Smart Shin Guard

Ali Mirzazadeh

Faculty Member #1: Professor Thad Starner

Signature: DocuSigned by:
30005B75D79641B...

Faculty Member #2: Professor Omer T. Inan

Signature: DocuSigned by:
Omer Inan
F6296C3B695F463...

Smart Shin Guard

STUDENT: ALI MIRZAZADEH, INJOO MOON
MENTOR: PROFESSOR THAD STARNER, PROFESSOR OMER INAN

Overview

Fatigue assessment is a highly subjective yet important marker for high-performance athletes as they strive to maintain fitness and avoid injuries during the season. Fatigue and overexertion is the leading cause of muscular injury in soccer players, primarily in the lower leg. This paper presents a smart shin-guard that can measure the bioimpedance of the calf muscle in a fully portable and wearable system. This marker can be linked to fatigue and fitness levels of the individual, allowing for both short and long-term tracking of player fitness levels.

1 INTRODUCTION

Muscular injuries account for over 30% of injuries in soccer, and 92% of these muscular injuries occur in the lower leg [18] [19]. The vast majority of these injuries occur within matches than in training and significantly increases in likelihood near the end of the match, pointing to overstraining of fatigued muscles as a likely major factor.

Fatigue assessment information is important for physios as they can use the information, particularly during the preseason, to ensure players are at a sufficient fitness level for the upcoming games and season. They can monitor and improve the player's fitness by suggesting changes in sleep, diet, and workout routine. Fatigue, however, is difficult to discern for players and managers alike, as self-reporting levels of fatigue is highly subjective and dependent on the player.

As a result, there is significant room for improvement in quantitative health and fatigue assessment of soccer players in matches, as it could provide the coaching staff with vital feedback to make appropriate decisions and avoid costly injuries.

This paper presents a new design for a wearable health monitoring system designed around soccer players. By using tetrapolar bioimpedance measurement devices fitted in a shin guard, we can track a player's fatigue and risk of injury. This information can then be gathered over the course of the season for each player, providing fitness and fatigue information for the coaching and medical staff.

2 BACKGROUND INFORMATION

Measuring the bioimpedance of the calf using a shin guard faces two major considerations: a justification of the calf as a suitable tissue to measure, and the logistics of measuring bioimpedance through a shin guard. Both obstacles will be addressed in the literature review.

2.1. Calf Justification

Tissue bioimpedance provides important insight into tissue health. It can provide information on tissue fatigue, blood flow, and injury. The implications on this are particularly pertinent in sports health, where the monitoring of athletes could prove vital in helping with injury prevention. Bioimpedance measures the current flow impeded by the body, and is affected by skin, tissue and blood content between the electrodes.The effect of muscular fatigue on bioimpedance has been explored in prior work [1] [5] [6] [7]. As a muscle exercises, blood flow in the region increases and this is known to cause an increase in bioimpedance in the region. Furthermore, a significant decrease in bioimpedance is observed when a muscle injury occurs in the region as a result of swelling that occurs in the days following injury [10].

Figura 1: Smart Shinguard with two sets of dry electrode placed on the straps to attach to the back of the calf

Though the majority of prior work has demonstrated bioimpedance on bicep muscle after eccentric activity, soccer seldom uses the hands so it would be an inaccurate estimate of fatigue. Furthermore, the majority of injuries occur in the hamstring (37%), adductors (23%), quadriceps (19%), and calf muscles (13%) [11], so it would be appropriate to instead measure muscular fatigue of the lower leg. Since soccer players are required to wear shin guards in matches, our sensor could be modeled into a shin guard form factor to be unobtrusive to the players.

The ability to monitor fatigue in a wearable setting would provide real-time insight into the fitness levels of players, and allow coaches to make appropriate choices to prevent injuries in the athletes. However, achieving this goal has a number of challenges in achieving a portable setup. This paper explores the limitations and creates a novel bioimpedance sensor in the form factor of a standard shin guard that can provide real time fitness information for coaches.

