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ORIGINAL RESEARCH

EMG OF SHOULDER MUSCLES DURING REACTIVE ISOMETRIC ELASTIC RESISTANCE EXERCISES

Michael J. Mullaney, DPT, SCS[1]
Christine Perkinson, PT[1]
Ian Kremenic, M.Eng[1]
Timothy F. Tyler, PT, ATC[1]
Karl Orishimo, MS,CSCS[1]
Christopher Johnson, MPT, MCMT[1]

ABSTRACT

Background: Traditionally, shoulder isometrics are introduced in the early stages of shoulder rehabilitation. A patient's isometric torque output is based on a subjective perception of force generation. By utilizing elastic resistance elongation (strain) to standardize force output, clinicians could prescribe shoulder therapeutic isometrics based on % maximum voluntary contraction (%MVC).

Purpose/Hypothesis: The purpose of this study was to measure electromyographic (EMG) activity and determine the %MVC during shoulder flexion, external rotation and abduction isometrics at varying lengths of TheraBand® elastic resistance. It was hypothesized that increased elongation of progressive resistance bands would proportionately increase the %MVC of the shoulder musculature.

Study Design: Laboratory design using healthy subjects.

Methods: Eight healthy subjects (16 shoulders) (5 females, 3 males; avg. age 29.2) were tested. Surface EMG electrodes were placed over the anterior deltoid, middle deltoid, and infraspinatus muscles. A force transducer was anchored to a stable surface with its corresponding end in series with an extremity strap securely holding the elastic band. Subjects were asked to maintain shoulder position for the proper isometric contraction (flexion, abduction and external rotation) while taking incremental steps away from the anchored elastic resistance, to the beat of a metronome to clearly marked distances on the floor (50, 100, 150, 200 and 250% of band elongation). This was repeated with yellow, red, green, and blue TheraBand® resistance levels. Maximum voluntary contractions for both force and EMG were collected for each subject in all three test positions. EMG data were normalized and expressed as a %MVC.

Results: For external rotation and flexion, the infraspinatus and anterior deltoid activity increased with band elongation ($p < 0.01$) and progressive colors ($p < 0.01$). The increases in EMG activity with elongation plateaued with the yellow and red bands but continued to increase with the green and blue bands ($p < 0.01$). The increase in infraspinatus and anterior deltoid EMG activity with progressive band color was more apparent for green and blue bands compared with yellow and red band ($p < 0.01$). For the abduction exercise, middle deltoid activity increased with band elongation ($p < 0.01$) and progressive color ($p < 0.01$). In all three exercises, there was an increase in force exerted by the band with increasing length and band color ($p < 0.001$). However, while there were clear increases in force from red to green to blue, there was no difference in force between yellow and red regardless of elongation ($p < 0.01$).

Conclusion: Isometric flexion, external rotation and abduction muscle activity can be accurately prescribed clinically by adjusting the elongation and resistance associated with progressive colors of resistance bands.

Level of Evidence: 3

Key words: Elastic resistance, isometric exercise, electromyography

CORRESPONDING AUTHOR
Michael J. Mullaney DPT, SCS
Nicholas Institute of Sports Medicine and Athletic Trauma
Manhattan Eye Ear and Throat Hospital - A division of Lenox Hill Hospital
210 East 64 Street
New York, New York 10065
732-970-4974
E-mail: mullaneypt@gmail.com

[1] Nicholas Institute of Sports Medicine and Athletic Trauma Lenox Hill Hospital, New York, NY, USA

INTRODUCTION

Rehabilitation programs for various shoulder conditions such as rotator cuff repair, stabilization procedures and glenohumeral impingement, emphasize the importance of a progressive rotator cuff strengthening program. Several authors have documented the electromyographic (EMG) activity of the glenohumeral musculature during common therapeutic shoulder exercises.[1,2,3,4,5,6,7,8,9,10] Rehabilitation guidelines for glenohumeral pathologies are typically divided into multiple phases.[9,11,12] Within each phase there is a gradual progression of rotator cuff loading based on muscle activation during specific exercises.[4,5,9,12,13] These programs progress from early isometric exercises to more advanced isotonic exercises in an effort to return the patient to full function.[11,13] Isometric exercises are regularly implemented by physical therapists for rehabilitation because they can often provide a controllable and safe training stimulus for patients with limited range of motion. [10,14,13] The challenge with performing these early-stage isometric exercises is the ability of the patient to accurately estimate the force being used to complete an exercise. The reported force production may be influenced by the sincerity, motivation and pain level of the patient. [15,16] A person's ability to continually reproduce a target muscle contraction, regardless if it is maximal or submaximal, is inconsistent.[17] The biomechanical factors that determine muscle force include muscle length, shortening velocity, activation history and current activation.[17] Patients will typically utilize their sense of "effort" rather than their sense of "force" when trying to produce a submaximal contraction.[17] Patients' perceptions of their effort may not always correlate with the force that they are actually producing. Therefore, it is proposed that using an active isometric technique with elastic resistance can assist in accurately predicting what percent of maximum voluntary contraction (% MVC) will be produced during isometric flexion, abduction, and external rotation of the upper extremity.

