CHAPTER IV

RESULTANT MUSCLE TORQUE AND ELECTROMYOGRAPHIC ACTIVITY DURING HIGH INTENSITY ELASTIC RESISTANCE AND FREE WEIGHT EXERCISES

4.0 Abstract

The purpose of this study was to quantify and compare Resultant Muscle Torque (RMT) and muscle activation (EMG) pattern, during resistance exercise comprising 8 repetitions maximum (8 RM) biceps curl with elastic resistance and free weight exercise. Sixteen male and female recreationally active subjects completed 8 RM biceps curl by each of three modalities of resistance exercise: (i) dumbbell (DB), (ii) elastic tubing with original un-stretched length at the commencement of contraction (E0), and (iii) elastic tubing with 30 % decrement of original length (E30) at the commencement of contraction. The magnitude of muscle activation, external force, acceleration as well as range of motion (ROM) were quantified and synchronized by specific software. The data were collected from all 8 repetitions but the first (initial), the 5th (middle) and the 8th (last) repetitions were selected for further data analysis. Each selected repetition was partitioned into a concentric and eccentric phase and then each phase was further divided into 3 equal segments (3 concentric and 3 eccentric = 6 segments per repetition). The EMG and RMT data demonstrated a bell-shaped muscle activation and muscle torque production pattern for the three modes of exercise. The E30 resulted in 15.40 % and 14.89 % higher total EMG as well as 36.85 % and 17.71 % higher RMT (N.m) than E0 and DB, respectively (all $P < 0.05$). These findings support the contention that an elastic resistance device (E30) has the capacity to provide an appropriate high resistance stimulus to meet the training requirement of elite athletes.

Key word: resistance training, elastic tubing, variable exercises, multiple repetitions maximum.

4.1 Introduction

The tensile force of elastic material offers an ascending external resistance curve which has been acknowledged by sport scientists (Anderson *et al.,* 2008; Wallace *et al.,* 2006). The benefits of this ascending elastic force can be substantiated in exercises such as biceps curl and shoulder abduction which the torque generating capacity of prime movers is greater at the beginning of the concentric phase (Harman, 2000). In this category of movements, the increment of provided external force by elastic material (due to further elongation) requires the active muscle to develop tension over the entire concentric phase (Hodges, 2006); although, using a conventional DCER, the acceleration of force at the beginning of concentric phase would reduce the force generating requirement at the end of concentric phase (Hodges, 2006).

The question that might arise regarding this notion is that "how ascending resistance curve of elastic device can be recommended for biceps curl exercise which possesses an ascending-descending force generating capability?" previous research studies have clarified this debate and demonstrated that despite providing an ascending resistance curve, ER device in conjunction with length of lever arm offers a bell-shaped torque curve which is compatible with torque generating capability in many human movements including the biceps curl (Hughes *et al.,* 1999; Simoneau *et al.,* 2001)

Although these findings validate using ER for this category of exercises, the practical inability of elastic resistance in providing a high external force, particularly at the beginning of the concentric phase, has limited the use of ER in high intensity training protocols (Newton *et al.,* 1996; Wallace *et al.,* 2006). This speculation however is true to a certain extent. Because, elastic tubing is now produced in several colour-codes and each colour denotes a specific resistance (for review refer to (Patterson *et al.*, 2001; Simoneau *et al.*, 2001). Hughes (1999) reported the resistance of elastic devices (Hygienic Corporation, Akron, Ohio) from of 3.3N (yellow) to 80.1N (silver) when elastic materials were at 18 % (minimum) and 250 % (Maximum) deformation from resting length (un-stretched), respectively. These magnitudes of tensile force provided by various color codes of elastic materials supported this idea that single string of elastic resistance device cannot lead muscles to maximal activation level in healthy trained subjects.

Accordingly, additional elastic bands were used in parallel to the current elastic device to improve the tensile force throughout the entire ROM (Hodges, 2006; Simoneau *et al.*, 2001) and the resting length of the elastic material was reduced to increase the provided elastic force particularly at the beginning of lifting phase (Page and Ellenbecker, 2003). The purposes of the study therefore were to quantify and compare the level and the pattern of EMG activity and Resultant Muscle Torque (RMT) of elbow flexors within performing 8 RM biceps curl exercise using DB and ER devices. We hypothesized that by applying these two strategies the failure of ER device in providing inadequate force at the beginning of concentric phase would be resolved. Accordingly, equal muscle activation and muscle torque production could be achieved with an ER device compared with conventional free weights during performing high intensity resistance exercises. In addition, the deceleration phase at the end of concentric phase would be disappeared and ER device provide significantly higher EMG activity and RMT compared with DB at this part of ROM.

4.2 Methods

4.2.1 Subjects

Sixteen healthy male (*n* = 10) and female (*n* = 6) recreationally active volunteers gave their informed consent to participate in this study. Their physical characteristics are presented in Table 4.1. The subjects had no experience of resistance training in the past 12 months and were requested to abstain from any exercises involving arm muscles 48 hours before main testing session. They had no history of injury or surgery, and were not currently receiving medical treatment. The percentage of body fat was assessed using a four-skinfold site (thigh, triceps, suprailiac, and abdomen) equation (Jackson and Pollock, 1978). This experiment was approved by the Ethics Committee of the Sport Center, University Malaya.

