Evaluation of Dynamic Gait Muscle Activation in Individuals with High and Low BMI using Electromyography

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***Abstract*— Electromyography offers valuable insights in the activity of muscles during ambulatory motion enhancing understanding of biomechanical mechanisms. The study investigates the activation patterns of lower limb muscles in individuals with high and low body mass index during gait using surface electromyography. The sEMG signals are acquired from 15 high BMI and 15 low BMI individuals while walking on a flat surface at a self-selected pace. Four major muscles — Rectus Femoris, Tibialis Anterior, Adductor Magnus, and Semitendinosus—are analysed by placement of electrode on the lower limb. Individuals with High BMI showed a 20-35% increase in RMS activity of muscles Rectus Femoris and Adductor Magnus indicating high activation while individuals with Low BMI showed more pronounced activation of the Semitendinosus muscle. The observed differences in muscle activation offer insights into neuromuscular co-ordination and can guide targeted rehabilitation for individuals with differing BMI profiles.**

Keywords— Surface Electromyography, Gait, Body Mass Index, Rectus Femoris, Tibialis Anterior, Adductor Magnus, Semitendinosus

I. INTRODUCTION

Gait is defined as the pattern of walking, including body appearance and the dynamics of human motion. Walking is one of the common daily activities, affecting the kinetics and kinematics of the gait pattern. It involves balance and coordination of muscle activity to propel the body forward serving as a critical indicator of weight management and muscle functionality [1]. The systematic study of the human walking pattern to assess and quantify locomotion is called gait analysis. A key component of gait analysis is the gait cycle, the time interval between consecutive heel strikes of the same foot. Gait cycle consist of two main phases: the Stance Phase (60% of the gait cycle) and the Swing Phase (40% of the gat cycle) [2,3]. The human gait cycle is illustrated by Fig. 1.

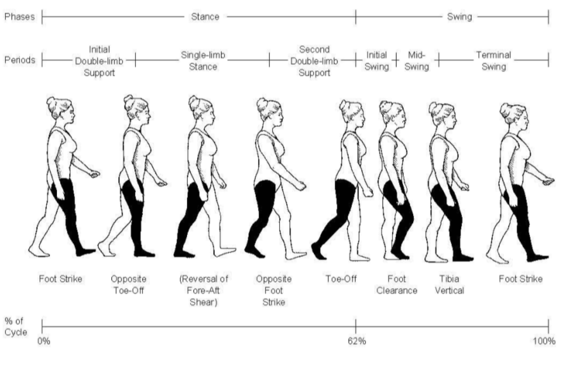


Fig. 1. Human Gait Cycle [15]

Walking is a fundamental activity often taken for granted. The inability to walk or maintain mobility can profoundly impact a person's independence and lead to significant short- or long-term health complications. While many individuals adapt to abnormal or asymmetrical gait patterns for years without any symptoms, an injury or pain can lead to potential consequences such as musculoskeletal problems, cardiovascular health issues and mental health challenges such as depression and loss of autonomy due to abnormal gait [4,5].

Therefore, a comprehensive study is proposed to analyse muscle activity during walking using surface electromyography. Surface Electromyography (sEMG) is a non-invasive technique of biosignal recording of the skeletal muscle activity of the body using surface electrodes. The study analyses surface electromyography signals acquired from four major different muscles involved in walking and correlates them across subjects with varying BMI categories. The objective aims to provide deeper understanding of muscle activity during walking, identify deviations in muscle activity that contribute to abnormal gait and aid in diagnosis of underlying musculoskeletal issues.

II. LITERATURE REVIEW

Electromyography analysis provides insights into muscle activity during movement in the study of human gait. Human gait incorporates complex motor tasks making it imperative to analyse the muscle activation patterns for diagnosing abnormalities and designing rehabilitation strategies. Over time, many studies have investigated the application electromyography in analysing various muscles providing advancements in biomechanics research. The literature review focuses on the methodologies, key findings, and application of surface electromyography to gait analysis, highlighting its role in enhancing in clinical and rehabilitation settings.

