Analyzing the impact of sports activity intensity on muscle capacity through integrated biosensor technology

Ervin Masita Dewi[1], Nurista Wahyu Kirana[1], Sugondo Hadiyoso[2]
[1]Department of Electrical Engineering, Bandung State Polytechnic, Bandung, Indonesia
[2]School of Applied Science, Telkom University, Bandung, Indonesia

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ABSTRACT

In the past few years, biosensor technology has paved the way for new insights into the physiological effects of physical exercise. Quantitative analysis, especially in the case of muscle capacity measurement, is the focus of studies to assess the impact of sports activities. Therefore, this study examines the impact of sports activity intensity on muscle capacity using an integrated biosensor system developed at Bandung State Polytechnic. Surface electromyography (sEMG) measurements were conducted on 30 participants aged 20–25 during various sports activities. Results showed a strong positive correlation (r=0.814) between sports activity frequency and muscle contraction, suggesting higher activity correlates with increased muscle activity. Conversely, the correlation during muscle relaxation was low (r=0.261), indicating independence from sports activity. In the future, it is expected that integrated biosensors will have the ability to concurrently measure and monitor various parameters like heart rate (via electrocardiogram), blood oxygen levels (via photoplethysmography), and blood pressure. The integrated biosensor system allows for comprehensive assessment and optimization of sports performance and injury prevention strategies.

Corresponding Author:

Sugondo Hadiyoso
School of Applied Science, Telkom University
St. Telekomunikasi 1, Terusan Buahbatu-Bojongsoang, Bandung, West Java 40257, Indonesia
Email: sugondo@telkomuniversity.ac.id

1. INTRODUCTION

The neuromuscular system consists of the body's nervous system and all the muscles in the body. Nerves and muscles cannot be separated in carrying out every movement carried out by the body [1]. Communication between nerves and muscles is so fast that the body is not even aware of it. Nerves and muscles as the neuromuscular system, working together make the body move as desired, breathing is one example [2].

The neuromuscular system has an important role in sports. Muscles whose function is to contractions and relaxations are controlled by the nervous system so that their strength, accuracy, and power are controlled [3]. In specific circumstances, the neuromuscular system may encounter disruption or diminished function, primarily stemming from a decline in the body's muscle mass due to aging and lifestyle factors, particularly excessive physical exertion [4], [5]. Excessive physical activity can lead to muscle fatigue and ultimately, muscle damage [6], [7]. In other term, excessive physical activity without sufficient rest can lead to muscle fatigue, which, if not managed properly, can result in significant muscle damage.

Surface electromyography (sEMG) signals can be adopted as a non-invasive assessment tool of the status of the neuromuscular system [8]. Through sEMG measurements after training, the rate of development of muscle strength, identification of the relationship between aging and decline in motor performance and changes in neuromuscular function can be monitored. The proposed technology is very useful, especially for analyzing physiological processes regarding motor control for exercise physiology and medical rehabilitation experts [9]–[11].

Therefore, this study conducted a quantitative analysis of the correlation between muscle contraction and activities related to muscle function. The study was carried out to determine the capacity of muscles as a result of physical exercise. The objective of this study is to assess the practicality of sEMG in the realm of sports utilizing biosensors developed by the biomedical research group at the Bandung State Polytechnic. This biosensor integrates multiple sensors, including the sEMG sensor, electrocardiography (ECG) sensor, photoplethysmography (PPG) sensor, and blood pressure (BP) sensor. The integrated biosensor will subsequently be employed in research endeavors, enabling simultaneous measurement of various parameters to yield more comprehensive results. Initially, sEMG testing was conducted on cohorts of students aged 20–25 years participating in different sports activities [12]–[20].

2. METHOD

The proposed study aims to investigate the influence of sports activity intensity on muscle capacity using an integrated biosensor system. The integrated biosensor, developed by the biomedical research team at the Bandung State Polytechnic, combines various sensors including sEMG, ECG, PP, and BP. By utilizing the comprehensive biosensor setup, its aim to assess how different levels of sports activity intensity affect muscle performance and capacity. Figure 1 shows the block diagram illustrating the integrated biosensor system [14], [20].

