

Original Research

## Effects of the Biomechanical Design of the Full Body Swimsuit on its Tensile Behavior in the Shoulder Area

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### ABSTRACT

Full body swimwear is one of the women's swimming suits. It has been designed based on full coverage as well as hijab. Swimwear has a great influence on the swimming speed and quality. Hence, it is important to study the design of swimwear according to the swimming biomechanical principles. The current study investigated the effect of the sleeve design of the full body swimwear on the tensile behavior in the swimmer's shoulder area. Accordingly, two different full body swim suits with drop (or set-in) and raglan style sleeves in the size of 38 were designed and produced using a polyester/lycra knitted fabric. To investigate the tension variations induced by the hand movements during swimming, a metal yarn containing 80% stainless steel fibers was sewn in armpit and near the armhole seam. The sleeve extension and consequently, the swimmer's shoulder tension were measured by the metal yarn. The metal yarn functioned as a sensor in an electronic circuit, detecting the extension. The voltage difference between the two ends of the metal yarn was measured during the hand movement and converted to resistance. The results showed that the tension variation induced by the swimmer's hand movements was lower for the raglan sleeve ( $0.26 \pm 0.031$  ohm and  $0.09 \pm 0.025$  ohm), as compared to the drop one ( $0.35 \pm 0.034$  ohm and  $0.21 \pm 0.015$  ohm), in both tested positions. Reducing the tension variation at the shoulder area of the full body swimsuit could increase the swimmer speed and freedom of action. This is the reason why the raglan sleeve could be used for most sport suits, including the full body swimsuit.

**Keywords:** Full body Swimsuit, Biomechanical Design, Sleeve, Tensile Behavior, Metal Yarn, Electronic equipment.

### Introduction

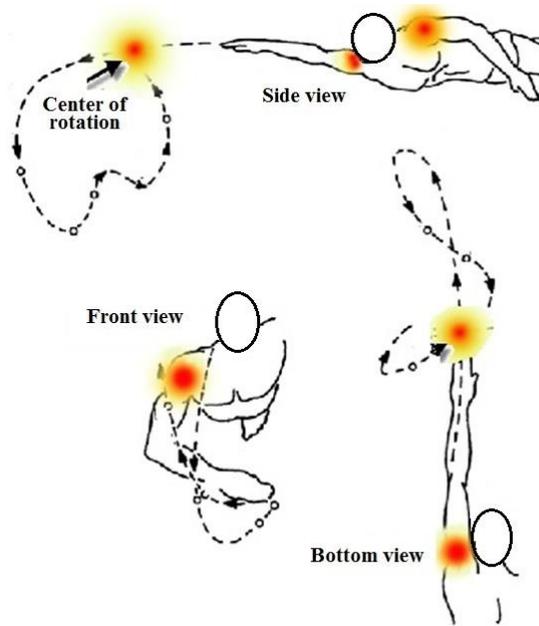
In the recent decades, many scientific studies have been conducted on different sport areas, with all contributing to the development and improvement of the athletes' performance. One of the most important areas is the sport biomechanics, which analyzes the mechanics of the human movement. Determining the safest method for performing a particular sport like swimming is the area wherein biomechanics can be useful, based on body loading [1]. With the development of technology, it is required to conduct biomechanical studies on swimming. Nowadays, the time differences determining the winners in competitions are in a scale of 0.01-second, and swimmers are attempting to take the best use of specific tools to improve their performance. An important and basic tool in swimming which considerably affects the speed and quality is the choice of swimsuit. Swimsuits are a type of clothes designed for those who participate in water activities or sports, such as swimming, diving and surfing [2].

