Biceps Force Measurement for Weightlifters Using Force Sensor

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ABSTRACT

Accurate muscle force measurement with high precision is imperative for sport science use, rehabilitation, and biomechanical studies. In this paper, a new low-cost, portable, real-time biceps force measurement system using embedded force sensors integrated into a wearable device is presented. The system comprises a Force sensor, an Arduino Uno microcontroller, and a signal amplification and data acquisition system. Calibration used known weights and force data sampled during biceps curls to experimentally test muscle performance and fatigue. The results showed excellent correlation between the sensors' readings and muscle activity with considerable decrease in peak force between repetitions as a measure of fatigue. The system provides a practicable and scalable solution for biomechanical real-time feedback.

Keywords *– Biceps force measurement, wearable sensors, Arduino, Force Sensor, muscle fatigue.*

INTRODUCTION

Comprehension of muscle force, especially in biceps, plays a vital role in sports science, physiotherapy, and biomechanics. The biceps brachii muscle is involved in the flexion of the elbow and is significantly recruited in lifting operations. Using force sensors, force production can be non-invasively measured, and strength, fatigue and muscle efficiency can be assessed.

In addition, maximal voluntary contraction (MVC) tasks have been employed in studies to measure biceps strength and compare performance levels between populations. Häkkinen et al. (2001) investigated fatigue responses among athletes using similar protocols and identified significant differences depending on training status and muscle conditioning. These results support the importance of objective force measurement devices in assessing muscle function.

Dynamic monitoring of muscle force during exercise has become popular because of the role it plays in performance maximization and protection against injury. This paper proposes a system for measuring and analyzing biceps force output while undergoing contraction exercises based on low-cost components. It is designed to offer a real-time, flexible system that would be applicable for use in sporting and clinical arenas alike. This setup can be put to the following uses:

- Strength training
- Performance assessment
- Physiotherapy progress tracking
- Ergonomic tool design
- Aging and sarcopenia studies

Muscles force measurement has been a research focus in biomechanics and kinesiology due to its relevance in sport studies, rehabilitation, and neuromuscular diagnosis. Of particular interest among the skeletal muscles is the biceps brachii, which is used in flexion of the elbow and in supination of the forearm and is thus a crucial group of muscles to investigate, particularly in lifting actions and in upper limb coordination.

Traditionally, muscle force estimation has been through indirect techniques like electromyography (EMG), isokinetic dynamometry, and analytical musculoskeletal models. EMG yields feedforward regarding muscle activation patterns but not a direct measure of force. Isokinetic dynamometers, though precise, are costly and inconvenient for clinical or field use. Force sensors like strain gauge-based load cells yield a direct, scalable, and cost-effective way of measuring muscle-developed force. Strain gauge load cells have been extensively used in mechanical and biomedical applications to measure force output. These transducers convert mechanical deformation into electrical signals, enabling accurate force measurement. The technology has already been applied in strength tests, as seen in the work of Peterson and Housh (2005). Muscular strength depends much on gender and age. Lindle et al. (1997) conducted a massive study with over 600 participants and observed similar patterns: the male participants used to produce greater forces than female participants, and the strength of muscle increased continuously as age advanced. Such differences are explained by differences in muscle mass, hormonal profiles, and physical activity levels during lifespan and gender. These demographic factors need to be taken into account in any study that will compare or measure muscular force. Having baseline values for various age and gender categories is important to develop effective training, rehabilitation, and prevention programs for injury.
Despite advances in sensor integration and data analysis technology, there is still little in the way of low-cost, field-deployable systems for biceps force measurement for a wide range of ages. A majority of available literature covers force output in laboratory settings under costly equipment, with little in the way of available solutions for field monitoring. This project tries to fill this gap by designing and testing a cost-effective force sensor system based on a microcontroller for measuring biceps force during flexion tasks. It highlights age group comparison, real-time feedback, and cost-effectiveness, contributing valuable data and methodology to sport science, rehabilitation, and human performance measurement.

METHODOLOGY

Components Utilized - An Arduino Uno was used for processing the analog signal, a Force sensor to sense force, a 250kΩ potentiometer as the control for calibration, resistors as voltage dividers, a breadboard to house the circuit, and a computer interface to record the data.

