

Modeling of Optimal Load Capacity Based on Surface Electromyography and the Borg Scale

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Abstract— Prolonged and intensive use of the musculoskeletal system can lead to muscle fatigue, physiological strain within muscle tissue, and the development of various musculoskeletal disorders. Consequently, there is a need for systems that can prevent individuals from overexerting their muscles and sustaining potential injuries during daily activities or physical tasks. This study aims to develop a muscle-specific load-lifting model by assessing both subjective and objective measures of individual load-carrying capacity. Data were collected from the biceps brachii muscle of a healthy 20-year-old participant, comprising 120 samples recorded using the BIOPAC MP36 system. Subjective assessments were obtained using the Borg CR 10 scale, while objective measurements included the applied muscle force and the average muscle electrical potential recorded within a 2-second interval. Relationships between muscle force and Borg score, muscle force and normalized EMG (sEMG) signals, and Borg score and sEMG signals were analyzed to model the applicable muscle load using sEMG signals. The results demonstrated strong positive correlations across all three pairings. Furthermore, the time-domain integrated sEMG signal was modeled with respect to the Borg score, and at a Borg score of 7, the individual's optimal muscle force capacity was estimated as 16.29 kg. The proposed model offers a valuable alternative for defining safe physical load thresholds and provides a basis for ergonomic load planning.

Keywords— muscle strength; load-lifting modeling; ergonomic load planning; sEMG; Borg CR-10 scale

I. INTRODUCTION

The worldwide prevalence of musculoskeletal disorders reaches 1.71 billion people [1]. People must handle different amounts of weight, changing from light shopping bags to heavy equipment, based on their daily activities, jobs, and sports training [2,3]. The musculoskeletal system experiences physiological strain and metabolic changes in muscle tissue when people use it extensively during long periods [4]. The system that carries physical loads experiences direct effects from this process, leading to the development of muscle fatigue. The symptoms of muscle fatigue include decreased muscle performance, weakened neuromuscular connections, and changes in muscle metabolism [5-7]. The changes in muscle function and tissue stress from these alterations can lead to short-term performance declines and small-scale tissue damage, which may develop into long-term musculoskeletal diseases. The impact of the negative conditions can vary according to inter-

individual structural and physiological differences. Therefore, modeling individual optimal load limits is critical for preventing weakness and degeneration of the skeletal muscles.

In the literature, muscle fatigue evaluation has generally relied on either the temporal or frequency characteristics of sEMG signals or purely subjective measurement methods. Troiano et al. investigated the relationship between force and fatigue in the trapezius muscle, combining subjective and objective indicators [8]. They claimed that these indicators can provide information on endurance time and force. Wu et al. focused on detection of fatigue integrating the time and frequency domain features of sEMG with a hybrid TCN and CNN-based model [9]. While these studies successfully validate the utility of sEMG and the Borg scale, their focus remains on general relationships and endurance time prediction; they do not provide a specific predictive model for determining the instantaneous, individual limit value of the maximum load a person can safely lift without overstraining the muscle. Therefore, the developed model enables general muscle endurance evaluation and, more importantly, creates a unique, quantitative method that supports individualized load management based on personal subjective perception.

II. MATERIALS AND METHODS

The study was conducted on a healthy 20-year-old female participant, randomly selected from the Department of Biomedical Engineering students at Samsun University, per ethical approval and voluntary participation principles. Surface EMG (sEMG) signals were recorded from the biceps brachii (m. biceps brachii) muscle using a high-precision BIOPAC MP36 data acquisition system (BIOPAC Systems Inc., Goleta, CA, USA). The signals were acquired in real time through the BIOPAC Student Lab 4.1 software integrated into the system. Fig. 1 shows the data acquisition position.

The participant received an isopropyl alcohol wipe cleaning on their forearm to reduce skin impedance before electrode placement. The forearm was positioned supine, with the elbow slightly flexed downward or at a right angle. Electrodes were placed 3–4 cm apart between the active and reference electrodes, while the ground electrode was positioned over the tendon [10]. At the beginning of the experiment, the participant's maximum average force applied by the dominant arm was measured. Subsequently, the range between zero and



Figure 1. The data acquiring position

the maximum average force was divided into four equal intervals to determine four distinct load levels in ascending order. For each of these four threshold force levels, the participant's sEMG signal was recorded for two seconds. The procedure was performed thirty times while the subject rested for five minutes between each attempt. One of the raw EMG signals obtained during these measurements is presented in Fig. 2. Fig. 3 shows force signals corresponding to the four threshold levels exerted by the participant measured using an SS25LB dynamometer. And Fig. 4 indicates the time-dependent integrated EMG signals. In addition, the perception level of the subject experienced was assessed and recorded using the Borg scale provided in Table I.