Various types of swimsuits are used by men, women and children. A wide range of modern swimsuit styles are available; these are different in material and body coverage. The styles are selected considering the social norms, fashion, and individual preferences. Women's swimsuits are divided into four groups in terms of body

coverage: one-piece, two-piece, three-piece, and full body swimsuits. For all these types, except the full body one, only certain parts of the body are covered by the swimsuit, while the full body swimsuit has the same parts along with a fabric piece that covers a large portion of the body [3]. The latest innovation for the women's full body swimsuit is the Islamic swimsuit, also known as Burkini, which is designed in accordance with the Islamic clothing orders, covering the hands up to the wrists, legs up to the ankles and all the body up to the neck [4]. This swimsuit was introduced by the Lebanese-Australian designer, Ahda Zanti, in 2004. Her objective was to eliminate the Muslim women's limitations in swimming, surprisingly attracting non-Muslim women's attention as well. Burqini has been designed in two types: one type has a skirt on the pants, while the other one does not have a skirt and covers the neck and hair. This women's swimsuit makes it easy for Muslim women to swim in the pools and international tournaments [5].

Many studies have been conducted on swimsuits and their effects on the swimmer's performance, leading to some specific designs [6-8]. The initial attempts aimed at producing specific swimsuits to improve swimming performance were made in 1996 by the Speedo Company [9]. After conducting many studies, they introduced the Fast Skin swimsuit, inspired by the shark skin. The shark skin is covered by very small individual tooth-like scales called dermal denticles, providing a maximum drag reduction. The shark skin-inspired swimsuit has made the fastest swimming [10]. Then, the studies were continued to make a comparison between the performance of the typical swimsuits and the high-tech ones [11,12]. Toussaint et al. (2012) also investigated the effects of using a Fast Skin swimsuit, showing that it reduced the drag force by 2% [13]. Material, fabric weight and density, and seam specifications are the important parameters of swimsuits. Swimsuits must have very low weights without water absorption. Preferably, swimsuits have been designed with the lowest or no sewn seams, so the stress applied to the body would be reduced; in fact, the softer and smoother the swimsuit, the lower the friction and stresses applied to the body. As mentioned above, the full body swimsuit has sleeves (short or long). As can be seen in Figure 1, the shoulders are the center of the hand movements according to the swimming biomechanics [14].

Thus, the sleeves connection with the suit (sleeve ring) is an important and stressed spot in swimsuits, affecting the swimmer's freedom of action. However, no study has yet been conducted on the effects of the design of full body swimsuits on the swimmer's performance. Providing the requirements of swimsuits, such studies aim to eliminate the existing defects and provide better swimsuits for the future. This study, therefore, attempts to investigate the effects of the sleeve style on the tensile behavior of the full body swimsuit.



**Figure 1.** Stress concentration on sleeves during hand movements in swimming.

## Material and Methods

Wearable sensors developed over the past decade have led to some new technological advances in designing smart, small and lightweight monitoring systems [15,16]. This study investigated the tension variations within the sleeves of the full body swimsuit using a conductive yarn as a force sensor. The conductive yarn incorporated into an electrical circuit had the potential of sewability and stretchability [17]. The sleeve tension variations were measured using a piece of a metal yarn sewn into the area near the armhole seam and its tension variations under the hand movement were investigated [18]. Due to high extensibility, polyester/lycra weft knitted fabric was employed for the preparation of the samples. Two full body swimsuits with two different sleeve styles, i.e., raglan and drop, were designed in the size 38 (see Figure 2). The suits were sewn using the textured polyester thread and 304, 504 and 516 stitches. Figure 3 displays the swimsuits.



**Figure 2.** Drop and raglan style sleeves in the full body swimsuit.



**Figure 3.** Full body swimsuit with (a) drop style sleeves and (b) raglan style sleeves.

The metal yarn containing 80% stainless steel fibers (due to high resistance) and 20% polyester fibers was sewn within the area near the armhole seam to record the tension variation induced by the hand movements. Table 1 presents the specifications of the metal yarn. During the extension of the conductive yarn, the conductive fibers slipped over each other, and causing the linear resistance variation of the conductive yarn which could be recorded by an electronic circuit board and converted from an analog form to a digital one [19]. The metal yarn cross section is also shown in Figure 4.