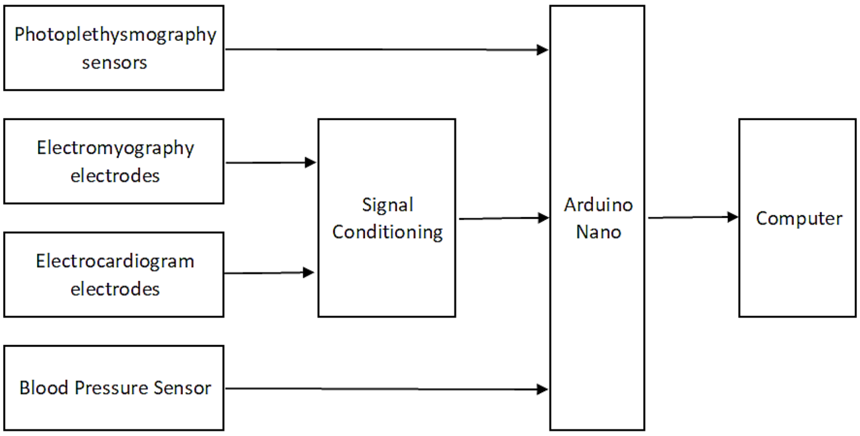

Figure 1. Illustration of integrated biosensor system

The study involves conducting sEMG measurements on individuals engaged in various sports activities, with a particular focus on assessing muscle capacity under different intensities of physical exertion. Participants in the study consist of cohorts of individuals aged between 20–25 years, representing a diverse range of sports activities and fitness levels. Through rigorous data analysis and statistical modeling, we aim to elucidate the relationship between sports activity intensity and muscle capacity, providing valuable insights for sports performance optimization and injury prevention strategies.

Electromyography (EMG) is the process of recording muscle electrical activity to determine whether they are actively contracting or not. Muscles play a crucial role in various human activities such as work, sports, learning, and even during sleep. EMG signals typically have a frequency range between 20–500 Hz and amplitudes ranging from 0–10 mV. Since most outputs from biomedical sensors, including EMG, produce weak signals, a signal conditioning circuit is necessary to ensure proper detection and display on a monitor. EMG signals convey valuable information about muscle condition and can be used to diagnose damage to the peripheral nervous system [21]–[25].

Calculating muscle tension using an EMG sensor involves several steps:

– Preparation: before placing the surface electrodes, the skin area where the electrodes will be attached needs to be cleaned to remove any oils or dirt that could interfere with the signal. Additionally, any excess hair may need to be shaved to ensure good electrode contact with the skin.

- Placement of electrodes: surface electrodes are then placed on the skin over the muscle or muscles of interest. The exact placement depends on the specific muscles being measured and the goals of the measurement. Typically, electrodes are placed in a bipolar configuration, with one electrode serving as the active (recording) electrode and another as the reference electrode. It's essential to ensure consistent electrode placement across participants and sessions to maintain data consistency.
- EMG signal recording: the EMG sensor records the electrical signals generated by muscle activity during contraction or relaxation.
- Signal processing: the recorded EMG signal is then processed to remove noise and artifacts and to obtain more detailed information about muscle activity.
- Determining muscle tension: muscle tension calculated from the EMG signal using root mean square (RMS) methods. RMS is the average value of the squared EMG signal over a certain period of time. It provides an estimate of the strength or intensity of muscle contraction [26].

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \quad (1)$$

  N is the number of samples in the data and x_i is the value of each sample in the data.
- Interpretation and analysis: the calculated muscle tension can then be interpreted and analyzed in the context of the observed activity or movement. This can be used to monitor muscle strength, fatigue levels, or evaluate sports performance.

$$EMG\ signal = row\ signal\ x\ \frac{V\ reff}{ADC\ resolution} \quad (2)$$

  $EMG\ signal$ is the measurement of EMG in Volt, $row\ signal$ is the measurement of EMG from electrodes, $V\ reff$ is the voltage reference for determines the range voltage, and $ADC\ resolution$ is the refers to the number of bits used to represent the analog input signal in digital form.