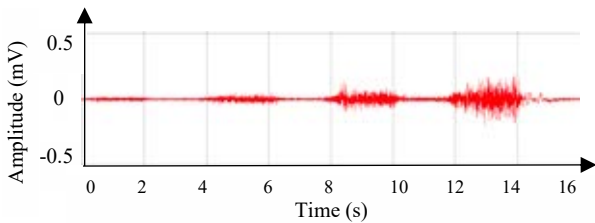


Figure 2. Raw EMG signal

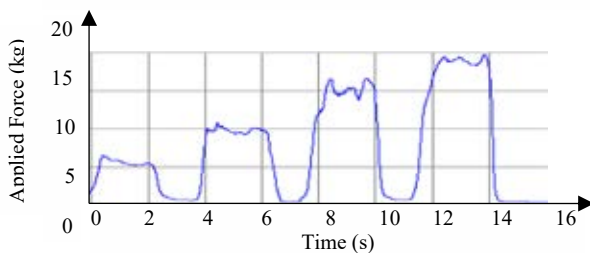


Figure 3. Forces applied during the experiment in 2-second intervals.

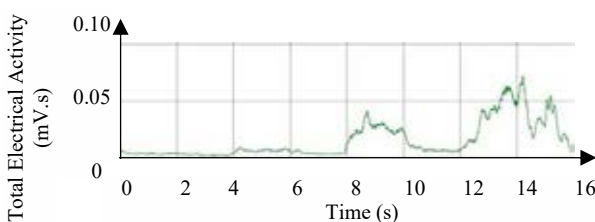


Figure 4. Time-integrated EMG signal.

TABLE I. BORG CR-10 SCALE [11]

Borg Scale of Perceived Exertion	
Score	Effort Level
0	Nothing at all (no exertion/pain)
0.5	Very, very easy
1	Very easy
2	Easy
3	Moderate
4	Comfortable
5	Somewhat difficult
6	Difficult
7	Hard
8	Extremely hard
9	Near maximal exertion
10	Maximal exertion / exhaustion

Lower scores on the Borg CR-10 scale indicate that the activity was perceived as very light and caused little to no exertion. In contrast, higher scores represent extremely demanding activities that require maximal effort. The participant was informed to indicate each exercise's perceived difficulty level by selecting the appropriate value from the numerical range based on personal perception. As the scale is subjective, there are no right or wrong responses; rather, it reflects the individual's experienced level of exertion. The sEMG, Borg CR-10, and muscle force data obtained from the participant were statistically analyzed using SPSS software (version 31.0).

III. RESULTS

We analyzed the subject muscle force against their reported perceived exertion levels. By considering the average muscle force as the independent variable and the Borg CR-10 scale scores as the dependent variable, a statistically significant and strongly positive correlation was revealed. The correlation coefficient ($R^2 = 0.824$) and p-value ($p < 0.001$) demonstrate a strong positive relationship between the variables which proves that muscle force averages directly affect perceived exertion levels. The corresponding graph and regression model derived from the data provides a visual illustration of this relationship as shown in Fig. 5. The two variables show a strong relationship because of the biological processes which control muscle strength generation and the sense of work intensity. The amount of muscle force people use determines their energy expenditure and metabolic needs which leads to increased feelings of exertion.

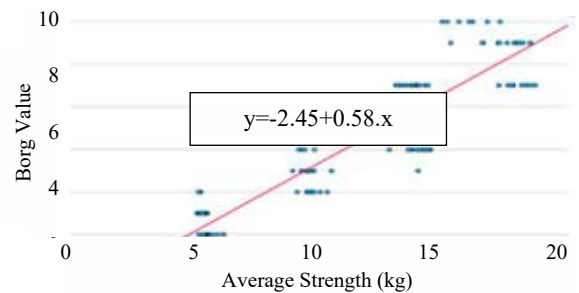


Figure 5. The linear relationship between average muscle strength and Borg CR-10 score

The regression model developed through statistical analysis reveals essential information about the biological processes which link muscle force to electrical activity. By examining the Fig. 6 and the regression model, it is evident that there is a strong positive correlation between the average applied muscle force and the total electrical activity of the muscle. The muscle activation level rises when the applied force strength increases according to these results.

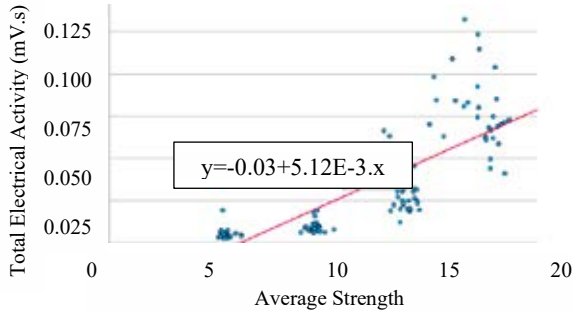


Figure 6. Linear relationship between the applied average muscle force and total electrical activity

The relationship between perceived exertion and muscle electrical activity is a complex phenomenon that has been explored through the utilization of the Borg CR-10 scale and sEMG signals. We used the Borg scale to measure subjective exertion while sEMG signal integration serves as an objective measure of electrical activity to establish their quantitative relationship. As shown in Fig. 7, perceived exertion directly correlates with muscle electrical activity because muscle electrical activity increases when perceived exertion increases ($R^2 = 0.722$, $p < 0.001$). The findings of this analysis have significant implications for our understanding of physiological responses to exercise and physical activity. Research that measures both perceived exertion against force and muscle electrical activity against force enables us to correlate the perception of the subject and sEMG signal.