**Table 1.** The specifications of the metal yarn

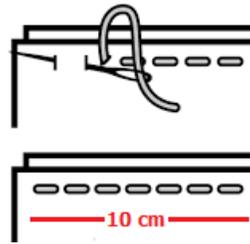
Linear Density (Tex)	Breaking Strength (cN/tex)	Breaking Elongation (%)	Linear Resistance ( $\Omega$ /m)
59.50	9.46 (10.53)*	7.89 (11.45)	158 (8.55)

\*Data in parentheses represent the coefficient of variation (CV %)



**Figure 4.** The cross section of the conductive yarn [20].

According to the biomechanics of swimming, two areas with the highest tension were selected for sewing the metal yarn: the armpits (near the armhole seam) and armhole seam [14]. Sewing condition clearly affects the tension measurement. Therefore, a quite similar hand stitch method with 7 stitches per 10 centimeters density was used for all samples, which was approximately tension-free, assuring that there was no pre tension in the yarn before test. The metal yarn was stitched on the fabric with 10 cm length and 10-15 cm extra length at both ends to be connected into the electronic circuit (see Figures 5 and 6).



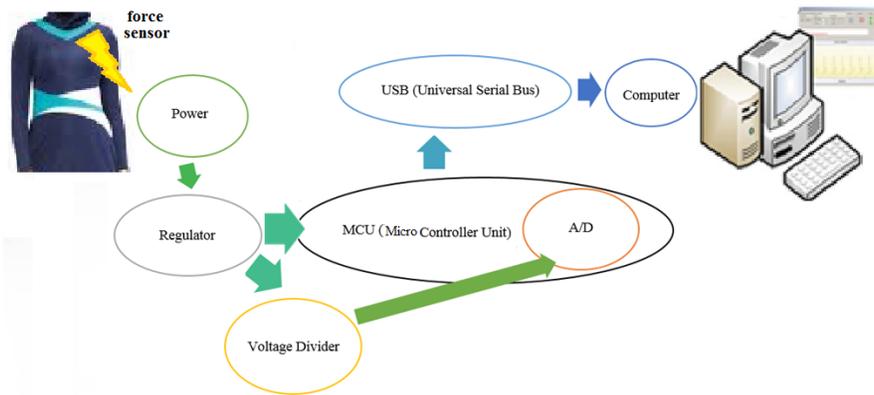
**Figure 5.** Schematic of the sewing condition of the metal yarn.



**Figure 6.** Metal yarn in the proposed full body swimsuits with (a) drop sleeves and (b) raglan sleeves.

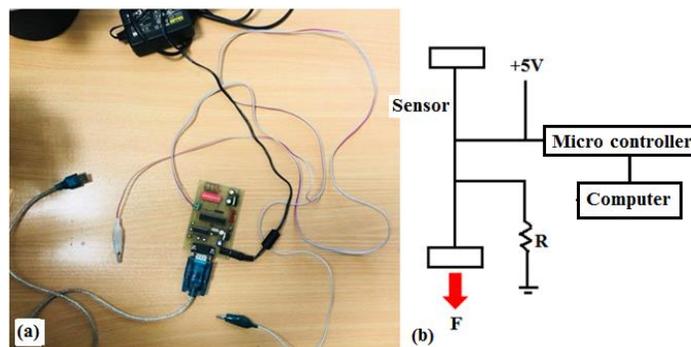
Afterward, the full body swimsuits were worn by an individual female with a suitable size and the alligator clips of the electronic circuit were connected to the two ends of the metal yarn. Then, one period of the hand movement during swimming was done by the individual [21] and the software was run. This experiment was repeated for three identical samples of each swimsuit type and the data were recorded. The electronic circuit

consisted of a computer, sensors, alligator clips, board and power supply. The analog quantity of the yarn length variation was translated into the numerical quantity of resistance using an Analog-to-Digital converter. Figure 7 demonstrates the components on the board.



