 2

Zamparo, P., Turri1, E., Peterson Silveira1, R., Poli, A. (2014). The interplay between arms-only propelling efficiency, power output and speed in master swimmers. *Eur J Appl Physiol,* DOI 10.1007/s00421-014-2860-7
^^^Zamparo et al, 2014 investigated propelling proficiency and mechanical power output of master swimmers on a arm crank ergometer. We can compare the power output data from our study to Wmax.

Int J Sports Med. 2013 Apr;34(4):324-9. doi: 10.1055/s-0032-1323721. Epub 2012 Oct 12.

An updated protocol to assess arm swimming power in front crawl.

Dominguez-Castells R1, Izquierdo M, Arellano R.

-Measured mechanical power output during supramaximal exercise while performing a front crawl.

Int J Sports Physiol Perform. 2014 Mar 11. [Epub ahead of print]

Fatigue Thresholds Assessments in 50m All Out Swimming.

Soares SM1, Fernandes RJ, Machado JL, Maia JA, Daly DJ, Vilas-Boas JP.

-Soares et al, (14) investigated the fatigue thresholds of competitive swimmers during a supramaximal 50m front crawl swim test. The difference in speed and stroke parameters were analyzed. They found multiple thresholds-- item waiting to get from library on loan.

Int J Sports Med. 1992 Jul;13(5):367-71.

A simple method for determining critical speed as swimming fatigue threshold in competitive swimming.

Wakayoshi K1, Yoshida T, Udo M, Kasai T, Moritani T, Mutoh Y, Miyashita M.

Ceccon, S., Ceseracciu, E., Sawacha, Z, Gatta, G., Cortesi, M., Cobelli, C., Fantozzi, S. (2013). Motion analysis of front crawl swimming applying CAST technique by means of automatic tracking. *Journal of Sports Sciences, 31*(3): 276-287. DOI 10.1080/02640414.2012.729134
Ceccon et al, (13) researched the applicability of markerless motion capture to kinematics analysis of front crawl swimming using six underwater color analog wide-angle cameras. They used two techniques: a video-based, markerless system for the analysis of arm movements compared to the traditional manual digitization. Their findings showed good accuracy for wrist joint, and reliability using a root mean square distance (RMSD) values to determine trajectories estimated with the two techniques. Therefore using the video-based markerless system technique rather than the manual digitization technique is helpful for future studies consisting of quantitative wide-scale studies on swimmers' motion (Ceccon et al., 2013).

Crotty, N.M., Smith, J. (2000). Alterations in scapular position with fatigue: a study in swimmers.
Clin J Sport Med, 10(4): 251-258. http://www.ncbi.nlm.nih.gov/pubmed/11086750
In a study performed by Crotty (00) the difference in scapular position in swimmers was compared in the dominant and nondominant arm/ shoulders. The study was conducted during a normal 2 hour swimming practice at full effort while scapular positions were measured at the beginning and end of the practice. The results showed no change in scapular position. For the present study, when we are looking for any changes within our surfers in the scapular region; swimmers and surfers perform the same motions of the scapula making it easily comparable. Although we are not looking to mainly investigate scapular positioning, we can still use this data to see if there is a change in scapula position after adding a wet suit to the arm. This new information can be an addition to our fatigue findings and may add more understanding for other findings that we attain.

Magalhaes, F.A., Sawacha, Z., Di Michele, R., Cortesi, M., Gatta, G., Fantozzi, S. (2013). Effectiveness of an automatic tracking software in underwater motion analysis. *J Sports Sci Med, 12*(4): 660-667. http://www.ncbi.nlm.nih.gov/pubmed/24421725

McCabe, C.B., Sanders, R.H. (2012). Kinematic differences between front crawl sprint and distance swimmers at a distance pace. *J Sports Sci, 30*(6):601-608.
http://www.ncbi.nlm.nih.gov/pubmed/22315962

There were no differences in average stroke length stroke velocity stroke frequency and upper limb displacement (elbow and shoulder angle) in sprint swimmers compared to distance swimmers. Not quite sure how this one can relate…. There are no studies looking at shoulder joint kinematics of surfers…

Tomikawa M1, Nomura T. J Sci Med Sport. 2009 Mar;12(2):317-22. Epub 2007 Dec 20.
http://www.ncbi.nlm.nih.gov/pubmed/18083064

Tomikawa, M., Shimoyama, Y., Nomura, T. (2008). Factors related to the advantageous effects of
wearing a wetsuit during swim at different submaximal velocity in triathletes. *Journal of Sports Science Medicine*, *11*(4): 417-23.

Br J Sports Med. Mar 1991; 25(1): 31–33.

Wetsuits, body density and swimming performance.

L Cordain and R Kopriva

Literature Review

It is well known that wearing a wetsuit while swimming provides performance benefits (Tomikawa et al, 2009). Improved swimming performance while wearing a wetsuit can be partially attributed to increased stroke rate due to increased energy efficiency from added the buoyancy and reduced active drag (Cordain et al, 1991; Tomikawa et al, 2008; Dantas De Lucas et al, 2000). Swimming performance has been previously measured through factors such as, maximal oxygen uptake, VO2max and maximal mechanical power output (POmax) (Cordain et al, 1991; Tomikawa et al, 2008).

Oliver et al, (12) found that the majority of time spent during surf competitions (average 20 minute bouts) was spent paddling (mean 16.3+-4. 5 min) and (mean 4.2 +-0.8 min) was spent paddling for a wave, which suggests early fatigue in the shoulders of surfers would be detrimental to performance.

Tomikawa et al, (09) investigated the effects of wearing a wetsuit (WS) compared to not wearing a WS on VO2max and power output in triathletes. There was no change in VO2max. Interestingly enough, they found no change in a POmax during a maximal 400m sprint in a swimming flume, however, they did find a positive correlation between WS and POmax, which was most likely due to technical factors, such as propulsion efficiency. Based on these findings, it is of interest to investigate the variability in stroke and power output caused by wearing a wetsuit during submaximal swimming while on a surfboard.

Tomikawa et al, (08) studied the effects on swimming with a swim suit (SS) and with a wetsuit (WS). Experienced triathlete participants performed a continuous progressive test and submaximal steady state test in both SS and WS trials while energy cost of swimming (Cs), rating of perceived exertion (RPE), stroke length (SL) and stroke rate (SR) were recorded for each. This study found that Cs with a WS was lower in both swimming trials than with a SS. Also, there were no significant differences between conditions for recorded RPE. Wearing a WS did not affect SL but improved SR, showing that swimming performance was enhanced with the WS. Although this study does not look at power output of the arms, with the resistance of water, wetsuits are found to be beneficial for swimmers by reducing resistance and improving overall velocity while the RPE remained constant. In the present study, our goal is to investigate the effects of surfers paddling on a surfboard with and without a WS during submaximal exercise on RPE, stroke length and stroke rate.

Cordain et al, (91) analyzed the effects of body composition on swimming performance with and without wetsuits. The subjects consisted of 14 intercollegiate female swimmers who swam 400 and 1500 m trials. Hydrostatic weighing was used to measure wetsuit vs. non-wetsuit body densities. Their findings revealed that swim times were shorter with wetsuits than with no wetsuits. The results concluded that wetsuits increase buoyancy which allows greater energy to be used in propulsion, rather than keeping a horizontal position. These findings can be used for future studies that would analyze the effects on performance and fatigue depending the on the wetsuit thickness. Although we do not aim to investigate benefits of wetsuit buoyancy while surfing, it remains unclear whether the added buoyancy while wearing a wetsuit would benefit a surfer paddling.