2.2. Shin Guard Bioimpedance Integration

Bioimpedance measurements began with a bipolar electrode configuration using a conductive gel as an adhesive between the electrode and the skin. As a constant current was applied between the electrodes, the voltage across the electrodes was also measured, and thus the impedance was able to be calculated. However, problems arose in the electrode to skin interface creating impedances that interfered with the measured voltage, as well as a problem with measuring large impedances. Due to the proportional relationship between impedance and voltage, when the bioimpedance of the measured tissue reached a threshold, the power required to complete the circuit would exceed the power given by the current source. Thus, the tetrapolar bioimpedance measurement method was adopted. Two electrodes, that applied a constant voltage and measured current supplied, were placed on the outer limits of the subject tissue. Additionally, two other electrodes were placed between the first pair in order to measure the voltage across the tissue. With this method no matter how large the bioimpedance of the tissue became, since current is inversely proportional to impedance, the resolution of the measured bioimpedance was technically infinite. The additional impedance the outer electrodes created could also be measured and removed from the final data, since the voltage across both pairs of electrodes was being measured.

Integrating the tetrapolar method into a shin guard poses numerous challenges. However, across the industry of wearable dry electrodes, there are only several significant factors that need to be addressed when designing mounted dry electrodes. The first factor is the electrode and its characteristics. The size, shape, material, and location of contact all contribute to the quality of contact that the electrode makes with the skin. Margo et al. show even the possibility of micro-electrodes being able to give high quality bioimpedance data. The second factor is the method of connection between the electrodes and the data collecting device. One commonly used technique is to weave wires into the fabric of the wearable by use of the intarsia knitting technique. This technique allows a patch of yarn to be knit in the weave of another patch of yarn. By using standard fabric for the wearable and using intarsia with a fabric coated in metal or even metal wires themselves, one can use the wearable as the medium between the electrodes and the measuring device. The third factor is a solution to transpiration. In many cases, a buildup of sweat between the electrodes can cause a shortage, and thus ruin measurements. Hydrophobic material may be used as a barrier between electrodes to prevent shortage. However, depending on the design of the wearable, transpiration may be turned into an advantage. Paradiso et al.'s design inherently solved the problem of transpiration by using a design that employed an elastic fabric that could easily absorb water. The wet piece of fabric then became more adhesive to the skin than when it was originally dry, thus creating a more secure connection for the electrode.

3 METHODS

The methodology used to integrate bioimpedance measurement into a shin guard can be broken down into several components: the design and mounting of the electrodes, the connection between the electrodes and the measurement device, and the methods used to test and assess the quality of a configuration. The design was created keeping quality of data and comfort for the user as two priorities.

3.1. Equipment

The equipment used in our design are listed as the following:

- 4 small metal sheets - Aluminium, Copper, or Silver work well - 1cm x 4cm
- 1 shin guard
- A bioimpedance measurement device
- Using AD5933
- Electrical Tape
- A drill press
- Glue
- Copper Tape

3.2. Procedure

The 4 small metal sheets are used as the electrodes. Our prototype uses aluminium sheets, although we have seen that copper and silver electrodes also work well. As long as the material is conductive, the electrode will perform properly. The shape of the electrode is key. Since the band of the shin guard is elastic, the elongated shape of the electrode will stretch the elastic band, thus applying more pressure onto the electrode and thus mitigating the air gap in the skin-electrode interface. Additionally, the shape of the electrode provides a larger contact area with the skin, and is still small enough to avoid causing discomfort for the user.

In order for the electrodes to be securely mounted to an elastic band, they must be prepared appropriately. First the electrodes must have holes pressed along the short sides to allow for stitching. Then the electrodes must be paired and taped together. This gives some structural connection between the electrodes, and allows one electrode's mounting to help secure the other. It is also recommended to bend the electrodes slightly in order to apply more resistance to the band, thus increasing the pressure applied at the point of contact in the skin-electrode interface.

One can confirm the stability of the mounting by field testing the shin guard with a short run or jog.

Connections are then made between the bioimpedance measuring device and the electrodes by soldering wires from the device to the surface of the sheets. We found aluminum to be difficult to solder to, and thus used small squares of copper tape that were tightly adhered to the aluminum as solder points for the wires. Additionally, for a more flexible design, we used very loose wires that held little torque. This allows for a full range of motion for the user without risking the wires snapping at the solder points.

In order to test the quality of the configuration, data may be collected and analysed. For our bioimpedance device, a max of 20k Ohms were allowed for electrode impedance. Additionally, the structural integrity of the configuration may be tested by inspection after a field test. If there are no loose connections or electrodes, the configuration is structurally sound.

The electrodes are mounted onto the band of the shin guard by stitching and glue. The glue provides extra stability to the piece, while not significantly interfering with the elasticity of the band. The mounted electrodes are shown below in Figure 1.

