CHAPTER V

MUSCLE TORQUE AND EMG ACTIVITY DURING INTENSIVE ELASTIC RESISTANCE AND NAUTILUS MACHINE EXERCISES

5.0 Abstract

Variable Resistance Exercise has been setting out to accommodate muscle force output throughout the range of motion. Among modalities of VRE, CAM-Nautilus Machine (NM) and, recently, Elastic Resistance (ER) exercises have absorbed more applicants among athletes and recreational lifters. This investigation quantified and compared electromyographic activity (EMG) and Torque production (TRQ) pattern in quadriceps muscle using ER and NM. Sixteen subjects completed 8-RM seated knee extension by NM, elastic tubing with original length (E0) and elastic tubing with 30 % decrement of original length (E30). Every repetition was partitioned into 6 segments (3 concentric and 3 eccentric) and mean value for EMG as well as external force and acceleration were calculated and synchronized for every phase of lifting. The Pair sample *t-test* among Total Average EMG (3 repetitions × 6 segments) exhibited no significant difference between E30 and NM (p = .54). However, E30 and NM both exhibited a significantly higher value compared with E0 (p =.00 *and* p = .02 respectively*;* all $p < .05$). In the early concentric and late eccentric segments (1st and 6th segments), NM generated significantly higher EMG than both E30 and E0. However, in the mid-concentric and mid-eccentric (2nd and 5th segments) as well as late concentric and early eccentric segments (3rd and 4th segments) only E30 show significantly higher EMG than E0. In terms of RMT, NM exhibited significantly higher value than both modes of elastic exercises except late concentric phase (all $p < 0.05$). Decreasing 30 % of initial length and matching various color code of elastic tubing developed muscle activation (28.87 %) and RMT production (1.37 %) in elastic exercises. Therefore, a significantly lower level of RMT in E30 % than NM may introduce E30 % as a less demanding and unique mode of exercise for late rehabilitational training protocols. On the other hand, due to creating similar muscle stimulation, E30 % can be

introduced as a viable alternative exercise instead of expensive NM for athletes and recreationally active individuals.

5.1 Introduction

As comprehensively discussed in previous chapters, the ability of a muscle group to produce torque about a joint varies with the joint angle (the angle – torque relationship). For instance, knee extensor muscle group exhibit an ascending – descending torque curve in which strength increases and then decreases across the knee extension motion. The maximal torque generating capability of knee extensor was observed between 65° to 50° of knee flexion (Graves *et al.*, 1989). This is due to the length – tension relationship of the muscle and changes in the length of the lever arm. Therefore, to induce maximal muscle stimulation, the provided external resistance must accommodate the force generating capability of the prime mover (Elliott *et al.*, 1989; Manning *et al.*, 1990).

Except with accommodative dynamometers (e.g. Cybex and Biodex) which offer excellent resistance curve in accordance with strength capability and are very costly, VRT devices are the exercise apparatuses that have shown can partially provide external force in accordance with torque generating capability of muscles. Manning and colleagues (Manning *et al.*, 1990) define VRTs as training devices which attempt to accommodate the muscle changing level of force by providing a varying external resistance throughout the ROM. Fleck and Kraemer (2004) also described VRT apparatuses as a training device which attempt to match the user's strength curve.

CAM-Nautilus Machine (NM) and Elastic Resistance (ER) exercises are two modes of VRT that have increasingly gained popularity among athletes and recreational lifters (Anderson *et al.*, 2008; Folland and Morris, 2008; Harman, 2000; Manning *et al.*, 1990; Page and Ellenbecker, 2003; Treiber *et al.*, 1998). However, to best of our knowledge, there is no documented research which has compared the torque production and muscle activation pattern between these two modes of training within performing high intensity knee extension exercises. The importance of addressing this issue is underlined by the fact that elastic resistance has long been accepted as a cost-effective and portable exercise device compared expensive and cumbersome weight-stock machines (Page and Ellenbecker, 2003).