3. RESULTS AND DISCUSSION

The measurement was conducted on 30 students with varying levels of physical activity intensity ranging from low intensity (1-3 days per week) to moderate intensity (3-5 days per week). The measurements were obtained using an integrated biosensor, as depicted in Figure 2. The EMG electrodes were placed on the forearm, as shown in Figure 3, to assess the muscle strength of the participants.

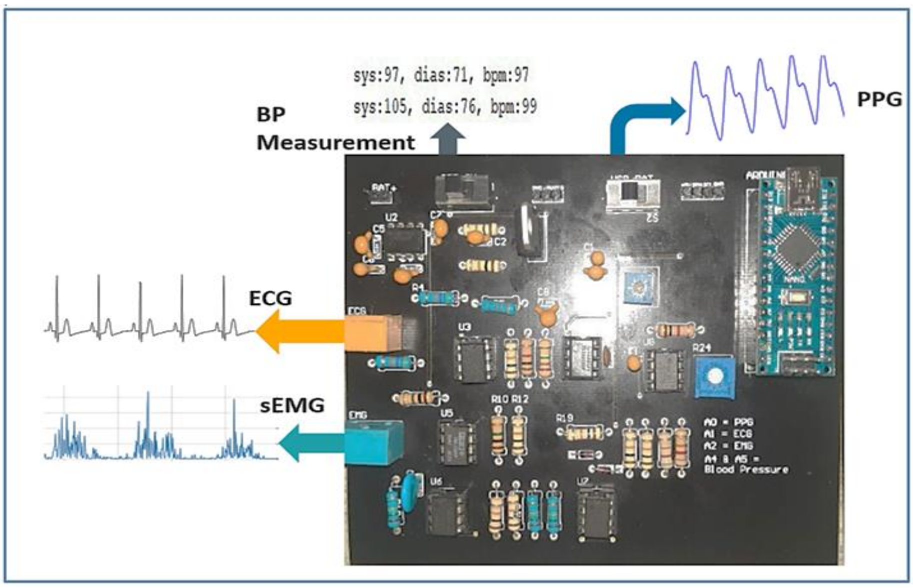

Figure 2. Illustration of integrated biosensor

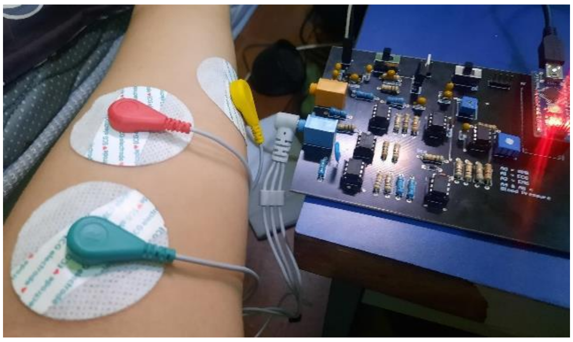

Figure 3. Illustration of the EMG electrodes were placed on the forearm

Figure 4 provides an example of EMG signal output from the participants, illustrating two conditions: contraction that indicating muscle activity, and relaxation that representing muscle rest. The measurements are conducted for one minute by instructing participants to perform gripping and relaxation movements. From this one-minute measurement, the RMS value is determined according to (1). Subsequently, the voltage value from the EMG signal is calculated using (2), with a reference voltage of 5 volts and a 10-bit analog-to-digital converter (ADC).