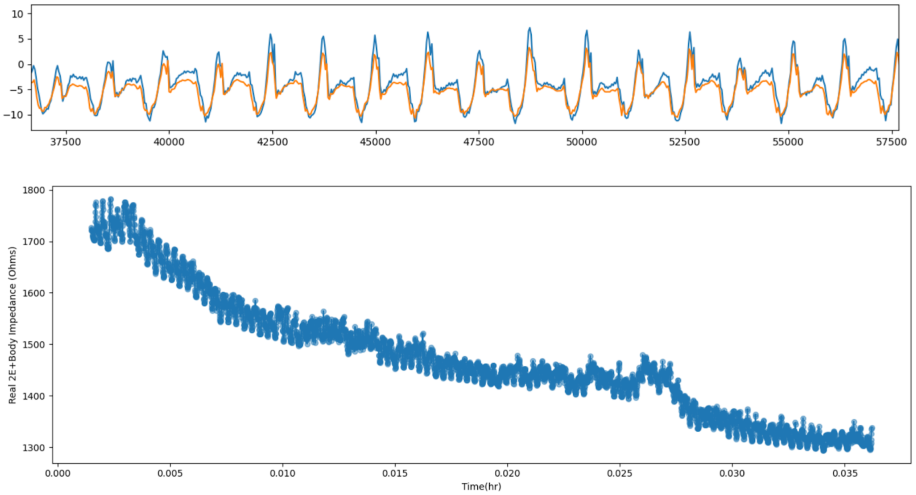

Figura 2: Recorded data from dry electrodes placed on calf. The top figure shows a zoomed in view of low and high frequency signals, while the bottom figure shows a time seris of the total system impedance.

A script then uses the tetrapolar layout properties to eliminate electrode impedance and isolate the body impedance. The script uses the accelerometer of the AD5933 to segment different points of the gate cycle and averages the impedances at each point, extracting useful metrics such as ranges of low and high frequency impedance.

4 RESULTS

4.1. Electrode Validation

The total system impedance (electrode plus body) was around 2000 ohms, comfortably below our cutoff of 20,000 ohms. The slight rigidity of the aluminum electrodes allowed for a snug connection even while walking and running, with minimal disconnects. Figure 2 shows a time-series plot of total impedance measured by the system.

4.2. Fatigue Measurement

To validate whether such a system can show fatigue with sufficient resolution, we designed a basic experiment where a user wore our bioimpedance monitoring device before and after a high-intensity, 90 minute soccer match. The results can be seen in figures 3 and 4. Before the match, the average reactance per step for the low and high frequency signals were quite similar, showing the same trend and converging to similar values. This implies that intracellular and extracellular impedance are both normal. However, post-exercise, the mean reactance between the low and high frequency clearly diverged, and became quite different in value as fatigue set in. This was the case for both walking and running, meaning that regardless of how the measurement was taken, the trend seen was due to activity that occurred between the two measurements.

5 DISCUSSION

This project has successfully demonstrated the acquisition of bioimpedance signals using dry electrodes on the calf muscle, with all hardware and circuitry fit in the form factor of a shin guard. The data could then be gathered for each player and tracked through a personalized fitness monitoring platform. The data could then be used to learn times of extreme or dangerous fatigue and alert the user or coach to prevent possible injuries in training or matches. Future work could collect this data and track soccer players as they use this data for an extended period of time, and create machine learning models to calculate a fatigue score for a player at any given time. Limitations in this study include the lack of extensive testing on different users to show robustness of the setup; however, the study does show that a dry electrode shin guard can provide high fidelity data that is highly correlated with data collected from gel electrodes on the lower leg. Overall, we are able to show a fully wearable athlete muscle fitness monitoring setup that could be of significant help in injury prevention in soccer, and adapted to different form factors for a variety of different sports as well.

6 REFERENCES

[1] Time-course bicep tissue bio-impedance changes throughout a fatiguing exercise protocol

[2] Bioimpedance data monitoring in physical preparation: a real interest for performance of elite skiers for Winter Olympic Games

[3] Campa F, Silva AM, Matias CN, Monteiro CP, Paoli A, Nunes JP, Talluri J, Lukaski H, Toselli S. Body Water Content and Morphological Characteristics Modify Bioimpedance Vector Patterns in Volleyball, Soccer, and Rugby Players. Int J Environ Res Public Health. 2020 Sep 10;17(18):6604. doi: 10.3390/ijerph17186604. PMID: 32927903; PMCID: PMC7559102.