Some documented studies indicated that Nautilus Machine has been invented to offer resistance torque based on torque generating capability of specific muscle groups across the ROM (Harman, 2000; Wolf, 1980). On this basis, to overcome the shortcoming of free weights and weight-stock machines, a cam-Pulley of variable radius is used in nautilus machines that change the length of moment arm thorough which the weight stocks acts. Graves and colleagues (1989) have reported that knee extension Nautilus machine could provide a uniform exercise stimulus across the whole ROM.

On the other hand, as far as elastic resistance concern, the length tension relationship of muscles during elastic resistance training has been shown to be ascending-descending provided that several biomechanical variables are considered. These variables include:

I. the length of elastic device (discussed in section 2.5)

II. the angle of origin to axis (AOA, Figure 5.1)

III. the resistance arm angle (RAA = the angle of the elastic device and the lever arm; Figure 5.1) (for more information see Page and Ellenbecker, 2003; Simoneau *et al.*, 2001) .

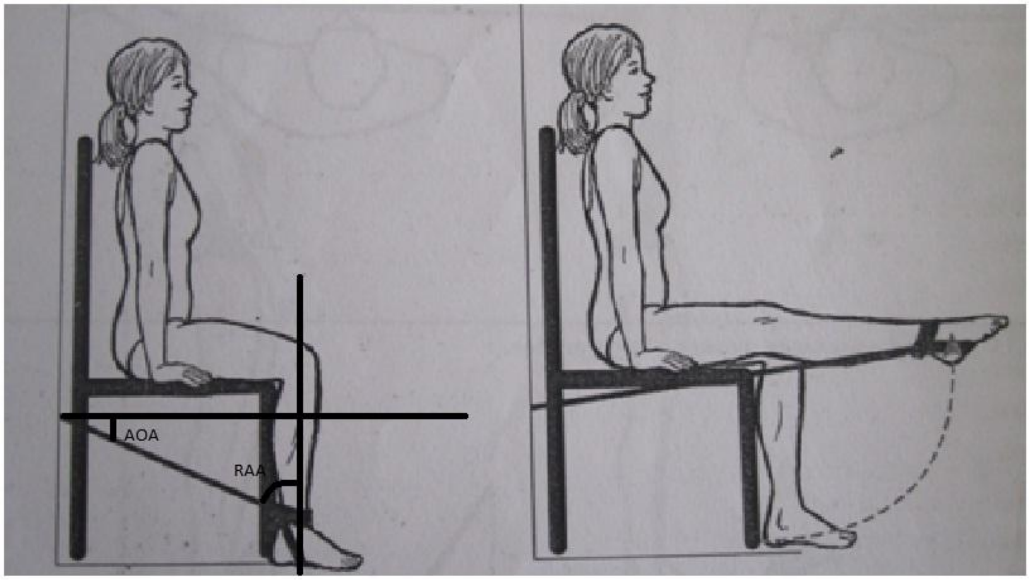

Figure 5.1 Proper position for knee extension using elastic resistance. Adopted from Page and Ellenbacker 2003 "The scientific and clinical application of elastic resistance" Human Kinetic.

Among various parameters which ascertain the torque – angle relationship of ER device, the AOA determined by position of elastic band origin is recognized as the critical parameter. More specifically, AOA determines the RAA which affects angle – torque relationship of the muscle (Page and Ellenbecker, 2003). Understanding of these relationships become much easier by referring to the equation recommended by Page and Ellenbecker (2003). The equation presented in following.

Force × Lever arm × Sine of the RAA (*Equation 5.1*)

Where:

Force = magnitude of applied force during NM or elastic training (N), Lever Arm length = the length of shank plus foot, and Sine of the RAA = the angle between lever arm of each apparatus and the force leg.