This robust correlation establishes a connection that allows for load management independent of direct force measurement. Specifically, if we can model the sEMG signal based on the individual's perceived exertion scale, we can effectively manage the lifting load by monitoring sEMG values. For example, a Borg score of 7 [11], which represents challenging yet acceptable exertion, corresponds to a calculated muscle force of

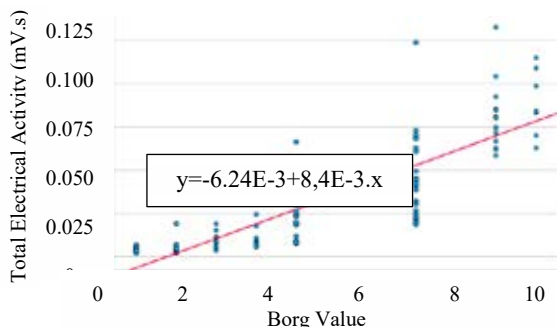


Figure 7 Linear relationship between Borg CR-10 score and total electrical activity

16.29 kg and an sEMG value of 0.0534 mVs. This ability to link a subjective, acceptable threshold (Borg score) to an objective, measurable physiological output (sEMG value) offers a powerful tool for personalized load guidance.

IV. DISCUSSION AND CONCLUSION

The evaluation of muscle fatigue has been a topic of interest in literature, with various studies relying on either the temporal or frequency characteristics of surface electromyography (sEMG) signals or purely subjective measurement methods. Troiano et al. examined the relationship between force and fatigue in the trapezius muscle, combining subjective and objective indicators [8]. The researchers established that these indicators enable scientists to evaluate both endurance duration and force production which are vital for muscle fatigue research. Wu et al. conducted research which presented an opposing perspective to the study. focused on the detection of fatigue by integrating the time and frequency domain features of sEMG with a hybrid Temporal Convolutional Network (TCN) and Convolutional Neural Network (CNN)-based model [9]. The researchers proved that sEMG technology and the Borg scale work effectively as tools for measuring physical exertion. While their approach demonstrated the potential of machine learning models in predicting muscle fatigue, it still relied on general relationships between sEMG features and fatigue. The absence of individualized load management predictive models requires a quantitative system which incorporates personal subjective perception data.

The research conducted by Troiano et al. and Wu et al. have contributed significantly to the understanding of muscle fatigue, they have certain limitations that highlight the need for a more comprehensive approach. A predictive model which unites quantitative and qualitative assessment techniques and considers personal variations in subjective perception will create a customized quantitative system for muscle fatigue assessment. In our study, the strong linear relationship identified between the Borg CR-10 scale and the sEMG electrical activity (as detailed in Fig. 7) allowed us to develop a personalized predictive model for load management. This model leverages the known relationship to derive a quantitative guide for the safe limits of physical exertion, which is a unique contribution distinguishing our work from general correlational studies [8] or classification models [9].

Specifically, the established linear regression equations (derived from the data in Fig. 5, Fig. 6, and Fig. 7) were used to generate Table II, which presents the individual-specific safe limits for the tested muscle and the subject. The Borg CR-10 scores directly match the Estimated Force (kg) values and limited sEMG (mV.s) values which establish the needed force to achieve particular perceived exertion levels. The Borg score of 7 which indicates 'challenging yet acceptable' exertion level corresponds to 16.29 kg as the maximum safe load and 0.0534 mV.s as the measurable sEMG activity threshold for the subject tested.

The Table II operates as a system which provides instant decision support to protect the person with the maximum sEMG values that prevent harmful perceived exertion levels (Borg 8 or higher). Real-time sEMG monitoring enables clinicians and coaches to track individual lifting loads which help them enforce

weight limits that protect users from overexertion and musculoskeletal strain.

TABLE II. TABLE OBTAINED THROUGH MODELING

Borg CR-10	Estimated Force (kg)	Limited yEMG (mV.s)
0	4,22	-0,0084
0,5	5,09	-0,004
1	5,95	0,0005
2	7,67	0,0093
3	9,4	0,0181
4	11,12	0,0269
5	12,84	0,0358
6	14,57	0,0446
7	16,29	0,0534
8	18,02	0,0622
9	19,74	0,0711
10	21,46	0,0799

In conclusion, this study demonstrates that the combined assessment of psychophysical and electrophysiological data can define individualized safe loading limits, thereby supporting personalized programs in health, safety, ergonomics, rehabilitation, and sports training.

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