Table 4.1 Physical characteristics of subjects participated in the study.

Subjects	Age (years)	Height (cm)	Mass (kg)	Percent body fat (%)
Male (η=10)	24.4±2.9	178.3±6.8	77.3±5.7	13.2±3.9
Female (η=6)	27.2±4.8	158.9±4.7	61.1±5.7	17.3±7.4

The sample-size in the study was estimated according to the statistical power calculations recommended by Vincent (2005) and Hopkins (1997). If the $p = .05$ and statistical power = .80, fifteen subjects were required to participate in a repeated measure study design in which subjects complete all the three modes of exercises (i.e. DB, E0 and E30).

4.2.2 Experimental Protocol

All subjects attended a preliminary testing session where anthropometric measurements including height, body mass and the length of the subject`s dominant forearm (slant distance from the elbow joint to the wrist joint) and forearm plus hand (tip of middle finger of the hand to the elbow) were undertaken and recorded from the subjects. The percentage of body fat was assessed using a four-site (thigh, triceps, suprailiac, and abdomen) equation (Jackson and Pollock, 1978).

The subjects were then familiarized with the testing procedure by practicing Maximal Voluntary Isometric contraction (MVIC) and 8 RM dynamic exercises including dumbbell (DB), elastic resistance device at un-stretched length (E0), and E0 length – 30% (E30). The resistance required for 8 RM was assessed by the three types of resistance training devices prior to the day of testing. The resting un-stretched length of E0 was determined for each subject by measuring the distance from the origin (ground) to the axis (distal end of the load cell attached to the handle of elastic device held by the subject standing in anatomical position). The resting length of E30 was therefore calculated as the length of E0 – 30%. The external load in each mode of training was either added or removed to meet actual 8 RM. To achieve this, different combination of elastic color codes were examined for E0 and E30 (each color denotes specific resistance; for more information see section 2.4 *Material properties of elastic resistance*). Accordingly, the color codes of E0 and E30 was the product of 8 RM and was different between the two modes of training.

To avoid inaccurate location of electrodes from day to day testing, all data were collected within one testing session. The test protocol began with a 5 minutes warm up consisting of 30 sec to 60 sec biceps curl exercise with minimal resistance followed by stretching of the upper limb musculature. Subjects then rested for 5 minutes during which time the electrogoniometer and accelerometer were strapped to the subject`s dominant arm. A pair of surface electrodes (20 mm interelectrode distance) was placed on the center of muscle belly in the direction of muscle fiber as recommended by Hermans *et al.,* (1999). The ground electrode was placed at the acromial process. Before placement of electrodes, the area of skin was shaved, abraded for removing dead skin with sandpaper and cleaned with alcohol to decrease skin resistance.

Prior to the dynamic exercises, subjects performed three MVIC for 5 s each at 2-minutes intervals. Measurements were performed while the subject stood on a test platform (height: 30 cm), holding the handle of a non-extensible strap and the elbow was positioned at 90º (Always *et al.,* 1992). The MIVC was calculated as the average amplitude over one second window of the highest rectified EMG signals (automatically selected by Myoresearch-XP). This value was established as reference value (100 % EMG) for normalizing muscle activation data during dynamic actions (% MVIC).

The subjects then completed 8 RM biceps curl exercises in a randomized order across each of the three training modalities. Ten to 15 minutes resting period was assigned between exercise modes. To control the arm position during dynamic contractions, two laser beams connected to an alarm system limited the ROM (20 - 140°) at each extremity (20° and 140° are the beginning and end of concentric phase, respectively). Therefore, an alarm sounded if subject`s hand extended beyond the laser spectrums. The cadence of performing the bicep curls was 2s concentric and 2s eccentric which was maintained by an auditory signal via a metronome. One second pause between every repetition was assigned to avoid potential stretch-shortening cycle interference. An attempt at 8 RM was deemed successful if all repetitions were performed in accordance with the pace of metronome without any compromise in ROM. Ten subjects were randomly selected to perform the same procedures and protocol 5 days following the test day. The test-re-test reliability for 8 RM dynamic trials was 0.89, 0.84 and 0.93 for E30, E0 and DB, respectively.

The data were collected from all 8 repetitions with the first (initial), the 5th (middle) and the 8th (last) repetitions were selected for further data analysis. Each of the assigned repetition was partitioned into a concentric and eccentric phase based on the end points determined from the electrogoniometer traces. Each concentric and eccentric phase was divided into 3 equal segments (3 concentric and 3 eccentric segments per repetition). The range of motion for each concentric segments comprised of 20 – 60° (segment 1), 60 – 100° segment 2) and 100 - 140° (segment 3). The range of motion for the 4th, the 5th and the 6th segments were similar as the 3rd, the 2nd and the 1st segments, respectively, however in opposite direction. The Root Mean Square (RMS) of rectified EMG signals was computed for each phase of movement. The average of 6 segments was used to calculate the value of every repetition. Finally, the obtained values from 1st, 5th and 8th repetitions were used to calculate the "Total Average EMG" (average of 6 segments × 3 repetitions) for each exercise modality.