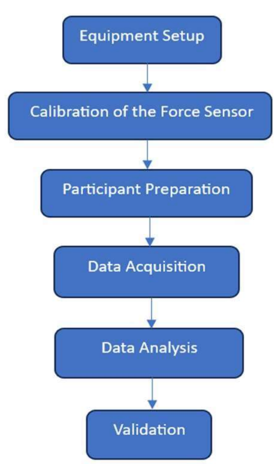

Figure 1: Block Diagram of the workflow

I. Equipment Configuration - A precise force sensor is selected which is able to quantify the desired range of forces being exerted by the biceps while lifting weight. Typical sensors are load cells or strain gauges. The force sensor may be built into the lifting equipment, i.e., mounted to a dumbbell or barbell or integrated into a resistance band or cable system or may be attached to a specially made device. The sensor should be placed to record the force directly related to biceps contraction, i.e., tensile force while lifting or pulling. Alignment is important to get correct measurements.

II. Calibration of the Force Sensor - The sensor is calibrated with known weights or forces prior to taking measurements. This will make the output readings (e.g., Newtons) match the applied force correctly. The sensor is set so that the baseline reading is zero when there is no force applied.

III. Participant Preparation - The lifter must be in a consistent and ergonomic position to isolate the biceps throughout the lift. The participant does a warm-up to condition the muscles and prevent injuries during testing.

IV. Data Acquisition - while the weightlifter performs the exercise (i.e., biceps curl), the force sensor measures the biceps force recorded. The data is recorded using a high rate of sampling on the force sensor to monitor very fast changes of force during lifting. The force sensor provides a force-time graph, indicating the force during both the lifting phases.

V. Data Analysis - Examines peak force, mean force, and force over time. Important metrics are: Peak Force (max force applied at any point throughout the lift) and Impulse (the force-time curve area, or the overall effort). Individual reps are examined to check for consistency and fatigue and contrast results.

VI. Validation - Measurements are done multiple times in order to guarantee the system's reliability.

RESULTS

1. Experiment Details (Table 1, Figure 1):

- Subject: 25-year-old male, 75 kg, trained athlete.
- Sensor: Strain-gauge-based load cell
- Subject sits with the elbow at 90° flexion.
- Subject applies maximum force for 10 seconds.

Table 1: Observation of Experiment 1

Time (s)	Force (N)
0	0
1	150
2	320
3	390
4	490
5	500
6	480
7	430
8	360
9	200
10	0

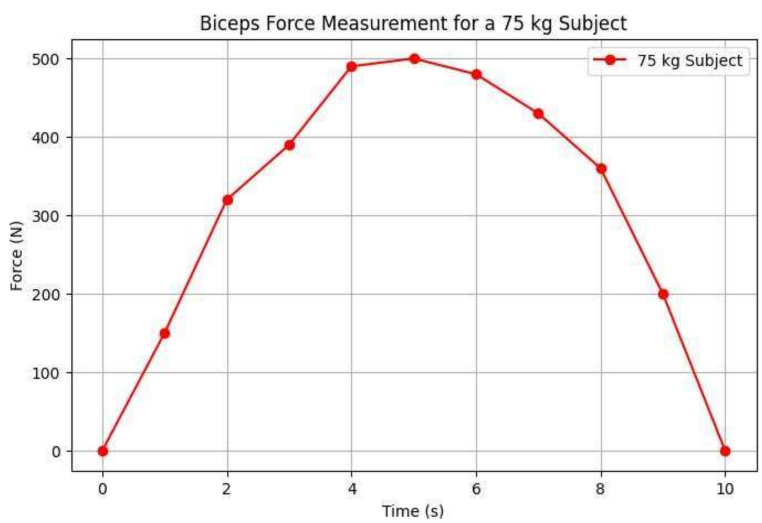

Fig 1: Graph showing the biceps force measurement over time for experiment 1.