Actual force production and muscle activation, as measured by EMG levels using elastic resistance during isometrics, has not been described and needs to be examined. The purpose of this study was to measure EMG activity and %MVC during shoulder flexion, external rotation and abduction isometrics at varying lengths of consecutive resistance levels of elastic resistance. It was hypothesized that an increased elongation of progressive resistance bands would proportionately increase the %MVC of the shoulder musculature.

METHODS

Participants

Eight healthy participants (16 shoulders: 6 males and 2 females; avg age 29.2) volunteered to participate in EMG testing of the glenohumeral joint during reactive isometric exercises. A reactive isometric utilizes elastic resistance as the external force opposing an isometrically held contraction. The external force is increased as the stationary segment (isometrically contracting muscle and joint) is moved further from the fixed end of the elastic resistance, causing increased elongation of the elastic resistance. Participants were excluded if they had a history of shoulder injury within one year or presented with pain during the testing protocol. All participants gave written informed consent. This study was approved by the Lenox Hill Hospital Institutional Review Board.

Testing

Prior to testing, yellow, red, green and blue elastic resistance bands (TheraBand®, Performance Health, Akron, Ohio) were cut to 50cm and pre-stretched 50 times to 100% elongation to pre-condition and develop an initial resting length of the bands.[18,19] Different colors represent progressive thickness of bands, which result in increasing levels of resistance. The elastic resistance bands were attached to a TheraBand® extremity strap at one end and secured to a stable surface with an in-line force transducer (Kistler Instrument Corp, Amherst, NY). Following skin prep (shaving, if necessary, skin abrasion and cleaning with alcohol), circular bipolar Ag-AgCl surface electrodes (Noraxon Dual Electrodes, Noraxon USA, Scosttsdale, Arizona; diameter, 1 cm; interelectrode distance, 2 cm) were applied bilaterally on the anterior deltoid, middle deltoid and infraspinatus muscles according to the recommendations of Perotto.[20] Muscle activity was recorded at 960 Hz using an 8-channel telemetry system with a bandwidth of 10 to 500 Hz (Noraxon Telemyo, Noraxon USA, Scottsdale, Arizona). Participants performed three, five-second MVCs in standing (one minute rest between

contractions) with a force transducer (Kistler Instrument Corp, Amherst, NY) for shoulder flexion (anterior deltoid), shoulder abduction (middle deltoid) and external rotation (infraspinatus). The average of the maximum force produced during each of the three contractions was used as the MVC. For MVC testing for flexion, the participants were placed in approximately 10-20° of shoulder abduction, 0° of shoulder flexion and 0° of elbow extension and was instructed to forward flex their shoulder. For shoulder abduction, the participants were placed in approximately 10-20° of shoulder abduction, 5-10° of shoulder flexion and 0° of elbow extension and instructed to maximally abduct their shoulder. For shoulder external rotation, participants were placed with elbow in 90° of flexion and the shoulder in neutral glenohumeral rotation with a towel roll placed between the humerus and the trunk bringing the shoulder to approximately 10° of shoulder abduction. These positions were chosen to keep in line with the stationary force transducer for consistent measurements during MVC tests and reactive isometric recording. These MVCs were performed on both dominant and non-dominant shoulders to develop % MVCs at each testing position.