The magnitude of Resultant Muscle Torque was calculated according to the equation recommended by Enoka (2002). In a very brief review, the dynamic analyze of the torque production about the prime mover is affected to angular kinematic of the system comprised of moment of inertia (I) and angular acceleration (α) and linear kinematic includes of mass of the system (M), linear acceleration of the system (a) the distance (d).

$$\sum \tau m = I\alpha + m \times a \times d \qquad \text{(Equation 4.1)}$$

$$\tau m - (F \times D1) - (m \times D2) = I\alpha + m \times a \times dx + m \times a \times dy \qquad \text{(Equation 4.2)}$$

Where:

τ m = Resultant Muscle Torque, F = external force, D1 = perpendicular horizontal distance from point of applied force to axis of rotation, m = mass of the segment, D2 = perpendicular horizontal distance from center of mass to axis of rotation, I= moment of inertia of the body segment, α = angular acceleration, a = acceleration, d x= distance which center of mass and external force pass on the x axis, and dy= distance which center of mass passes and external force pass on the y axis.

In this equation, the left-hand side of the equation represents the static value of the torque and the right-hand side quantifies the dynamic part. Including the movement of external moment of force (provided by DB and ER devices) in X and Y axis to the equation would result in following formula:

$$\tau m - F \times D1 - m \times D2 = I\alpha + (m \times a \times dx) + (m \times a \times dy) + (F \times a \times dx) + (F \times a \times dy) \quad \text{(Equations 4.3)}$$

$$\tau m = F \times D1 + m \times D2 + I\alpha + (m \times a \times dx) + (m \times a \times dy) + (F \times a \times dx) + (F \times a \times dy) \quad \text{(Equations 4.4)}$$

In this equation, the direction of acceleration (a) was perpendicular to the line of the arm and its values were determined by 2-D accelerometer on X and Y axis. In addition, dx and dy explicitly refer to horizontal and vertical components of distance where center of the mass and external force moved during dynamic action. Mass of the forearm plus hand (M), location of Center Of Mass (CoM) and Radii of Gyration was calculated using Zatsiorskie`s tables (Zatsiorsky, 2002) and Winter`s table C9.1 (Winter, 2004), respectively. All the tables containing segmental values are presented in appendix I.

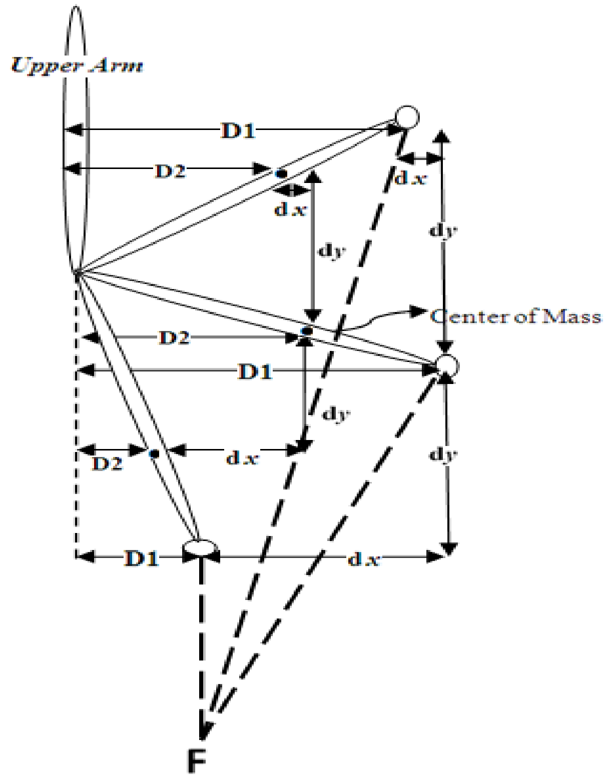

Figure 4.1. A schematic of the horizontal distance from point of applied force to the elbow (D1), the horizontal distance from center of mass to the elbow (D2), the distance which center of mass and external force pass horizontally on the x axis (d*x*), and the distance which center of mass and external force pass vertically on the *y* axis (d*y*). During elbow flexion, D1 and D2 changes throughout the curl movement. Therefore, although elastic force increases with elongation, the actual torque production of the joint accommodates the ascending-descending characteristics of most strength curves of joints in the body.

Moment of inertia (Iα) was determined based on the equation recommended by Grimshaw and colleague (2006). The I alpha (Iα) was measured as a product of inertia of forearm plus hand (determined from body segment parameter) and angular acceleration (measured by accelerometer). For this purpose, linear acceleration (m/s^2) derived from accelerometer is divided by the distance of the accelerometer to the axis of rotation (elbow) to be converted to angular form (rad/m^2). The equation is:

$$I = mk^2 \quad (\textit{Equation 4.5})$$

Where:

I = moment of inertia of a segment about the axis of rotation (the reluctance of the body to start, stop or changes in the rotational state which is measured in the unit of $kg.m^2$ (Grimshaw *et al.*, 2006), m= mass of the segment, k= radii of gyration (percentage of segment length; the values of k for different percentage of segmental length are presented in the Table in appendix III).