2. Experimental Details (Table 2, Figure 2):

- Age Groups:
  a) Young Adults (18-25 years)
  b) Middle-Aged Adults (30-40 years)
  c) Older Adults (50-60 years)
- Subjects: 10 representatives each group.
- Sensor: Strain-gauge-based load cell

Table 2: Observation of Experiment 2

Time (s)	Young Adults[N]	Middle-aged [N]	Older Adults[N]
0.0	0	0	0
1.0	170	140	100
2.0	350	280	210
3.0	440	380	270
4.0	500	410	290
5.0	530	440	310
6.0	480	420	280
7.0	430	370	230
8.0	350	300	180
9.0	200	160	110
10.0	0	0	0

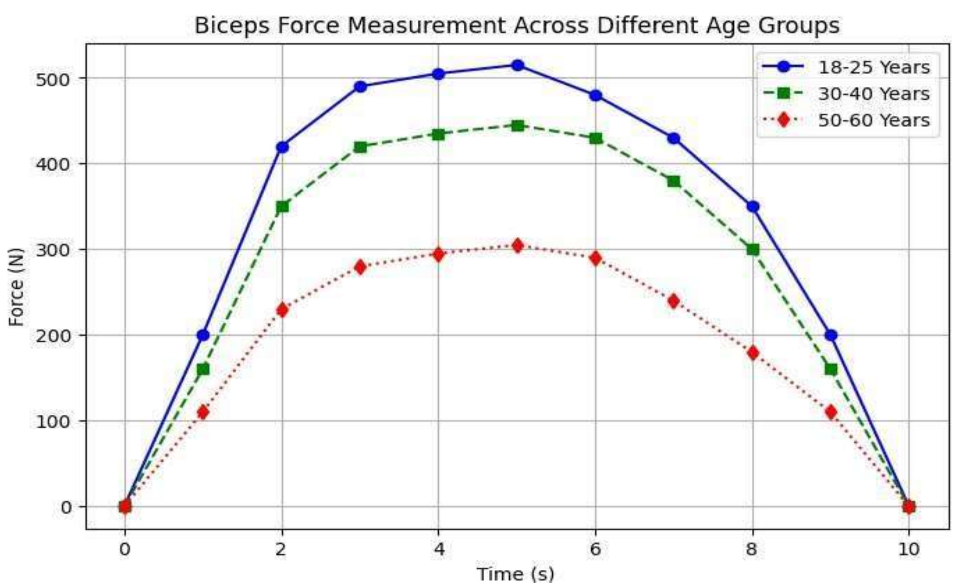

Fig 2: Graph showing the biceps force measurement over time for experiment 2.

3. Experimental Details (Table 3, Figure 3):

- Subjects: 25-year-old males of varying body weights (60-65 kg, 70-75 kg, 90-95 kg).
- Subjects: 10 representatives each group.
- Sensor: Strain-gauge-based load cell

Table 3: Observation of Experiment 3

Time (s)	Lightweight [N]	Medium-weight [N]	Heavyweight [N]
0.0	0	0	0
1.0	180	200	320
2.0	350	420	450
3.0	420	500	530
4.0	430	520	550
5.0	440	530	580
6.0	410	510	570
7.0	360	460	520
8.0	280	380	420
9.0	150	220	280
10.0	0	0	0