Rubana H. Chowdhury et al. research on surface electromyography signal processing and classification techniques identified associated noises and artifacts related to electromyographic signals. The study highlighted the algorithms and methodologies used for detecting, processing, and classifying EMG signals [6].

Nissan et.al evaluated muscle activity during walking by acquiring and analysing surface electromyography signals from Gastrocnemius and Soleus muscles of the leg. The results indicated significant variations in the Root Mean Square (RMS) amplitude levels and median frequency of the sEMG signals as the walking pace changed [7].

Brian R. Umberger et al conducted research titled "Stance and Swing phase costs in human walking" found that the foot makes a single ground contact (stance phase) and stays on the ground for about 60 to 62% of the entire gait cycle. Consequently, the period where the foot is lifted off the ground (swing phase) accounts for about 38 to 40% of the entire gait cycle [8].

Merlo et al proposed a novel method utilizing continuous wavelet transform for calculating on-off timing of human skeletal muscles during movement using surface electromyography signals. The method offers performance suitable for automatic clinical applications [9].

Siddiqi et al developed and tested a model considering slow and fast fibres that simulates surface electromyography signals of the tibialis anterior muscle. The model distinguished the fibres based on conduction velocity, and assumes the muscle to have a parallel structure. The results showed that the slopes of the linearity between the normalized root mean square, median frequency of the experimental and simulated sEMG signals, and force were statistically similar ($p>0.05$). This validated the accuracy and effectiveness of the proposed model for simulating sEMG signals [10].

Lovell et al assessed the activation of hip adduction muscles using electromyography (EMG) and force analysis during standard clinical tests, comparing athletes with and without a prior history of groin pain. The results stated that the test type had a major impact on EMG outputs for all four muscles while Body Mass Index (BMI) notably affecting the force output of the muscles [11].

III. METHODOLOGY

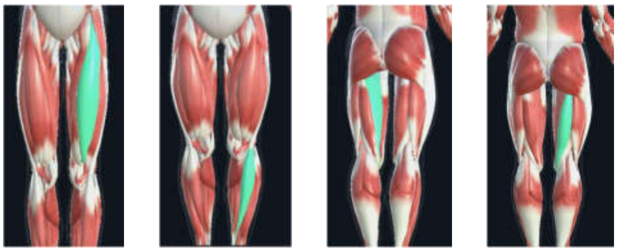
A. EMG Recording:

The BioRadio is a wireless data acquisition system to record, display and analyse physiological signals in real time. The system includes a wearable unit that amplifies, samples and digitizes signals from body attached sensors. The signals are transmitted via a Bluetooth connection (2.4 Hz- 2.484 GHz) to a computer within a range of approximately 100 feet for storage and analysis. The hardware comprises of two main hardware components: Primary Module and the Sensor Pod. The Primary Module offers two modes : Configuration Mode and Data Acquisition Mode for connecting and streaming data from the sensor pod to the connected system. Fig. 2 illustrates the hardware used to acquire the EMG signal.

Fig. 2. BioRadio Equipment

B. Choice of Muscle and Electrode Placement:

The muscle " Rectus Femoris, Tibialis Anterior, Adductor Magnus and Semitendinosus " of the lower limb is selected for the assessment of muscular activity using surface electromyography. Rectus Femoris is an important muscle due to its role in stabilizing and facilitating movement particularly in the weight-loading phase which corresponds to the first 25% of the gait cycle. Similarly, Tibialis Anterior play a crucial role due to its function in dorsiflexion and foot control during the gait cycle particularly in the swing phase and initial contact. The Adductor Magnus contributes to hip stabilization and adductor during the stance phase and the semitendinosus muscle is vital for knee flexion and hip extension contributing to propulsion and limb control during the gait cycle. The muscles collectively contribute to the stability, control and efficiency of the gait cycle highlighting their importance in biomechanical and clinical evaluation. Fig. 3. shows the muscles under consideration for the study.