[4] Fu B, Freeborn TJ. Cole-impedance parameters representing biceps tissue bioimpedance in healthy adults and their alterations following eccentric exercise. J Adv Res. 2020 Jun 2;25:285-293. doi: 10.1016/j.jare.2020.05.016. PMID: 32922994; PMCID: PMC7474209.

[5] T. J. Freeborn, G. Regard and B. Fu, "Localized Bicep Tissue Bioimpedance Alterations Following Eccentric Exercise in Healthy Young Adults,"in IEEE Access, vol. 8, pp. 23100-23109, 2020, doi: 10.1109/ACCESS.2020.2970314.

[6] Freeborn, T., & Fu, B. (2018). Fatigue-Induced Cole Electrical Impedance Model Changes of Biceps Tissue Bioimpedance.

[7] Li L, Shin H, Li X, Li S, Zhou P. Localized Electrical Impedance Myography of the Biceps Brachii Muscle during Different Levels of Isometric Contraction and Fatigue. Sensors (Basel). 2016 Apr 22;16(4):581. doi: 10.3390/s16040581. PMID: 27110795; PMCID: PMC4851095.

[8] Vescio G., Rosell J., Nescolarde L., Giovinazzo G. (2011) Muscle Fatigue Monitoring Using a Multi-frequency Bioimpedance Technique. In: Jobbagy A. (eds) 5th European Conference of the International Federation for Medical and Biological Engineering. IFMBE Proceedings, vol 37. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-23508-5_325

[9] Ikai T., Saigou R., Kyoso M., Ishijima M. (2007) Dynamic Electrical Characteristics of the Muscle with the Fatigue during Exercise. In: Magjarevic R., Nagel J.H. (eds) World Congress on Medical Physics and Biomedical Engineering 2006. IFMBE Proceedings, vol 14. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-36841-0_143

[10] Nescolarde L, Yanguas J, Lukaski H, Alomar X, Rosell-Ferrer J, Rodas G. Effects of muscle injury severity on localized bioimpedance measurements. Physiol Meas. 2015 Jan;36(1):27-42. doi: 10.1088/0967-3334/36/1/27. Epub 2014 Dec 11. PMID: 25500910.

[11] Margo C, Katrib J, Nadi M, Rouane A. A four-electrode low frequency impedance spectroscopy measurement system using the AD5933 measurement chip. Physiol Meas. 2013 Apr;34(4):391-405. doi: 10.1088/0967-3334/34/4/391. Epub 2013 Mar 13. PMID: 23481406.

[12] Mabrouk S, Hersek S, Jeong HK, Whittingslow D, Ganti VG, Wolkoff P, Inan OT. Robust Longitudinal Ankle Edema Assessment Using Wearable Bioimpedance Spectroscopy. IEEE Trans Biomed Eng. 2020 Apr;67(4):1019-1029. doi: 10.1109/TBME.2019.2927807. Epub 2019 Jul 10. PMID: 31295102; PMCID: PMC7217444.

[13] Ferreira J, Seoane F, Lindecrantz K. AD5933-based electrical bioimpedance spectrometer. Towards textile-enabled applications. Annu Int Conf IEEE Eng Med Biol Soc. 2011;2011:3282-5. doi: 10.1109/IEMBS.2011.6090891. PMID: 22255040.

[14] Marquez JC, Ferreira J, Seoane F, Buendia R, Lindecrantz K. Textile electrode straps for wrist-to-ankle bioimpedance measurements for Body Composition Analysis. Initial validation & experimental results. Annu Int Conf IEEE Eng Med Biol Soc. 2010;2010:6385-8. doi: 10.1109/IEMBS.2010.5627305. PMID: 21096699.

[15] Beckmann L, Neuhaus C, Medrano G, Jungbecker N, Walter M, Gries T, Leonhardt S. Characterization of textile electrodes and conductors using standardized measurement setups. Physiol Meas. 2010 Feb;31(2):233-47. doi: 10.1088/0967-3334/31/2/009. Epub 2010 Jan 20. PMID: 20086274.

[16] R. Paradiso, A. Gemignani, E. P. Scilingo and D. De Rossi, "Knitted bioclothes for cardiopulmonary monitoring,"Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No.03CH37439), 2003, pp. 3720-3723 Vol.4, doi: 10.1109/IEMBS.2003.1280968.

[17] Marquezruiz, Juan Carlos Seoane, Fernando & Välimäki, E. & Lindecrantz, Kaj. (2010). Comparison of Dry-Textile Electrodes for Electrical Bioimpedance Spectroscopy Measurements. Journal of Physics: Conference Series. 224. 012140. 10.1088/1742-6596/224/1/012140.