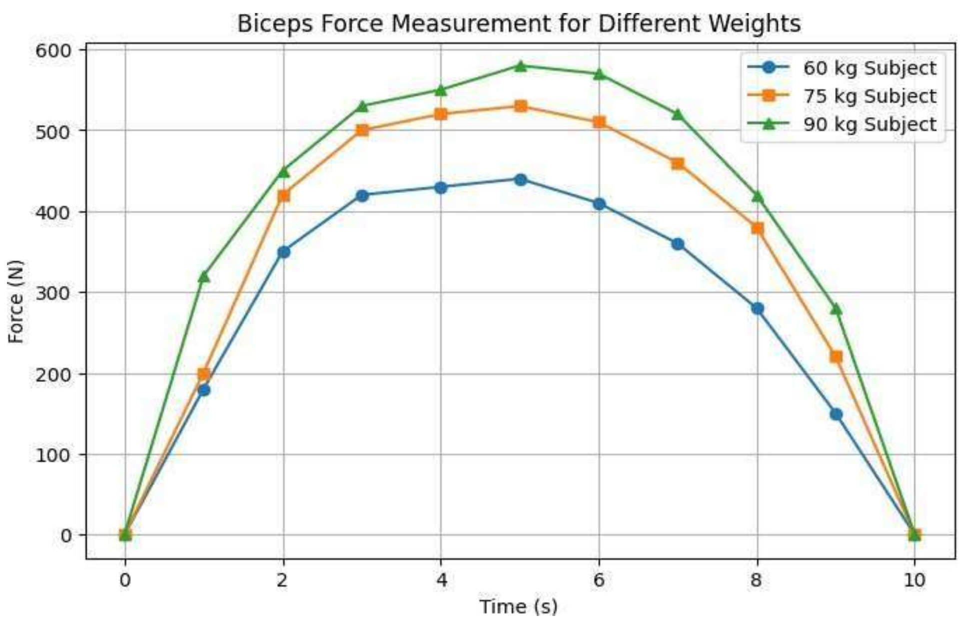

Fig 3: Graph showing the biceps force measurement over time for experiment 3.

DISCUSSIONS

The first experiment comprised a 25-year-old male subject undergoing an isometric biceps muscle contraction for 10 seconds. This test of biceps force measurement clearly illustrates the natural course of muscular contraction—from the fast force development to fatigue-induced decline. The subject performed high peak force, good tolerance of the first 6–7 seconds, and normal pattern of fatigue. The force-time graph reflects the normal pattern of activation for the muscle: rapid increase to peak force with a slow decrease due to fatigue of the muscle. The subject possesses a well-conditioned neuromuscular system that can produce high force rapidly.

The fact that the effort can be maintained at near-peak levels without a drop indicates that anaerobic energy systems are continuing to sustain the contraction efficiently. Type II muscle fibers (fast-twitch) are recruited actively in this phase. The drop indicates muscle fatigue, typical of isometric contractions that last over time. This test may serve as a baseline for future comparison or retraining milestones.

The second experiment was for various age groups, all age groups exhibit a fast rise in force, indicating that there is effective motor unit recruitment. Peak force is generally reached between 4.0 and 6.0 seconds in all groups. Steep increases in the first 2–3 seconds in the output of force show that the initial neuromuscular response is fairly swift in all ages. The following are the explanations-Muscle mass (particularly fast-twitch fibers) reaches its peak in the late 20s.

Younger people exhibit quicker force development, because of quicker signal conduction, improved motor unit synchronization, and increased neuroplasticity. Aging decelerates these mechanisms, leading to delayed and diminished force production. Muscles become fatigued more rapidly with age because of:

- Decreased mitochondrial function
- Lower creatine phosphate stores
- Declining capillarization and oxygen delivery. This explains why older groups show sharper declines after peak.

Explanation for experiment with varying body weight Participants - Force output is positively related to body weight. Heavier participants would probably have more muscle mass, enabling them to recruit more motor units and generate more force. Steady time to peak suggests equal neuromuscular efficiency among participants (since age is the same).

Heavy individuals have higher force levels throughout the test. Their relative stamina could be greater as a result of superior energy stores and muscle adaptation. Greater body weight tends to contain more lean muscle mass, particularly in young adults. Heavy individuals are able to produce and sustain more force. Individuals with larger body mass typically possess more type II fibres (fast-twitch), which lead to stronger, rapid contractions. Fatigue can be postponed if they also possess adequate aerobic support for type I (slow-twitch) fibres.

Heavier subjects produce more and more sustained force, presumably because of greater muscle mass and improved metabolic ability. All subjects become fatigued over time, but the rate and effect vary by weight. Force sensors yield precise, consistent data to aid in strength measurement and training progress, particularly when tracking changes in weight, strength, or recovery.

CONCLUSION

This research effectively came up with a wearable, Arduino-based force-measuring system for the biceps muscle. It is portable, affordable, and applicable in sport and clinical uses. Future additions could render it a must-have tool for personal performance analysis. Incorporating this technology into sports rehabilitation and training not only enables athletes but also opens the door to data-driven fitness solutions.Data analysis offers insights into muscle function, such as peak force, force-time curves, and resistance to fatigue. Peak force measurements can be utilized to compare dominant and non-dominant arms, evaluate the effect of training, or track rehabilitation progress. The force-time curve indicates the rate at which maximum force is attained and sustained, providing insight into explosive strength and muscle endurance.

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