Participants were then instructed in the three reactive isometric test positions. For external rotation, participants were placed with elbow in 90° of flexion and the shoulder in neutral glenohumeral rotation with a towel roll placed between the elbow and the trunk bringing the shoulder to approximately 10° of shoulder abduction, to help ensure the participant maintained the test position.(Figure 1) Participants were fitted with an extremity strap around the wrist for all isometric test positions. Participants were then instructed to step out laterally to clearly identified distances on the floor of 50%, 100%, 150%, 200% and 250% elongation (i.e., each being that percentage greater than the resting length) of the elastic band. Participants ensured they were stepping out the correct distance and maintaining the appropriate shoulder positioning by holding a laser pointer in their test hand that pointed towards the percent elongation marking on the floor. To test shoulder flexion, participants were placed in approximately 10-20° of shoulder abduction, 0° of shoulder flexion and 0° of elbow extension. (Figure 2) Participants were placed in 10-20° of abduction to prevent any soft tissue

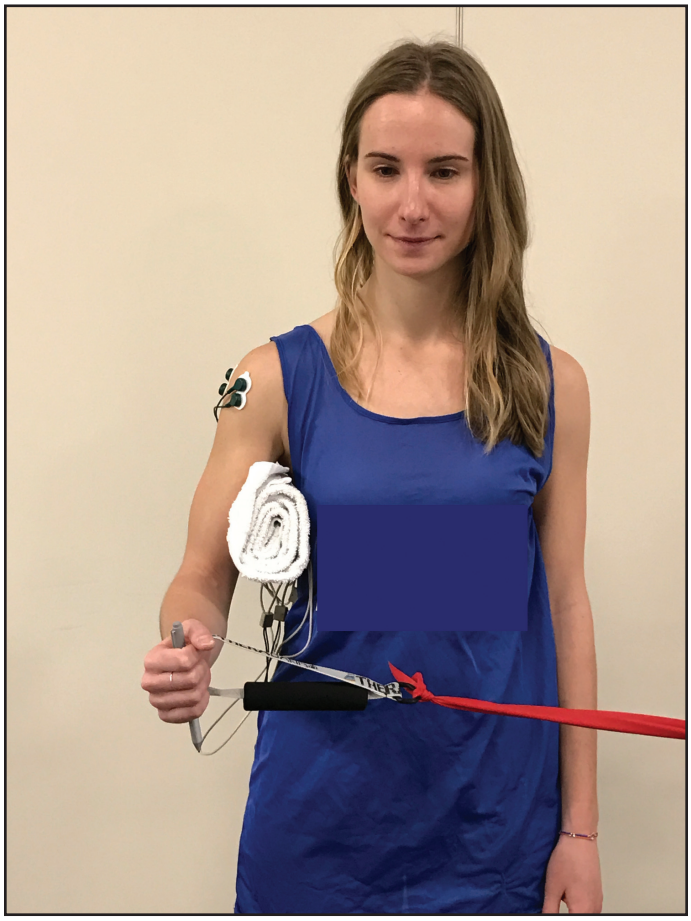


Figure 1.

between the thorax and humerus from interfering with the position. Participants then stepped anteriorly to each of the five elongation positions, resisting the posterior force of the elastic resistance. Once again, participants held a laser pointer to ensure elongation distances were consistent with each step. To test shoulder abduction, participants were also placed in approximately 10-20° of shoulder abduction, 5-10° of shoulder flexion and 0° of elbow extension. (Figure 3) Participants were placed into 5-10° flexion to clear any abdominal or hip soft tissue that could impede the elastic resistance band. Participants then stepped laterally to each of the five elongation positions, resisting the medial directed force of the elastic resistance. Subjects performed these five step distances sequentially from 50% to 250% stopping at each percent elongation position for approximately 3-4 seconds using a metronome. The metronome pace was set at 12 beats per minute to allow for enough contraction time at each elongation without risking



Figure 2.



Figure 3.

increased fatigue and loss of proper positioning. All three of these test positions were randomly ordered and performed with the yellow, red, green, and blue elastic resistance, also in random order.

Data Analysis

All EMG data were rectified and smoothed using a root mean square process with a 50-millisecond smoothing window. The maximum value for each contraction was used for analysis. Additionally, all data from the tested exercises were normalized and are presented as %MVC.

For each exercise, data were analyzed using repeated-measures ANOVA to examine the effects of arm side (dominant vs. non-dominant), band elongation (five percentages) and band resistance (four colors) on the primary muscle activated for that exercise: the infraspinatus for isometric external rotation, the anterior deltoid for isometric flexion and the middle deltoid for isometric abduction. Statistical significance was set at $p < 0.05$.