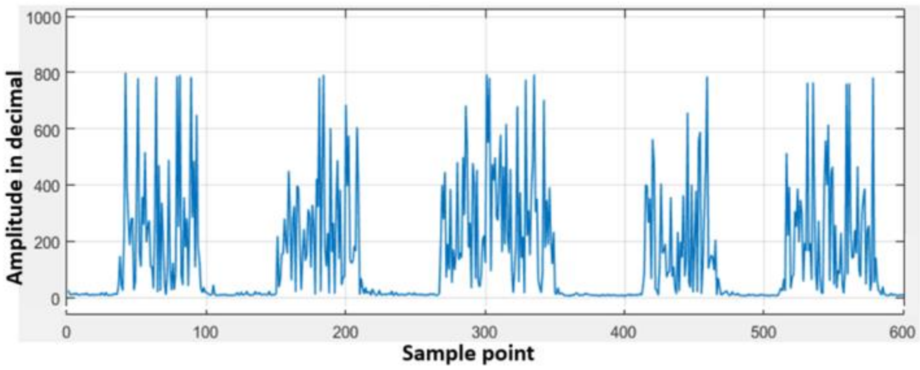

Figure 4. Illustration of the EMG signal from one of the participants

Table 1 displays the measurement results from 30 participants. Correlation analysis was conducted between the frequency of sports activities (times a month) and the EMG signal during muscle contraction/relaxation based on the data in the table. The obtained result shows a correlation of 0.814 between the frequency of sports activities and the EMG signal during muscle contraction. This suggests a strong positive relationship between the frequency of sports activities and the EMG signal during muscle contraction. Meanwhile, the correlation between the frequency of sports activities and the EMG signal during muscle relaxation is quite low, only 0.261, indicating that the EMG signal during relaxation is not dependent on an individual’s sports activity. The comparison chart of sports activity frequency with EMG signals during muscle contraction and relaxation can be observed in Figure 5. Figure 5 provides a better understanding of the results presented in Table 1.

Figure 5 shows the relationship between exercise frequency, muscle contraction, and relaxation. The blue line shows the exercise frequency, as exercise frequency increases, muscle contraction increases, as shown by the orange line. This shows a positive correlation between the two parameters. The linear contraction trend, shown by the dashed orange line, highlights the steady increase in muscle contraction over time. Meanwhile, the gray line shows muscle relaxation remained consistently low throughout the period. This shows that as the frequency of physical activity increases, muscle contraction increases while muscle relaxation is low. This shows that the muscles are under stress as the activity level increases. Overall, the graph illustrates how increasing exercise activity leads to greater muscle contraction, with less relaxation.

Table 1. The EMG signal measurements on 30 participants

No	Age (years)	Height (cm)	Body weight (kg)	frequency of sports activities (times a month)	EMG signal during muscle contraction (volt)	EMG signal during muscle relaxation (volt)
1	21	170	59	2	2.30	0.00
2	20	165	53	0	2.10	0.06
3	21	174	58	1	2.40	0.03
4	20	165	65	0	1.47	0.03
5	20	172	67	1	2.70	0.09
6	21	149	57	0	1.90	0.02
7	20	175	52	0	1.80	0.00
8	21	163	48	0	2.17	0.04
9	20	174	51	0	1.57	0.08
10	20	170	55	4	3.80	0.00
11	20	166	90	0	2.59	0.02
12	20	170	56	0	2.59	0.01
13	20	152	50	0	1.70	0.15
14	21	170	68	4	4.20	0.14
15	21	169	47	3	3.46	0.00
16	20	165	50	2	2.67	0.16
17	20	170	53	0	1.18	0.04
18	22	169	56	0	2.90	0.03
19	23	172	63	3	3.40	0.01
20	22	172	60	0	2.47	0.01
21	24	174	65	4	3.40	0.01
22	21	170	64	0	2.70	0.05
23	24	168	59	4	3.50	0.04
24	23	171	59	4	3.38	0.01
25	24	169	60	2	3.20	0.07
26	20	174	61	0	2.50	0.01
27	20	172	68	2	2.80	0.03
28	25	173	65	0	2.50	0.05
29	23	170	62	4	3.10	0.50
30	21	169	57	2	2.81	0.35