4.2.3 Statistical analyses

Test-retest reliability was evaluated using the data obtained on the main testing session and the follow-up testing session (5 days later) and interclass correlation coefficient (ICC) of average dynamic force was computed for the three types of training. The EMG and RMT value during various phases (1 to 6), repetitions (initial, middle and end) and modalities of exercise (DB, E0 and E30) were computed using a 6 × 3 × 3 repeated measure analyze of variance (ANOVA, SPSS v 15). If significant results were obtained from ANOVA testing, then a series of pair sample *t-tests* were used to compare analogous repetitions and phases among modes of exercise. Significance was defined as $P < .05$.

4.3 Results

4.3.1 EMG. The results addressing the Total Average EMG (3 repetitions × 6 segments) are presented in Figure 4.2. Analysis of variance revealed significantly higher value for E30 compared with both E0 (60.25 ± 6.52 vs 52.20 ± 6.92) and DB (60.25 ± 6.52 vs 52.44 ± 6.86; all $P < .05$). No significant difference was observed between E0 and DB (52.20 ± 6.92 vs 52.44 ± 6.86).

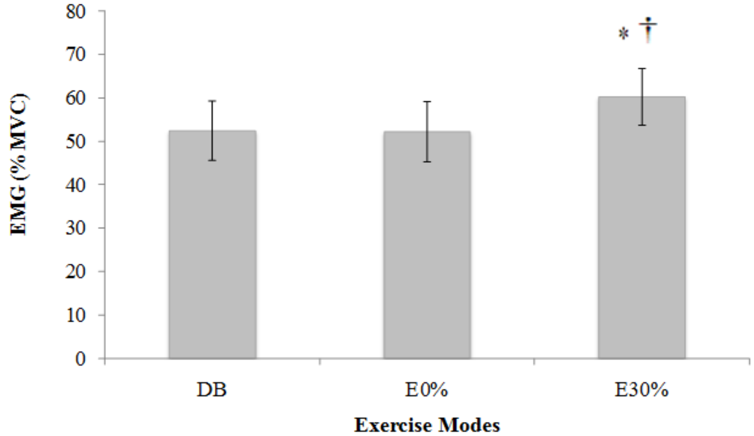

Figure 4.2 Total average EMG (% of MVC) within various exercise modes. The value of every column comprises of average of 3 repetitions × 6 segments. * = E30% is significantly higher than E0%. † = E30% is significantly higher than DB.

The differences in EMG level between similar segments across three modes of exercise are presented in Table 4.2. In addition, to exhibit the profile of muscle activation for each mode of training the electromyographic activation patterns are depicted graphically in Figure 4.3. The data indicated that at the 1st and 6th segments E30 and DB demonstrated significantly higher EMG compared with E0, though, no statistical difference was observed between E30 and DB. At the 2nd and 5th segments E30 exhibited higher EMG than both DB and E0, although the difference was not significant between E30 and DB at the 5th segment. At the 3rd segment ANOVA revealed a trend at which E30 > E0 > DB. At the 4th segment both E30 and E0 demonstrated significantly higher value than DB (all $P < .05$).

Table 4.2. Integrated-EMG values within various levels of exercise modalities

EMG (% of MVC)									
	DB Average of 6 Segs × 3 Reps			E0 Average of 6 Segs × 3 Reps			E30 Average of 6 Segs × 3 Reps		
	52.43 (6.85)			52.20 (6.91)			60.24▲♦ (6.52)		
	Average of 6 Segments			Average of 6 Segments			Average of 6 Segments		
	Rep 1	Rep 4	Rep 8	Rep 1	Rep 4	Rep 8	Rep 1	Rep 4	Rep 8
	43.53 (6.64)	42.64 (7.55)	50.73 (8.05)	56.89 (8.71)	56.90 (8.34)	63.26 (6.09)	56.89 ▲♦ (6.28)	57.07 ▲♦ (6.34)	66.75▲♦ (6.52)
Mean (±SD) of RMS-EMG values of every segments (N=16)									
1	48.91 * (11.03)	75.12 * (17.52)	88.94* (7.60)	37.52 (10.23)	59.94 (13.21)	64.94 (11.89)	49.14 ▲ (11.74)	69.18 ▲ (11.75)	83.39▲ (9.42)
2	65.51 (14.37)	84.02 (10.62)	85.20 (11.78)	65.28 (15.38)	84.88 (10.25)	87.35 (7.77)	75.32 ▲♦ (14.14)	94.09 ▲ ♦ (4.80)	94.71 ▲ ♦ (4.46)
3	42.85 (8.92)	57.22 (17.48)	47.97 (6.58)	60.78 ‡ (15.89)	78.95 ‡ (7.69)	70.12 ‡ (10.07)	75.07 ▲♦ (12.70)	83.09 ♦ (8.08)	93.27 ▲♦ (3.60)
4	26.55 (7.21)	33.26 (13.02)	31.38 (9.29)	35.44 ‡ (6.67)	48.51‡ (10.63)	53.23 ‡ (10.95)	37.40 ♦ (8.10)	49.39 ♦ (10.26)	51.60 ♦ (14.09)
5	35.83 (9.86)	43.53 (10.78)	47.37 (11.90)	32.05 (9.12)	42.91 (12.65)	44.17 (10.01)	37.55 (12.76)	50.90 ▲ (15.94)	51.24 ▲ (14.54)
6	41.55 *† (14.25)	48.22 *† (16.36)	40.48 *† (10.90)	24.77 (9.76)	26.23 (11.42)	22.59 (5.80)	26.88 (8.71)	32.93 (10.40)	33.29 (6.71)