**Figure 7.** Electronic circuit components recording the tension variations.

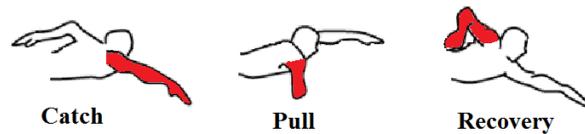
The electric board was connected to the two ends of the metal yarn with a long connection to investigate the output voltage variations during the metal yarn elongation; also, its specific resistance was measured. Afterward, the samples worn by the individual were applied to the circuit to record the voltage variations during the metal yarn elongation through one period of hand movements and swimsuit expansion. It was possible to convert the recorded voltage variations for each sample into resistance variations. The resistance variations were transferred to the computer connected to the board by a device. Figure 8 illustrates the structure of the electronic circuit.



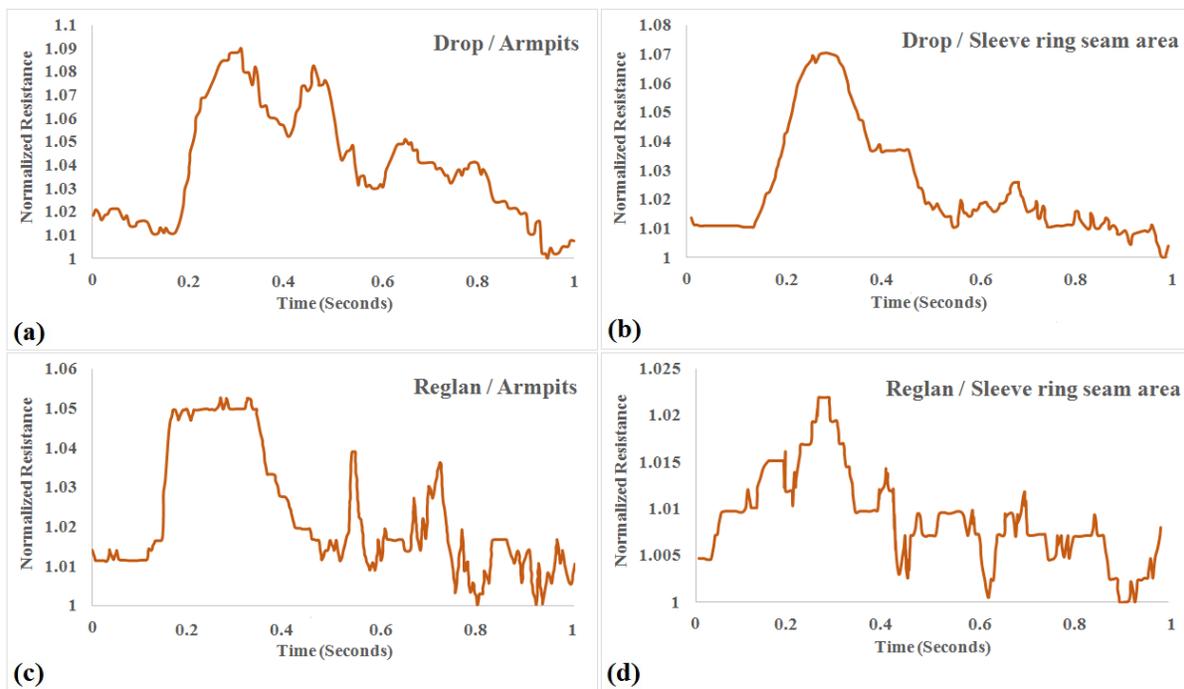
**Figure 8.** (a) Electronic equipment used in the experiment and (b) resistance variation measurement circuit of the conductive yarn during elongation.

## Results and Discussion

An individual simulated the front crawl arm action. Essential parts of the front crawl arm technique were divided into catch, pull and recovery [22] (see Figure 9). In the catch phase, the individual’s hand reached forward until the arm was fully extended. In the pull phase, her arm was pulled under the body towards the hip; then, her elbow was bent and the arm was fully relaxed during the recovery phase. The resistance variations were recorded for two styles of full body swimsuits during hand movements for a cycle of the front crawl arm action. For each sleeve style, according to the positions of the sewn metal yarn, resistance variation versus time was determined. The metal yarn resistance variation was a criterion of its tension variation during hand movements. The mean results of the experiments are demonstrated in Figure 10. It should be noted that the precision of the used sensor was one hundred-thousandth of an ohm.