On the basis of this formula, the highest torque value provided by elastic device is at the beginning of concentric phase (knee extension), where the Sine of the RAA in nearly 90° (Sine 90° = 1). However, as knee get extended and foreleg approach to the end of concentric phase, the RAA represent an angle closer to 180° and consequently the magnitude of torque declines (Sine 180° = 0). These explanation supported the idea that although linearly ascending resistance is provided by elastic device, ascending – descending torque pattern is produced by this exercise device because of the changing in angle of pulling (Raastad *et al.,* 2000).

Despite these explanation that validate using elastic device for developing muscle activation in exercise such as knee extension, there are however controversial evidences in utilizing this mode of exercise in intensive training protocols (Treiber *et al.,* 1998). Therefore, the utilization of ER has been confined to the initial and intermediate stages of rehabilitation protocols (Hintermeister *et al.,* 1998; Hopkins *et al.,* 1999; Matheson *et al.,* 2001).

Similar as prior study, two strategies were used to increase the magnitude of elastic force; i) reducing the initial length of the elastic material (Treiber *et al.,* 1998); and ii) using additional elastic bands in parallel to the current elastic device (Page and Ellenbecker, 2003). It is worth reminding that in the present investigation no equalization of external force was performed among the three modes of training (DB, E0 and E30); Instead, subjects completed 8 RM biceps curl by each exercise type. A further consideration was that undertaking 8 RM was believed to make the research outcomes more applicable to athletic conditioning.

The aim of the present study therefore was to compare the magnitude of applied force, the pattern of torque production and rate of muscle activation between ER devices and NM.

It is worth noting that this study was not to investigate the capability of NM and ER devices in accommodating the biomechanical capabilities of knee extensors in detail. In fact, the issue that whether ER and NM can accommodate the length tension relationship of the knee extensor muscle is a biomechanical topic which requires completely different research approach. While, the main objective of this study was to compare the magnitude of torque production during performing ER and NM exercises which in conjunction with EMG could facilitate a better perspective about training stress within performing each mode of training.

It was hypothesized that reducing the initial length of the elastic material and using additional elastic bands in parallel to the current elastic device would increase the provided tensile force in E30 and result in significantly higher EMG and applied load are achievable by E30 compared with E0, particularly at the beginning of the concentric and end of eccentric segments. In addition, a combination of the above mentioned strategies in E30 was expected to reduce distinction between NM and E0 (non-shortened elastic device) in terms of applied force, torque production and rate of muscle activation at the beginning of concentric and end of eccentric phases.

5.2 Methods

5.2.1 Subjects

Seven female (mean ± SD; 22.4 4.7 yrs, 60.05 ± 6.17 kg, 158 ± 3 cm) and 9 male, (24.0 ± 3.6 age, 78.14 ± 7.2 kg, 174 ± 7cm) recreationally active volunteers gave their consent to participate in this study. The subjects had no experience of resistance training in the past 12 months. They neither had any history of injury or surgery nor currently underwent any kind of treatments. This experiment was approved by ethics committee of Sport Center, University Malaya. In addition, students were asked not to participate in any type of training 48 hours before data collection. Subjects were recruited from male and female students studying sport science in Sport Center, University Malaya.

The sample-size in the study was estimated according to the statistical power calculations recommended by Vincent WJ. (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. NM, E0 and E30).

Inclusion and Exclusion Criteria. Subjects must be healthy, age 18 to 30 years. The subjects must have not undertaken resistance training in the past 12 menthes. They must have not had previous history of lower limb surgery, current pain or injury, or previous history of any type of repetitive injury. They couldn't be taking any medication, athletic supplement or be smoker or have a history of chronic illness or mental or physical disability.