RESULTS

Initial analysis showed no effect of side on any muscle activity or force measurement ($p = 0.155$); therefore, dominant and non-dominant arms were grouped together for purposes of analysis. The %MVC for each position and resistance in flexion, external rotation and abduction are listed in the Appendix. Most notable is the change of %MVC in each position from 50% elongation in the yellow to 250% elongation using the blue elastic resistance. Anterior deltoid %MVC increased from $11.2 \pm 1.3\%$ at 50% elongation of yellow to $26.3 \pm 2.3\%$ at 250% elongation of blue. Infraspinatus %MVC increased from $16.2 \pm 2.1\%$ at 50% elongation of yellow to $29.5 \pm 5\%$ at 250% elongation of blue. Middle deltoid %MVC increased from $22.5 \pm 2.7\%$ at 50% elongation of yellow to $36.7 \pm 4.5\%$ at 250% elongation of blue.

For external rotation (Figure 4a) and flexion exercises (Figures 5a and 5b), the infraspinatus and anterior deltoid activity increased with elongation ($p < 0.01$)

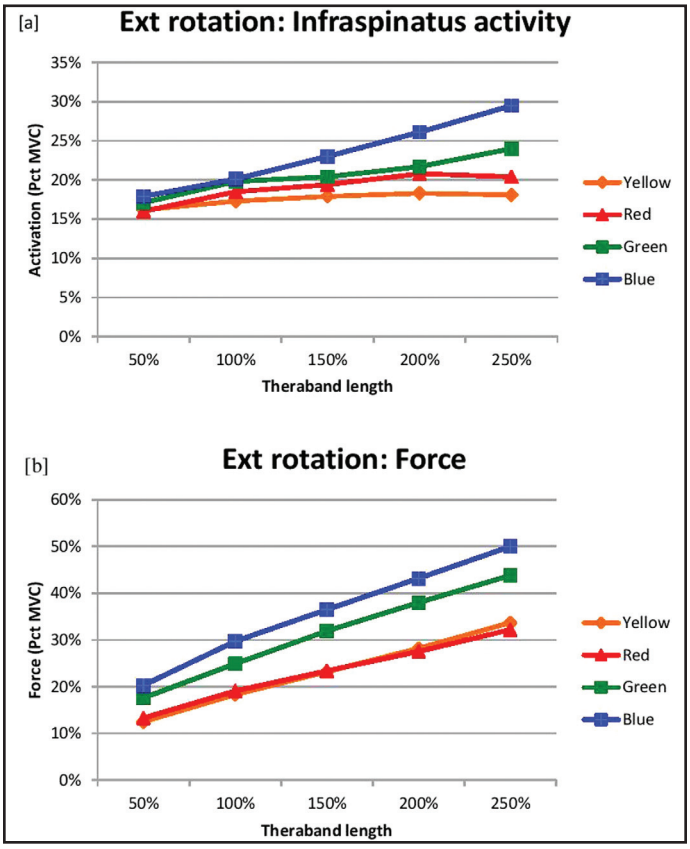


Figure 4.

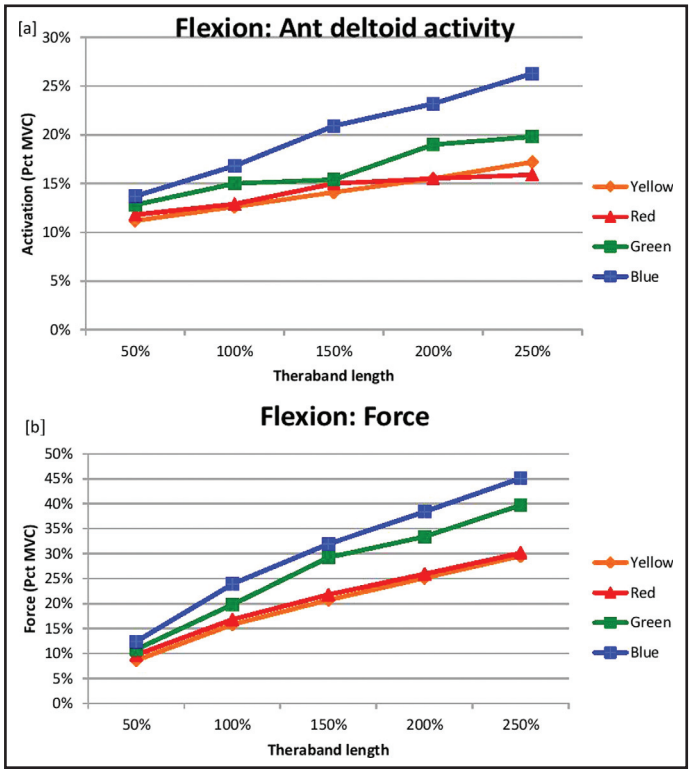


Figure 5.