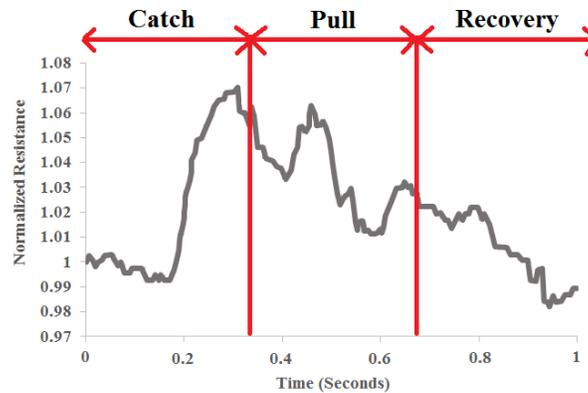
**Figure 9.** Essential parts of the front crawl arm technique.



**Figure 10.** Metal yarn resistance variations for (a) drop sleeves with the metal yarn on the armpits, (b) drop sleeves with the metal yarn near the seam, (c) raglan sleeves with the metal yarn on the armpits, and (d) raglan sleeves with the metal yarn near the seam (normalized resistance is the division of resistance at any time to the resistance of the non-extended state)

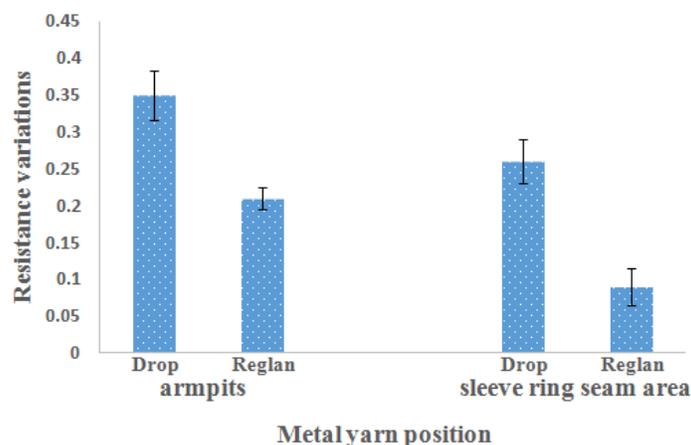
As can be seen in Figure 10, the dominant peak occurred in the first seconds (lower than 0.4 seconds) for all sleeve’s types. By starting the hand movements and reaching the full extension, the highest tension happened on the armpits and near the seams (see Figure 11). In the following, the tension was reduced as the hands were

pulled backward, with short irregular peaks being seen in the graphs. Figure 11 clearly demonstrates that there were three areas in the resistance curve that corresponded to the three phases of the front crawl arm action.



**Figure 11.** A typical resistance-time diagram for three front crawl arm actions.

Figure 12 indicates the difference between the highest and lowest resistance of the tensioned yarn for both sleeves' types and both metal yarn positions. As expected, the difference for the armpits was higher than that near the seam for both sleeve types. According to swimming biomechanics, the highest tension caused by the hand movements was applied to the shoulder [14]. This difference was about 0.35 and 0.21 ohm for drop and raglan style sleeves, respectively. At the same time, the metal yarn resistance difference was about 0.26 and 0.09 ohm near the armhole seam for the drop and raglan style sleeves, respectively. The results, therefore, showed that the difference in the tensioned metal yarn resistance for both positions was lower for the raglan style sleeves, as compared to the drop ones. Thus, it could be concluded that the tension variations were lower during swimming with the raglan-sleeved full body swimsuit. Since the main goal of the swimsuit designs is to reduce the tension and stress during swimming, raglan sleeves could be more suitable. The use of this sleeve type in the full body swimsuit can, therefore, provide better speed and freedom of action, while ensuring sufficient coverage as well. This is the reason that why raglan sleeves are employed for most sports wears including swimsuits.