[18] Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. Br J Sports Med. 2011 Jun;45(7):553-8. doi: 10.1136/bjsm.2009.060582. Epub 2009 Jun 23. PMID: 19553225.

[19] Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011 Jun;39(6):1226-32. doi: 10.1177/0363546510395879. Epub 2011 Feb 18. PMID: 21335353.

7 SUPPLEMENTARY INFORMATION

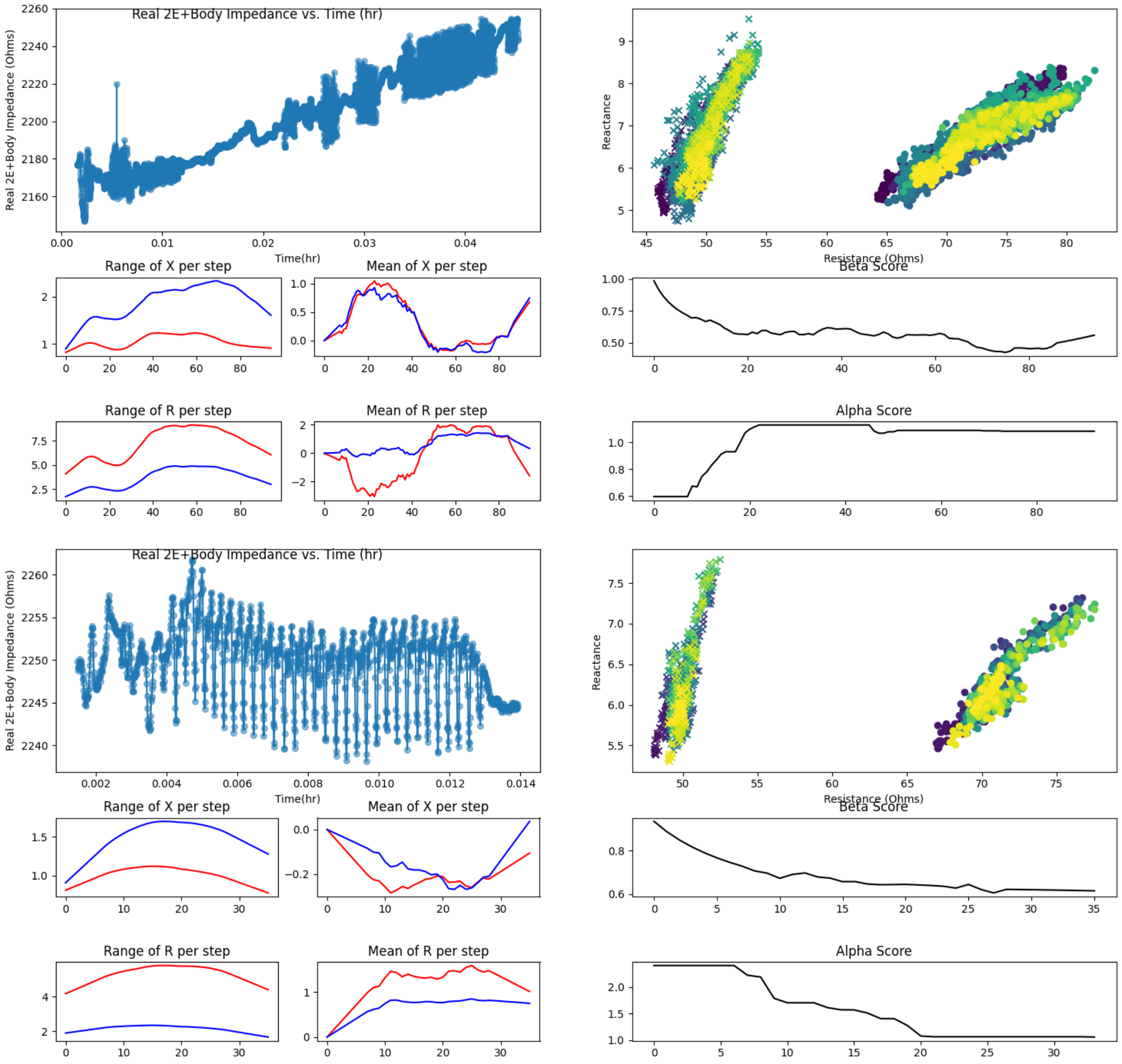

Figura 3: Pre Workout Data. Figure a is the time series total impedance, figure b is a scatter plot of reactance vs resistance for all data points, figure c is the mean and range of reactance and resistance per step, and figure d is the alpha and beta (indicative of swelling) over the recording.