5.2.2 Experimental measurement

A week prior to the main testing all participants attended an orientation session in which anthropometric measurements such as height, body mass and the length of foreleg were acquired from the subjects. The subjects were then familiarized with the testing procedure and instrumentations by practicing trials of MVC as well as dynamic exercises. The magnitude of external resistance during performing 8 RM knee extension trials was identified for the three modes of exercise to avoid any further trial and error testing to gain actual 8 RM in the main testing day. The load of the weight stock (kg) in nautilus machine and the arrangement of color codes for elastic resistance device were recorded from the best 8 RM performance of the subject. Subjects were asked to demonstrate their best performance during the MVC and the 8 RM tests for all three modes of exercise. They tried to complete the highest amount of load that they could continuously lift-up 8 times with correct style of movement. If additional testing trial was necessary, 3 to 5 minutes resting period was provided to prevent fatigue effects. After each testing trial the load was increased by adding up extra weight stock to the nautilus machine and adding various the color code of tubing, till the subject was unable to perform more than 8 repetitions. For instance, if subject could perform 8 RM with silver color tubing (the heaviest color code), additional resistance was administrated by adding lighter tubing (yellow, red or blue) to the initial unit. Adjustment of the resistance was continued until the subjects were not able to complete the exercise in correct style. Usually, within two or three trials the 8 RM was achievable.

All data were collected within one testing session and the order of the measurement was randomized across 3 exercise modalities. Since changes in the location of the electrodes affect the reproducibility of EMG, all measurements had to be performed in a day for a subject. Before the testing, warm up was performed comprising static stretching and 5 minutes biking on an ergometer with self selected pace. Following the warm up, the subjects were allowed to rest for 5 minutes, during which time the electrogoniometer was strapped to the subject`s dominant leg. Elastic wrap was used to fix goniometer. A pair of surface electrodes (20mm interelectrode distance) was placed on the center of Vastus Lateralis (VL) muscle belly in the direction of muscle fiber as recommended by Hermans *et al.,* (Hermens *et al.,* 1999). The ground electrode was placed on the patella bone. Before placement of electrodes, the subject`s skin was shaved and cleaned with alcohol to reduce skin impedance.

The neuromuscular activation pattern was measured via EMG of VL with a sample rate of 1000 Hz using a 16-bit acquisition mode with an eight-channel TeleMyo™ 2400T G2 EMG system (Noraxon, Scottsdale, Arizona, USA). The EMG signals were passed through inbuilt preamplifier leads with Input impedance > 100 MΩ with common mode rejection ratio > 80 dB. Receiver unit collected the telemetry signals from the receiver amplified and filtered (15 Hz to 1000 Hz) the signals. The external resistance of elastic device was measured using a force transducer placed in series with elastic device and lever arm of nautilus machine. Before testing, sensors were calibrated based on the recommended instruction by manufacture.

In order to avoid any biomechanical interference in position of the subjects, the nautilus knee extension machine was used for elastic tubing exercise testing as well. The initial length of elastic material (Hygienic Corporation, Akron, OH) was determined for every subject by measuring the distance from the origin of the elastic device (base of the NM chair) to the axis (distal end of a load cell). The load cell was attached to the custom made leather ankle cuff.

After electrodes placement, subjects were seated on the knee extension NM according to procedure reported by Manning *et al.,* (1990). The position of the seat was adjusted for each subject to meet 110º of hip and 80º of knee at the initial of knee extension exercise. The MVC was collected while the lever arm of the nautilus machine was fixed at 110º of knee extension (180º was when the knee was at full extension position). A five-second baseline EMG signal was collected from the muscles to ensure no artifacts existed. All the subjects completed 3 trials of unilateral MVC with dominant leg. Each MVC trial lasted 5 seconds with 2 minutes rest intervals between the trials to prevent fatigue (Matheson *et al.*, 2001). The MVC was determined as the average force over a one second period of the highest isometric force value automatically selected by Myoresearch-XP. The RMS value extracted from MVC test used to normalize all EMG values within dynamic actions as a percentage of MVC value (%MVC). In fact, the MVC value exhibits the maximum level of motor unit activation in respective muscle. On this basis, we can measure the level of muscle activation that each mode of exercise can produce within performing the dynamic exercise. The reliability coefficients of isometric strength at single joint angles has been reported $r = 0.91 - 0.99$ (Kroll, 1963).