**Figure 12.** Metal yarn resistance variations for drop and raglan sleeves.

## Conclusion

Scientific researches in different sport areas have played an important role in the development and improvement of the athletes' performance [23-25]. Various sports, in particular, swimming, are associated with biomechanics; so, it is necessary to conduct biomechanical studies with the emergence of new technologies. Swimsuits can be regarded as an important and fundamental tool in swimming, significantly influencing the swimming speed and quality. Hence, the design of swimsuits according to swimming biomechanical principles is of great importance. The full body swimsuit has been designed to allow women to have full coverage, as well as ensuring hijab while swimming. As the shoulders are the rotation center of the hands in swimming, it is required to investigate the tension variations in the sleeves area of the swimsuits. This study explored the sleeve designs for the full body swimsuits and investigated the effects of the sleeve styles on their tensile behavior. Accordingly, two full body swimsuits were proposed with drop and raglan style sleeves in the size of 38 using the polyester/Lycra fabric. A piece of the metal yarn was employed on the armpits and near the armhole seam to examine the tension variations during the hand movements. The length variation of the metal yarn due to the hand movements was recorded in the form of resistance variations, serving as a criterion of sleeve tension variations. The results indicated that the tension variations induced by the swimmer's hand movements were lower for the raglan sleeves, as compared to the drop ones. The use of raglan style sleeves in the full body swimsuit can, therefore, reduce the tension variations on the sleeves, thereby increasing the swimmer's speed and freedom of action.

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## چکیده فارسی

### بررسی تأثیر طراحی بیومکانیک لباس شنای یکسره (سرهمی) بر رفتار کششی آن در ناحیه‌ی شانه

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#### چکیده فارسی

لباس شنای یکسره، یکی از انواع البسه‌ی شنای زنان است که بر اساس تأکیدات دین اسلام بر پوشش کامل بدن، طراحی شده است. لباس شنا تأثیر زیادی بر سرعت و کیفیت شنا دارد و از اینرو بررسی طراحی، برش و دوخت لباس شنا بر اساس اصول بیومکانیک این ورزش اهمیت ویژه‌ای می‌یابد. در این پژوهش، تأثیر فرم برش آستین لباس شنای اسلامی بر رفتار کششی در ناحیه شانه مورد بررسی قرار گرفته است. دو نوع لباس شنای اسلامی مختلف شامل آستین معمولی و رگلان در سایز ۳۸ الگوکشی و با استفاده از پارچه‌ی حلقوی پلی‌استر/لایکرا تولید شده‌اند. جهت بررسی تغییرات کششی مطابق با حرکات دست در شنا، از یک نخ فلزی حاوی ۸۰٪ فولاد در دو قسمت زیر بغل و کنار حلقه آستین (نزدیک درز) استفاده شده است. کشش اعمالی به آستین و به تبع آن شانه شناگر توسط نخ فلزی اندازه‌گیری می‌شود. نخ فلزی بعنوان حسگر در یک مدار الکتریکی قرار گرفته است و میزان کشش اعمالی را تشخیص می‌دهد. اختلاف ولتاژ بین دو سر نخ فلزی در حین حرکت دست در شنا اندازه‌گیری شده و به مقاومت الکتریکی تبدیل می‌شود. نتایج نشان می‌دهد تغییرات کشش ناشی از حرکات دست شناگر در هر دو موقعیت آزمایش شده، در لباس شنا با آستین رگلان ( $0.26 \pm 0.031$  اهم و  $0.09 \pm 0.025$  اهم) کمتر از آستین معمولی ( $0.34 \pm 0.034$  اهم و  $0.21 \pm 0.015$  اهم) است. کاهش تغییرات کشش در محل آستین لباس شنای اسلامی و ناحیه شانه سبب افزایش سرعت و آزادی عمل شناگر خواهد شد. استفاده از آستین رگلان در اغلب البسه‌ی ورزشی از جمله لباس شنای اسلامی نیز در این راستاست.

**واژه‌های کلیدی:** لباس شنای اسلامی، طراحی بیومکانیک، آستین، رفتار کششی، نخ فلزی، تجهیزات الکتریکی.