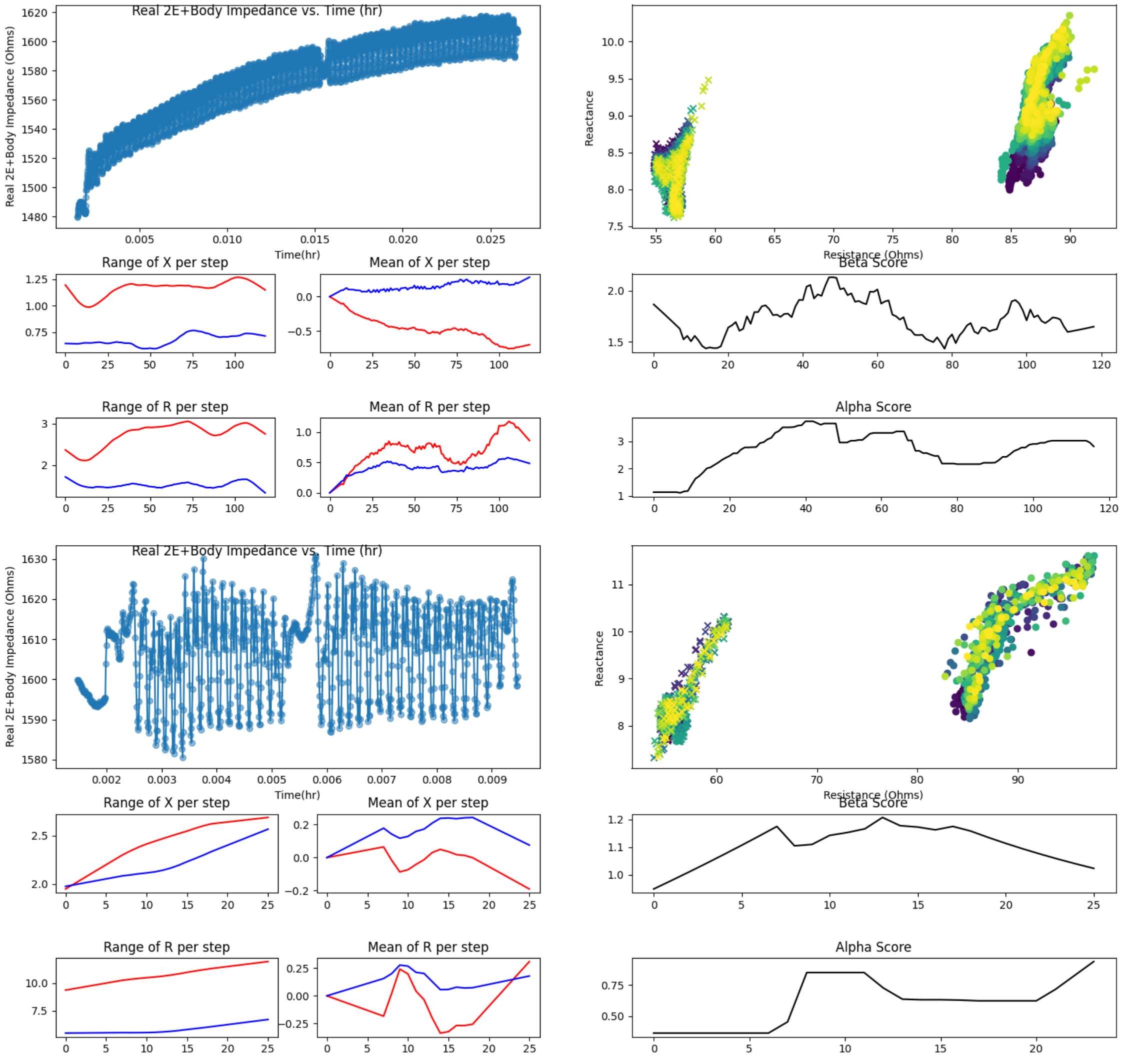

Figura 4: Post Workout Data. Figure a is the time series total impedance, figure b is a scatter plot of reactance vs resistance for all data points, figure c is the mean and range of reactance and resistance per step, and figure d is the alpha and beta (indicative of swelling) over the recording.