Note: *= DB is significantly higher than E0. †= DB is significantly higher than E30. ▲= E30 is significantly higher than E0. ♦ = E30 is significantly higher than DB. ‡= E0 is significantly higher than DB. (All in $P < 0.05$)

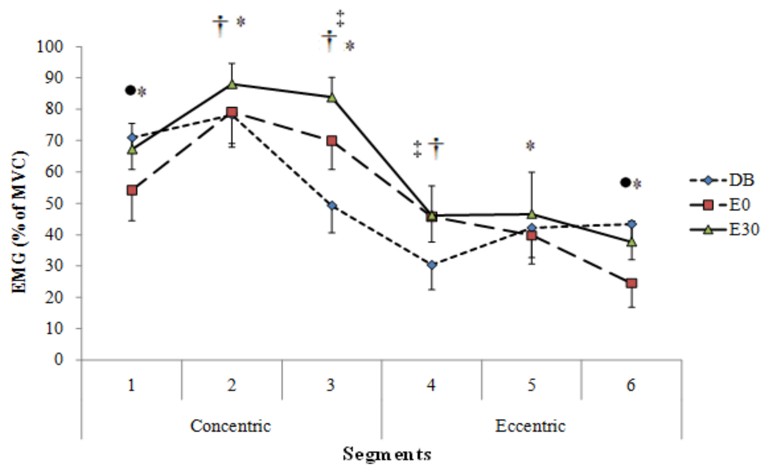

Figure 4.3. EMG (% of MVC) within various segments of exercise modes. The value of every segment includes the average of 1st + 5th + 8th repetitions. ● = DB is significantly higher than E0%. ‡ = E0% is significantly higher than DB. † = E30% is significantly higher than DB. * = E30% is significantly higher than E0%.

4.3.2 RMT (N.m). The results addressing the Total Average RMT between modalities of exercise were presented in Figure 4.5. Analysis of variance exhibited a significantly higher value for DB compared with E0 (23.31 ± 7.58 vs 20.05 ± 6.64, p = *.00*). In addition, E30 represented a significantly higher value than both E0 (27.44 ± 10.21 vs 20.05 ± 6.64, p = *.00*) and DB (27.44 ± 10.21 vs 23.31 ± 7.58, P = *.012*).

The differences in magnitude of RMT between similar segments across three modes of exercise are presented in Table 4.3. In addition to exhibit the profile of applied force and resultant muscle torque production for each mode of training the force and RMT pattern are depicted graphically in Figures 4.4, 4.5 and 4.6. The data indicated that at the 1st and 6th segments, DB and E30 elicited significantly higher RMT compared with E0 (p = *.00*), though, no statistical difference was observed between E30 and DB. At the 2nd segment, E30 exhibited higher value than both DB and E0 (p = *.00*) and no difference was observed between E0 and DB. At the 3rd segment, ANOVA revealed a trend at which E30 > E0 > DB (all p = .00). However, at the 4th segment all three types of resistant training resulted in equal muscle torque production. At the 5th segment, DB demonstrated higher RMT value than both modes of elastic resistance training, though, this difference was only significant for DB compared with E0 (all $P < .05$).