and progressive band color ($p < 0.01$). The increases in EMG activity with elongation plateaued with the yellow and red bands, but continued to increase with the green and blue bands ($p < 0.01$). Additionally, the increase in infraspinatus (Figure 5a) and anterior deltoid (Figures 5a and 5b) EMG activity with progressive band color was more apparent for green and blue bands compared with yellow and red bands ($p < 0.01$). For the abduction exercise, middle deltoid activity (Figure 6a) increased with elongation ($P < 0.01$) and progressive band color ($p < 0.01$). In all three exercises, there was an increase in band force (Figures 4a, 4b, and 4c) with increasing elongation and progressive color ($p < 0.001$). However, while there were clear increases in force production from red to green to blue, there was no difference in force production between yellow and red regardless of percent elongation ($p < 0.01$).

DISCUSSION

This study offers insight into the utilization of elastic resistance in prescribing reactive isometrics for

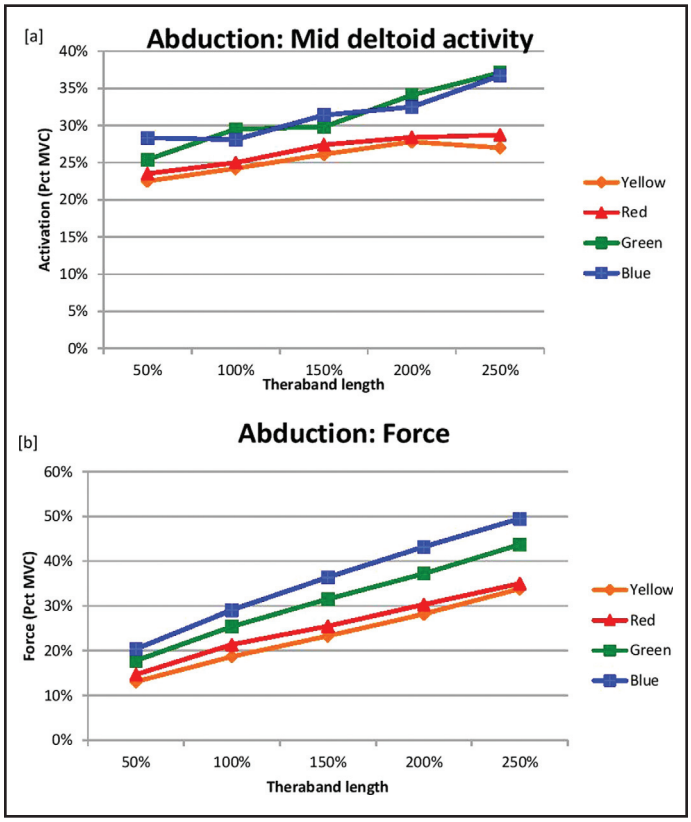


Figure 6.

shoulder rehabilitation. The force exerted by elastic resistance depends on percentage of elongation. In work by Page et al,[21] the slope of the force-elongation curve of elastic bands varies with changes in the thickness of elastic material; specifically, the force-elongation slope of progressive colors slightly increases with increasing thickness. Because elastic resistance is normally prescribed by color, one cannot assume that changes in resistance (color) will cause a standard gradual increase in muscle activation when proceeding from one color resistance to the next in the progression. This concept is clearly seen in the present study as each band was elongated from 50% to 250%. Although the trend shows gradual band force and %MVC increase at each percent elongation, the changes are not of equal percentages based on band color. This study highlights the fact that the greater the resistance supplied by the bands (blue and green) during reactive isometrics, the faster both exerted forces and EMG activity went up, which is consistent with increasing slopes of force-elongation. In contrast, for the bands supplying less resistance (yellow and red) during reactive isometrics, exerted forces and EMG activity increased more slowly.

Previous studies have highlighted the use of elastic resistance during shoulder exercises and shoulder rehabilitation programs.[6,22,23,24,25] This is the first study on progressive reactive isometric exercise prescription utilizing elastic resistance bands. These findings highlight an increase in muscle activity for each exercise based on band elongation and progressive color. As utilization of isometrics is often limited based on patients' sincerity, motivation, and pain level,[15,16] this study provides insight into muscle activity and resistance one can expect to see using reactive isometric resistance exercises with a variety of elastic band resistances.