Subjects then performed 8 RM knee extension exercise with 3 modes of training in a randomized order. Five minutes rest was allowed between exercises for recovery of phosphagen system. Subjects were instructed to perform the exercises within 80º to 180º of knee extension with the cadence of 3 second for each repetition, set by a metronome. To control the position of shank during dynamic contractions, two laser beams connected to an alarm system limited the range of motion at each extremity. Therefore, an alarm sounded if the subject`s foot touched a laser spectrum. An attempt at 8 RM was deemed successful if all repetitions were performed in accordance with the metronome pace, without any compromise in ROM. Moderate velocity of contraction was assigned for all testing trials because:

I. Moderate velocity made participants able to demonstrate their maximal force generating capability.
II. Following the rhythm of the metronome to elicit same angular velocity was more feasible.
III. Faster velocity of contraction might interfere the benefits of stretch shortening cycle

(transferring from eccentric to concentric phase).

Verbal correction was provided from the examiner to achieve appointed exercise pattern. Participants were required to perform 8 RM test through their full ROM for knee extension without compromising the movement patter as observed by the examiners. Repetitions in each set were continued until subject could keep the pace with metronome and cover the assigned ROM without any compromise in the correct style. A combination of elastic materials with various tensile force (but similar length) comprised of: high resistance (silver and black color), moderate resistance (blue and green) and low resistance (red and yellow) were used to meet the requiring number of repetitions maximum (8 RM) knee extension exercise. Therefore, during exercising with both E0 and E30 the elastic material was added or removed so that the subjects were able to finish the required 8 RM (Treiber *et al.*, 1998). In this method, the arrangement of the color codes was different for each subject based on his or her strength and endurance capability.

The Myoreseach-XP software synchronized the EMG and the force transducer and goniometer sensors. Although data were collected from all repetitions of 8 RM, the first (initial), the 5th (middle) and the 8th (last) repetitions were selected for further analysis. Appointed repetitions were partitioned into concentric and eccentric phases based on the end points determined by the electrogoniometer traces. Then, the value of every phase was divided in to 3 equal segments. Accordingly, we had three concentric (80-113.3°, 113.3-146.6° and 146.6-180°) and three eccentric segments (180-146.6°, 146.6-113.3° and 113.3-80°). The EMG signals were rectified and the RMS value was calculated for every segment of motion as well as average of external force (N). The EMG values of segments were then used in calculating the mean value of every repetition (average of all 6 segments). The mean values of the three selected repetitions (1st, 5th and 8th) were used for calculating the Total Average of EMG for every exercise modalities. It is worth noting that to measure reliability of data, 10 subjects were randomly selected to duplicate a similar procedure after 5 days to compute the reliability of testing on two occasions. The test-re-test reliability for the magnitude of external force was 0.92, 0.89 and 0.95 for E30, E0 and NM respectively.

The magnitude of Torque provided by each mode of training was calculated based on the equation recommended by Page and Ellenbecker (2003). This equation is defined as followes:

Force × Lever arm × Sine of the RAA

Where:

Force = magnitude of applied force during NM or elastic training (N), Lever Arm length = the length of shank plus foot, and Sine of the RAA = the angle between lever arm of each apparatus and the force leg.

5.2.3 Statistical Analysis

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 Differences in EMG and RMT value within various segments (1 to 6), repetitions (initial, middle and end) and modalities of exercise (DB, E0 and E30) were examined using a 3 × 3 × 6 repeated measure analysis of variance (ANOVA) across the factors (phases, repetitions, modalities). It is worth mentioning that identical time intervals were compared between three modes of exercises. Therefore, since repeated measure ANOVA doesn't monitor differences across every couple of segments, if significant results were obtained from ANOVA testing, then a series of pair *t-tests* were used to examine the effects of various modes of exercises in EMG and RMT within analogous repetitions and segments. These comparisons were implemented for 1) similar segments in analogous repetitions within various modalities of exercise and 2) similar segment in various repetitions within a particular mode of exercise. Analyzes were performed using a statistical software package (SPSS 15). Significance was defined as $P < .05$.