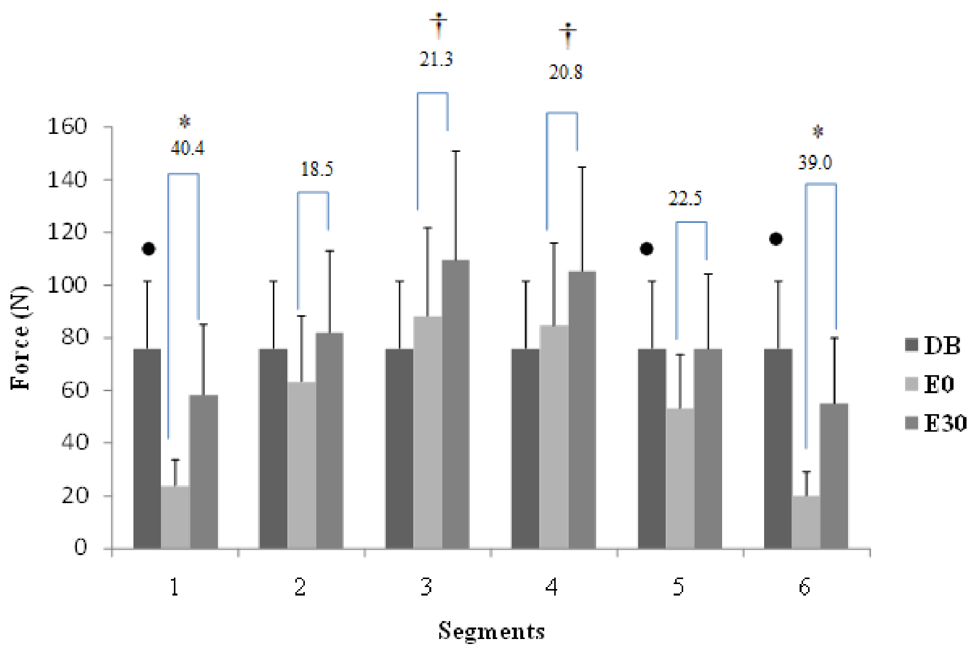

Figure 4.4. The magnitude of applied Force (N) in the three modes of training within various segments of motion. The value of every phase includes the average of 1st + 5th + 8th repetitions. The values above the E0 and E30 are the mean different between the two modes of training. ● = DB is significantly higher than E0%. † = E30% is significantly higher than DB. * = E30% is significantly higher than E0%.

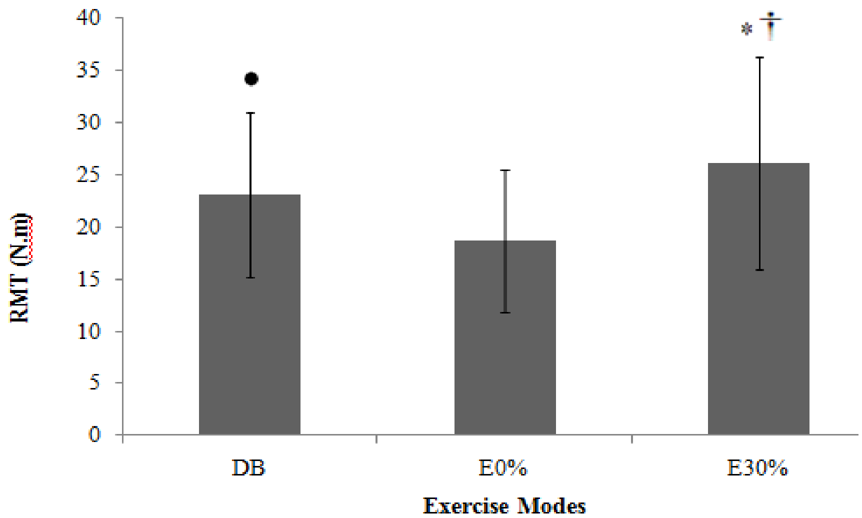

Figure 4.5. Total average RMT (N.m) within various exercise modes. The value of every column comprises of average of 3 repetitions × 6 Segments. * = E30% is significantly higher than E0%. † = E30% is significantly higher than DB. ● = DB is significantly higher than E0%.

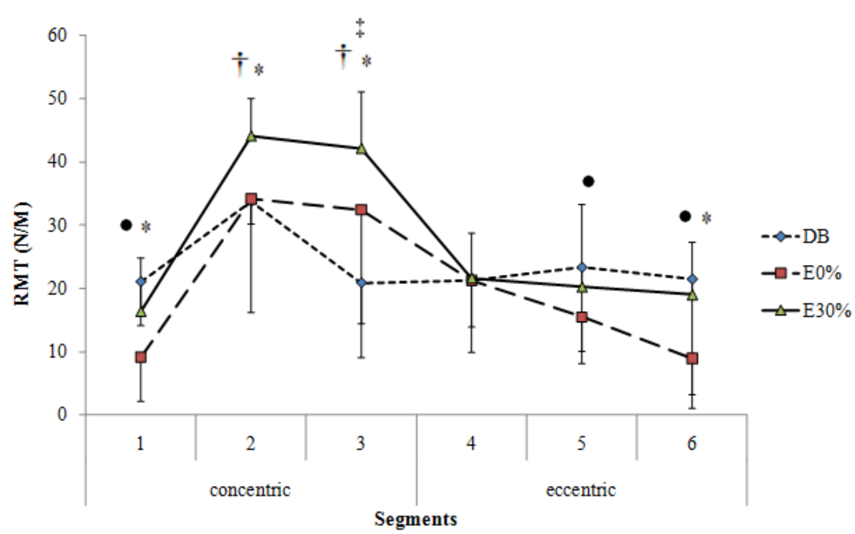

Figure 4.6. RMT (N.m) values within various segments of exercise modes. The value of every segment includes the average of 1st + 5th + 8th repetitions. ● = DB is significantly higher than E0%. ‡ = E0% is significantly higher than DB. † = E30% is significantly higher than DB. * = E30% is significantly higher than E0%.