Clinically, this allows physical therapists to further understand the load placed on shoulder muscles during specific exercises. The data provided offers guidance when prescribing these types of exercises. Clinically, the most important factor is the color (resistance level) of the band. The color of the band drives the increased resistance during longer elongations of reactive isometrics. The absence of this effect for the middle deltoid may indicate that the middle deltoid is not as much of a prime mover as was assumed for the abduction isometric exercise, at this range of motion, with the muscles of the rotator cuff potentially working more than expected. Subjectively, subjects indicated that the task became difficult during the higher elongations, particularly for the higher resistance bands; thus, it is logical to assume there is a large degree of co-contraction of agonist muscles while performing these reactive isometrics at higher loads.

Of note is that all exercises produced muscle activity measured as less than 40% MVC, with the vast majority being under 30% MVC. This should be considered when prescribing therapeutic exercises during the early stages of rehabilitation. Many authors recommend exercising at <20% MVC muscle activation during the early stages following rotator cuff repair.[3,7,10,23] Utilization of the yellow, red, and green reactive isometrics for flexion at 250% elongation falls below this 20% MVC threshold for early stages of rehabilitation. Utilization of reactive isometrics for external rotation fall within this <20% threshold for anterior deltoid for yellow and red up to 150% elongation. Abduction reactive isometrics appear to initiate at >20% MVC of the middle deltoid and should be used with caution during the earlier stages of rehabilitation, and reserved for the middle stages of rehabilitation. Dockery et al[3] have shown that the use of pulleys for "passive motion" can activate the deltoid up to 25% MVC.

This study presents with areas of limitations. It is important to note that these values are in normal, healthy population and should be considered during exercise prescription for patients with shoulder pathology. Patients with pathology may present with an altered neuromuscular firing patterns that may not necessarily reflect that of a non-pathological shoulder. This study utilized surface EMG and it is possible that kinesiologic fine wire EMG may have different results. Standardization of test positions/movements were achieved with floor marking, the use of a laser pointer, and a metronome pace; however, subject movement during testing is often a variable that is difficult to control.

CONCLUSIONS

Isometric flexion, external rotation and abduction muscle activity progressively increases when using varied colors of elastic resistance band (increas-

ing resistance by color) and increasing the percent elongation. The higher resistance bands (green and blue) produced forces faster and EMG activity went up faster than in the lower resistance bands (yellow and red). Using varied choices of elastic resistance to increase the muscle activation during isometric exercises is a novel approach that can allow clinicians to accurately prescribe these exercises.

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Appendix. *Percent MVC for each position*

Anterior Deltoid: Flexion

% elongation	Yellow	Red	Green	Blue
50%	11.2%±1.3	11.8%±1.5	12.8%±1.5	13.7%±1.3
100%	12.6%±1.3	12.9%±1.5	15%±1.4	16.8%±1.5
150%	14.1%±1.2	15%±1.6	15.4%±1.6	20.9%±1.8
200%	15.5%±1.3	15.5%±1.5	19%±1.7	23.2%±1.9
250%	17.2%±1.4	15.9±1.5	19.8%±1.6	26.3%±2.3

Infraspinatus: External Rotation

% elongation	Yellow	Red	Green	Blue
50%	16.2%±2.1	1.6%±2.6	17.1%±2.4	17.9%±2.9
100%	17.3%±2.2	18.5%±2.7	19.8%±2.8	20.1%±2.9
150%	17.9%±2	19.4%±2.8	20.4%±2.7	23%±3.3
200%	18.3%±2.1	20.8%±2.9	21.7%±2.9	26.1%±3.9
250%	18.1%±2.1	20.4%±2.8	24%±2.9	29.5%±5

Lateral Deltoid: Abduction

% elongation	Yellow	Red	Green	Blue
50%	22.5%±2.7	23.5%2.8	25.4%±3	28.3%±3.2
100%	24.2%±2.8	25%±2.8	29.5%±3.8	28.1%±3.3
150%	26.1%±3.2	27.4%±3.4	29.8%±3.9	31.4%±3.9
200%	27.8%±3.3	28.4%±3.9	34.1%±5.4	32.5%±4.1
250%	27%±3.3	28.7%±3.9	37.1%±6	36.7%±4.5