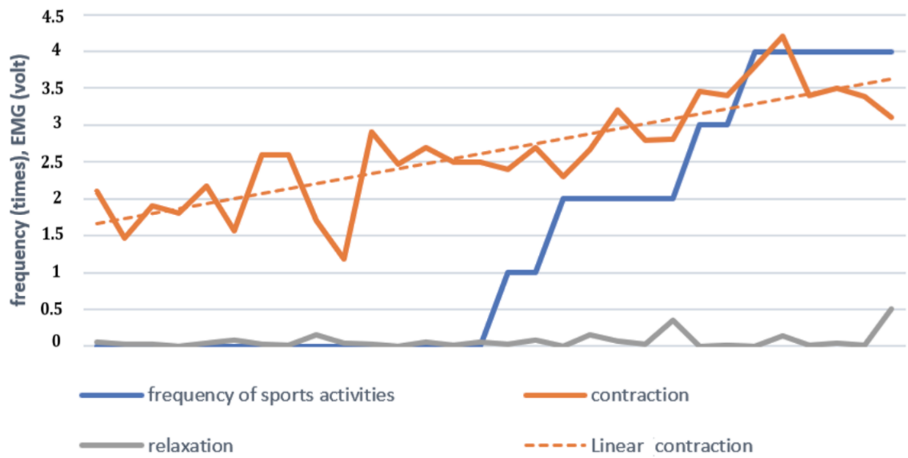

Figure 5. Illustration of comparison between sports activity frequency with EMG signals during muscle contraction and relaxation

4. CONCLUSION

This study findings revealed a correlation analysis between the frequency of sports activities (times a month) and the EMG signal during muscle contraction/relaxation. The analysis demonstrated a correlation coefficient of 0.814 between the frequency of sports activities and the EMG signal during muscle contraction, indicating a strong positive relationship. Conversely, the correlation between the frequency of sports activities and the EMG signal during muscle relaxation was relatively low at 0.261. This suggests that the EMG signal during relaxation is not significantly influenced by an individual's sports activity level. By simultaneously monitoring parameters such as heart rate (via ECG), blood oxygen levels (via PPG), and blood pressure (via BP), we seek to gain insights into the physiological responses accompanying different levels of sports activity intensity. The limitation of this study is that the current integrated biosensor system relies on near field communication (NFC), which requires close proximity for data collection, limiting its applicability in scenarios requiring remote monitoring. Future work will focus on developing wireless technology to enable remote access and seamless integration with telehealth systems.

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BIOGRAPHIES OF AUTHORS

Ervin Masita Dewi received the Doctor degree Biomedical Engineering from the School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia, with the Dissertation "Cardiovascular System Modeling Using Windkessel Segmentation Model Based on Photoplethysmography Measurements". She is a lecturer of biomedical instrumentation and biomedical system design, at Department of Electrical, Politeknik Negeri Bandung, Bandung, Indonesia. She has published 8 papers in journal/conference proceedings with the topic of early detection cardiovascular disease. She can be contacted at email: ervinmasita@polban.ac.id.

Nurista Wahyu Kirana received the B.Eng. degree in Telecommunication Engineering from the Electronics Engineering Polytechnic Institute of Surabaya, Surabaya, Indonesia, in 2010, and the Master's degree in Electrical Engineering from the Brawijaya University, Malang, Indonesia, in 2016. She is currently a lecturer at Department of Electrical Engineering, Polytechnic State of Bandung. Her current research interests include biomedical engineering, digital signal processing, antenna, and microwave propagation. She can be contacted at email: nurista.wahyu@polban.ac.id.

Sugondo Hadiyoso received the Doctor in Electrical Engineering from Institut Teknologi Bandung, Indonesia in March 2023. Since 2010, he joined as a lecturer in the Diploma of telecommunication technology, School of Applied Science, Telkom University. He is also currently members of Biomedical Instrumentation Research Group in Telkom Univesity. His research interests are wireless sensor network, embedded system, logic design on FPGA, and biomedical engineering. The focus of his doctoral research is signal processing and analysis of EEG signals. He can be contacted at email: sugondo@telkomuniversity.ac.id.