Table 4.3. RMT values within various levels of exercise modalities

RMT (N.m)			
	DB Total Average of 6 Segments	E0 Total Average of 6 Segments	E30 Total Average of 6 Segments
	23.31* (7.58)	20.05 (6.64)	27.44 ▲♦ (10.21)
Mean and SD of RMT values of every phases within repetition 5 (N=14)			
1	21.04 *† (6.95)	9.12 (3.61)	16.39▲ (6.47)
2	33.76 (11.43)	34.16 (13.24)	44.08 ▲♦ (18.26)
3	20.85 (6.99)	32.44 ‡ (17.97)	42.12 ▲♦ (23.40)
4	21.28 (7.39)	21.15 (8.20)	21.64 (7.89)
5	23.30 *† (8.38)	15.48 (5.93)	20.23 (8.93)
6	21.43 * (7.06)	8.92 (3.00)	19.00 ▲ (8.28)

Note: *= DB is significantly higher than E 0%. †= DB is significantly higher than E30%. ▲= E30% is significantly higher than E 0%. ♦ = E30% is significantly higher than DB. ‡= E0% is significantly higher than DB. (all $P < .05$)

4.4 Discussion

The purpose of this descriptive study was to quantify and compare the electromyographic activity and the resultant muscle torque pattern between three modes of resistance training (DB, E0 and E30) during the performance of high resistance biceps curl exercises. Previous investigators have speculated that ER does not elicit maximal activation because the external force is less than that requiring maximal activation (Matheson *et al.*, 2001; Page *et al.*, 1993; Treiber *et al.*, 1998).

4.4.1 Total Average EMG and RMT. Comparing the values obtained from the three modes of training (Figures 2 and 4) revealed that E30 demonstrated 15.40 % and 14.89 % higher muscle activation (EMG) and 36.85 % and 17.71 % higher muscle torque production (RMT) compared with E0 and DB, respectively. This highlights the ability of elastic device to meet the training requirement for an elite athlete who need to practice a high exercise intensities. In line with our finding, Matheson *et al.,* (2001) and Muhitch (2006) concluded that elastic resistance could be used as a viable alternative to conventional free weights, provided that adequate external resistance is applied. Our findings question the recommendations of prior studies that are based on a low tensile force of elastic material and conclude that the utility of elastic devices is confined to applications centred on rehabilitation (Hintermeister *et al.,* 1998; Hostler *et al.,* 2001).

Theoretically, developing muscle strength has been closely related to greater force application, longer duration of muscle tension and a greater total amount of work (Hortobagyi *et al.,* 1996; Linnamo *et al.,* 2005). In high resistance weight training the initial gains in strength are primarily attributed to a greater central neural drive to the muscle with further subsequent strength gains associated with muscle hypertrophy (Moritani *et al.,* 1982). On this basis, one would expect that higher total average muscle activation and muscle torque production in E30 may result in greater strength gains compared with E0 and DB. Further research is required to substantiate this postulate.

4.4.2 EMG and RMT Pattern. The present EMG and RMT data acquired from six segments of contraction demonstrated a bell-shaped muscle activation and muscle torque production pattern for the three modes of exercise (Figures 4.3 and 4.6). These data support previous findings that although elastic force increases with elongation, the interaction effects of leverage systems and the stretch-shortening cycle create an ascending-descending torque curve which is compatible with torque generating capability in the elbow flexors (Hodges, 2006; Lim and Chow, 1998). In this case, shorter moment arm length (horizontal distance from line of action of elastic device to the elbow joint) at the beginning and end of the concentric phase creates a bell-shaped torque curve with the elastic device, thus making the lifting motion easier in these areas (Hughes *et al.,* 1999).

However, the key finding of the present study concerns the positive influence of manipulating the initial elastic device length and resistance (and matching color codes of elastic material) in achieving higher EMG and RMT with the elastic device. Firstly, it is worth mentioning that in order to achieve 8 RM exercise intensity, it is inevitable that additional elastic tubing has to be used in parallel to the current device. Hughes (1999) reported the resistance of an elastic device (Hygienic Corporation, Akron, Ohio) from of 3.3N (yellow) to 70.1N (silver) when elastic materials were at 18% (minimum) and 159% (Maximum) of deformation from resting length (un-stretched), respectively. These data indicate that one unit of the commercially produced elastic tubing cannot possibly provide adequate external force necessary to accomplish high exercise resistance training for an elite athlete. Therefore, matching various color codes of elastic material (of different grades of "stiffness") is a basic strategy to increase the external force required in using the ER device for training purposes.