(a) (b) (c) (d)

Fig. 3. Muscles activated during Gait Cycle: (A) Rectus Femoris; (B) Tibialis Anterior; (C) Adductor Magnus; (D) Semitendinosus

The electromyographic signals of these muscle are acquired using non-invasive, self-adhesive surface electrodes. The electrodes are precisely positioned at the motor points of the muscles, corresponding to their origin and insertion sites. The placement was determined using manual flexion and palpation of the muscle to locate the motor points beneath the skin [13]. The surface electromyography setup included attaching positive (active) and negative electrodes at the designated motor points of each muscle. The reference (Ground) electrode was placed over a bony prominence to establish a stable ground potential, ensuring accurate and artifact free signal acquisition. The surface electrodes used to acquire EMG is shown by Fig. 4.

Fig. 4. Surface EMG Electrodes

C. Acquisition of EMG:

Thirty participants between the age 20-29 years are selected for the study and classified into four categories: Lean, Obese, Athlete and Idler. Four muscles : Rectus Femoris, Tibialis Anterior, Adductor Magnus, and Semitendinosus are identified and assessed based on their activity during gait cycle. Participants followed a predefined protocol and the electromyographic data from the selected muscles are recorded using the BioRadio wireless acquisition system. A single gait cycle comprising of four consecutive heel strikes is considered, corresponding to a duration of 3-4 seconds depending on the walking speed. Each muscle was assigned a separate recording channel, with data captured at a sampling frequency of 250 Hz.

- Channel 1: Rectus Femoris

- Channel 2: Tibialis Anterior
- Channel 3: Adductor Magnus
- Channel 4: Semitendinosus

Samples between 600–750 per gait cycle, with multiple cycles are recorded for each participant to ensure comprehensive data collection. The acquired electromyographic signals are illustrated by Fig. 5.

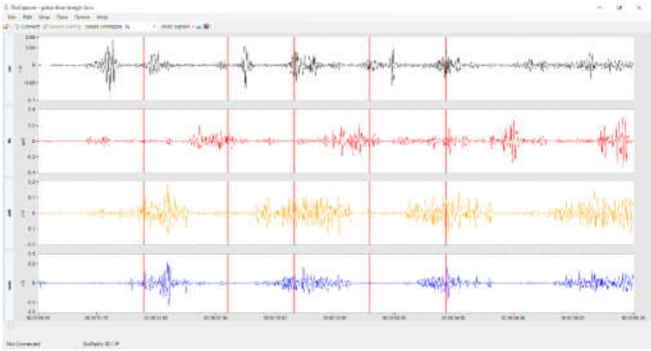


Fig. 5. Acquired EMG Signal

D. EMG Pre-Processing:

Electromyographic Signals are highly sensitive to external noise sources that includes noise due to Power Line Interference, electrode displacement, motion artifacts, ambient and inherent noise from electrical and electronic equipment [12]. Utilizing such contaminated signals results in poor and unreliable outcomes. Hence, the raw recorded EMG signal as illustrated Figure containing significant noise thereby necessitating pre-processing to eliminate unwanted artifacts.

Noise from sources such as electrodes and motion artifacts can be eliminated using appropriate filters such as band-pass filter typically in the range of 10–500 Hz [14]. To attenuate power line interference a Notch Filter at 60Hz is applied to further improve the signal quality. Fig. 6 illustrates the pre-processed EMG Signal of Semitendinosus muscle.

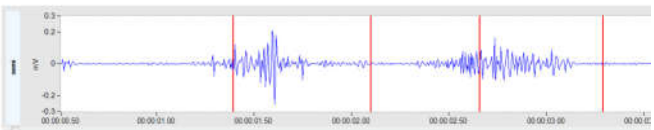


Fig. 6. Pre-processed EMG Signal of Semitendinosus Muscle

E. EMG Analysis:

Following the pre-processing of the recorded EMG signal, the data was subjected to analysis. The filtered signal is imported to MATLAB where various statistical parameters are computed. The analysis is conducted for two distinct subjects classified based on BMI and muscle activity into four categories: Lean Idler, Obese Idler, Lean Athlete, and Obese Athlete.