Alternatively, the length of elastic material concerned may be shortened to require an increased force of "stretching" to approximate the force required for training purposes. This approach was used with the E30 condition which resulted in significantly higher EMG and RMT compared with E0 across all concentric phase (Figures 4.3 and 4.6). These data disclose the importance of reducing the initial length as an essential strategy to develop muscle activation and torque production when using an ER device. Thus, although matching elastic color codes was implemented in both E30 and E0, this strategy in E0 was insufficient in eliciting maximal activation of the muscle. In eccentric phase however the differences between E0 and E30 diminished (Figures 4.3 and 4.6). During the 4th segment, the forearm is accelerating toward the same direction that elastic force is acting (downward). Since muscle tension must reduce to facilitate extension motion, the variation of external force between E30 and E0 does not make any significant EMG and RMT difference between the two modes of training. However, to decelerate and to stop the forearm motion in the 5th and 6th segments, higher muscle activation is required to overcome the greater torque generated by E30.

The question that arises regarding the present data is: “How did subjects complete the same number of repetitions (8 RM) with E0 and E30, although higher EMG and RMT values were achieved by E30 (Figures 4.3 and 4.6)?” One might speculate that due to increased resistance with shorter elastic tubing (in E30) subjects should not be able to complete 8 RM. There are several possible explanations for these apparent paradoxical findings. Firstly, in the present study, the 8 RM was assigned as equating criterion between the three modes of training. On this basis, subjects naturally used less resistive tubing for E30 to counterbalance the effect of shorter length; unless, they were not able to complete 8 RM. As a result, E0 and E30 provided different patterns of tensile force across the ROM (Figure 4.4). The data indicates that although E30 offers greater force across all phases compared with E0, only significant differences were observed at the 1st and 6th phases (Mean difference = 40 N, Figure 4.4). These findings suggest that although the interplay between resistance and length of tubing in E30 could have resulted in higher EMG and RMT compared with E0, it was not of a magnitude that changed the number of repetitions.

Another explanation for subjects achieving 8 RM in the E30 condition despite overcoming a greater "lifting" resistance may involve a neurophysiological mechanism whereby a signaling pathway increases motor unit recruitment to overcome the resistance. Previous investigations have demonstrated that preloading muscle at the inception of concentric and end of eccentric phases (i.e. in the present study happens in E30 compared with E0) could stretch the intrafusal muscle fibers, facilitate greater discharge of efferent impulses to extrafusal fibers and increase the force of the contraction in the muscle (Aura and Komi, 1986). In addition, muscle preloading has been shown to reduce time constants of the stimulation-active state coupling as well as the interaction between series elastic components and contractile elements, that help to enhance muscle stimulation during concentric phase (Bobbert *et al.*, 1996). This mechanisms however have been suggested to increase force production during exercises involving the stretch-shortening cycle (SSC) action (Moore and Schilling, 2005; Sheppard *et al.*, 2008); while in the present study a one second pause at the transition from eccentric to concentric phase was designed to dissipate stored elastic energy within the muscles. Clearly more investigation is required to determine the effects of preloading muscle by elastic devices on the pattern of subsequent muscle force production.

The comparison between E30 and DB also indicated superiority of E30 in producing considerably higher EMG in 2nd, 3rd and 4th segments and greater RMT in 2nd, 3rd segments of contraction (Figures 4.3 and 4.6). These data support the hypothesis that the ascending elastic force curve causes the prime movers to develop muscle tension across the entire concentric phase to enable completion of the lifting motion (Hodges, 2006). However, providing constant external force by DB resulted in reduced muscle activation and muscle torque production at the end of concentric phase. In this case, given that the torque generating capability of elbow flexors is greater at the beginning of the concentric phase (Harman, 2000), the load is accelerated across the 1^{st} segment and produces a moment of torque which would shift to the 3^{rd} segment and reduce muscle activation. Numerous investigators have highlighted this period of low muscle stimulation as one of the limitations of conventional free weights (Cronin *et al.*, 2003 ; Wallace *et al.*, 2006). These researchers have speculated that the reduction of muscle tension in the late concentric phase can constrain strength development in this area of range of motion (ROM).

Yessis (1980) stated that although the DB may offer a heavy load at the beginning of lifting position (concentric phase), the effective resistance impose to the biceps is nearly zero because the length of lever or moment arm is nearly zero. However, as the elbow approaches 90° flexion the resistance impacted to the biceps muscle increase and show the maximal muscle torque when the lever arm take perpendicular position in elbow joint. As the moment arm moves in either direction away from 90°, the resistance falls off disproportionately to the muscle`s potential strength. Such deficiencies in quality resistance exist in all conventional free weight and pulley machine exercises. it seem quite to be logic to assume that during those angle of motion which exercise does not evoke maximal stimulation in the muscle, no further adaptation would be expected in terms of muscle strength.

4.5 Conclusion

The results of the present study indicated that the E30 achieved EMG and RMT values similar to the DB in early concentric and late eccentric segments (1 and 6 segments). Thus, the data could be taken to indicate that applying the two aforementioned strategies in

E30 could partially offset the weakness of standard ER exercises in not providing a high external force during the early concentric phase of contraction. Although this study validates utilizing ER for achieving a higher stimulus for muscle activation among athletes, our comments are speculative as to whether adaptation to the E30 condition could result in even higher levels of central neural activation, muscle hypertrophy and increased strength development.