IV. RESULT AND DISCUSSION

The mean values of the extracted features of the acquired surface electromyographic signals from muscles Rectus Femoris, Tibialis Anterior, Adductor Magnus and Semitendinosus for participants classified into Low and High BMI categories is shown by Table 1 and Table 2. The features offer insights into the physiological differences in muscle activity between individuals with low and high BMI, highlighting trends and variations in the acquired EMG signal.

TABLE I. COMPARATIVE FEATURE EXTRACTION FOR DIFFERENT MUSCLES (LOW BMI)

Features	Rectus Femoris	Tibialis Anterior	Adductor Magnus	Semitendinosus
Mean	2.86E-06	5.64E-06	4.81E-06	1.81E-05
Variance	4.29E-04	2.27E-03	0.000292	0.000452
Median	-2.39E-04	6.49E-05	-2.23E-04	-0.0000296
Standard Deviation	0.0202	0.0471	0.0170	0.0205
Kurtosis	9.2683	6.2153	6.7802	9.635
Skewness	0.0917	0.01994	0.0265	0.1954
RMS	0.0202	0.0471	0.01698	0.0205

From the above table it is inferred that, individuals with Low Body Mass Index (BMI) show distinct muscle activation pattern as indicated by the feature extraction values. The Tibialis Anterior is the most affected muscle during gait in Low BMI individuals as displayed by its high variance, standard deviation, and RMS (Root Mean Square) values. It implies that individuals with Low BMI may encounter instability or variability in the activation of the Tibialis Anterior which is crucial role for dorsiflexion and foot control during walking. The Rectus Femoris and Semitendinosus show high kurtosis indicating intermittent spikes in activity, associated with compensatory mechanisms due to lower muscle mass. The Adductor Magnus muscle highlights the least variation, indicating it is less influenced due to Low BMI.

TABLE II. COMPARATIVE FEATURE EXTRACTION FOR DIFFERENT MUSCLES (HIGH BMI)

Features	Rectus Femoris	Tibialis Anterior	Adductor Magnus	Semitendinosus
Mean	2.15E-05	-1.03E-01	1.62E-05	1.25E-06
Variance	4.46E-04	3.86E-03	0.0009	0.000605
Median	2.90E-05	7.75E-04	-0.0001	-0.000142
Standard Deviation	2.02E-02	5.29E-02	0.0297	0.0242
Kurtosis	9.21E+00	1.09E+01	12.6	13.6
Skewness	-0.091	-5.70E-02	0.164	0.441
RMS	2.01E-02	5.28E-02	0.0296	0.0242

Similarly for individuals with High BMI, the Tibialis Anterior is characterised by the highest variance, standard deviation and RMS values indicating increased fluctuations and variability in muscle activation. Due to compensatory mechanisms for maintaining balance and stability during gait, the Adductor Magnus and Semitendinosus show the highest kurtosis values, implying more frequent extreme variations in muscle activity. Low Variance and Standard Deviation is indicated by Rectus Femoris indicating more stable activation compared to other muscles. Overall, High BMI contributes to greater variability in Tibialis Anterior muscle activation and extreme fluctuations in Adductor Magnus and Semitendinosus, which may impact stability and muscle efficiency during walking.

To further analyse, the mean values for all four muscles (Rectus Femoris, Tibialis Anterior, Adductor Magnus, and Semitendinosus) across the two subject categories are compared. The mean value analysis highlights differences in muscle activation patterns across different muscles underscoring the influence of body mass index on muscle activation and functional adaptation. Fig. 7, Fig. 8 and Fig. 9 illustrates the muscle activation differences between High BMI and Low BMI for various muscles.

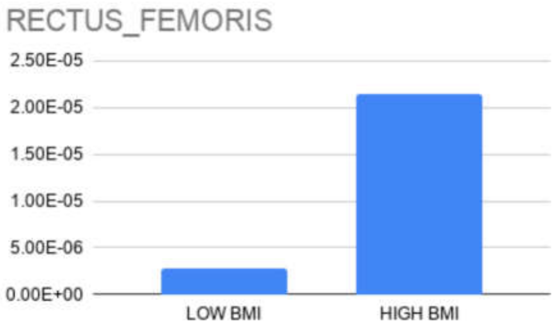


Fig. 7. Muscle Activation of Rectus Femoris Muscle

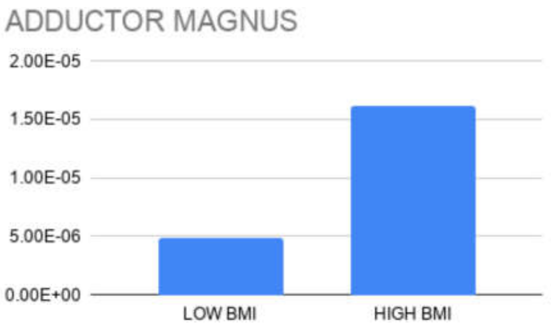


Fig. 8. Muscle Activation of Adductor Magnus Muscle

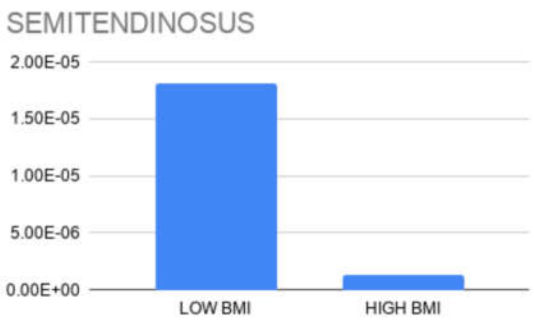


Fig. 9. Muscle Activation of Semitendinosus Muscle

The activation ratios corresponding to each muscle are as follows:

- Rectus femoris: Ratio between LOW BMI and HIGH BMI is 1:7.6
- Adductor Magnus: Ratio between LOW BMI and HIGH BMI is 1:3.37
- Semitendinosus: Ratio between LOW BMI and HIGH BMI is 1:14.5

The above activation ratio analysis indicates that individuals with high BMI exhibit greater muscle activation compared to those with Low BMI, suggesting an increased demand for muscle engagement to support body weight and maintain stability. Based on the four muscles under study, the Rectus Femoris shows high activation level in individuals with High BMI whereas in individuals with Low BMI the muscle display partial activation. Similarly, the Adductor Magnus is more effectively utilized and fully activated in High BMI individuals, while Low BMI individuals show partial activation. The Semitendinosus muscle shows the highest disparity, implying that individuals with higher BMI depend on this muscle for postural support and movement control. The Rectus Femoris has a high activation ratio due to its role in knee extension and gait propulsion. The Adductor Magnus muscle has comparatively lower activation ratio suggesting a less pronounced yet notable increase in muscle engagement during gait.

V. CONCLUSION

The study demonstrates the influence of body mass index on muscles on activation patterns during gait. Based on the observations made using surface electromyographic signal analysis in individuals with low and high BMI, it is concluded that the Rector Femoris and Adductor Magnus muscles function effectively in High BMI individuals but are partially activated in low BMI individuals. However, the semitendinosus muscle plays a prominent role in individuals with low BMI where it displays full muscle activation during gait, increasing the risk of strain or damage to the muscle over time. The distinction can be used to automate the detection of localized muscle deficiencies, with applications in physiotherapy and workplace ergonomics. Future studies can focus on collecting larger datasets to enhance the accuracy and reliability of signal analysis. Additionally, the development of a hardware to monitor the gait cycle based on muscle activation pattern is proposed to aid in early diagnosis of muscle imbalance and support physiotherapy interventions. The advancements could contribute to personalized rehabilitation interventions.

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