5.3 Results

5.3.1 Applied Force. The results addressing the magnitude of applied forces for three modes of exercise are presented in Table 5.1. Statistically significant value was observed for the interaction of the main effects segments × repetitions × training modes ($p < .01$). Subsequently, a series of pair sample *t-tests* among the Total Average force applied during the three modes of training (3 reps × 6 segments) indicated a trend in which NM > E30 > E0 (Figure 5.2; all $p < .001$).

The profiles of applied force for three modes of training are graphically depicted in Figure 5.3. In the 1st, 5th and 6th segments significantly higher external force was applied by NM and E30 compared with E0 and during NM compared with E30. In the 2nd segment both NM and E30 employed significantly higher force than E0, while no difference was found between NM and E30. In the 3rd and 4th segment no significant difference was observed between three modes of training (all $p < .05$). In the 3rd segment slightly greater magnitude of applied force for E0 and E30 compared with NM was not significant.

Table 5.1. The magnitude of applied force within various levels of exercise modalities.

Applied Force (N)			
	NM Total Average of 6 segments	E0 Total Average of 6 segments	E30 Total Average of 6 segments
	263*† (115)	139 (52)	175‡ (58)
Mean (±SD) of Applied Force for every segment of motion (N=16)			
1	395*† (170)	53 (19)	109‡ (32)
2	238* (110)	167 (66)	198‡ (68)
3	205 (90)	233 (103)	245 (90)
4	279 (128)	218 (89)	237 (85)
5	311*† (146)	125 (43)	167‡ (53)
6	270*† (128)	38 (13)	94‡ (32)

NOTE. Mean (±SD) of applied force for various segments of contraction (1-6). The Total Average applied force was calculated as values of 3 Repetitions × 6 segments for each mode of exercises. The value of each segment is the average of three repetitions (1^{st}, 5^{th} and 8^{th}) in that respective exercise type. *= NM is significantly higher than E0. ‡= E30 is significantly higher than E0. †=NM is significantly higher than E30 (all $p < 0.05$).

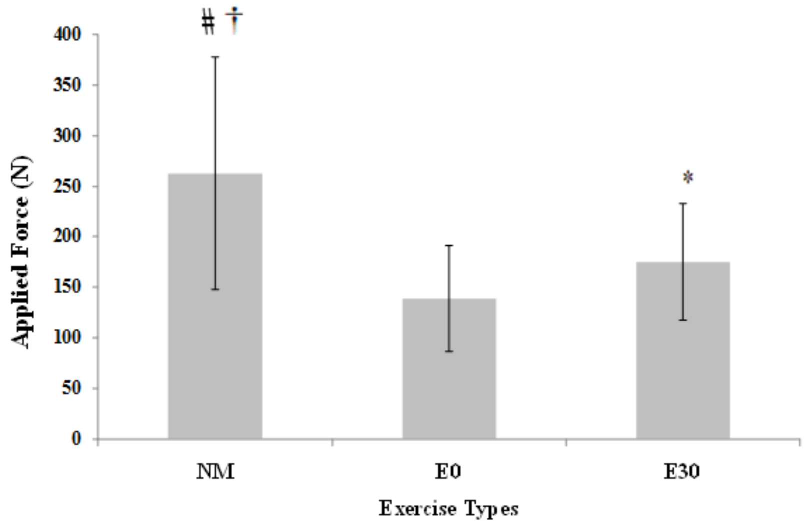

Figure 5.2 Total average Applied Force ± SD (N) within various exercise modes.The value of every column includes the average of 3 repetitions and 6 segments.* = E30 is significantly higher than E0. † = NM is significantly higher than E0. # = NM is significantly higher than E30.

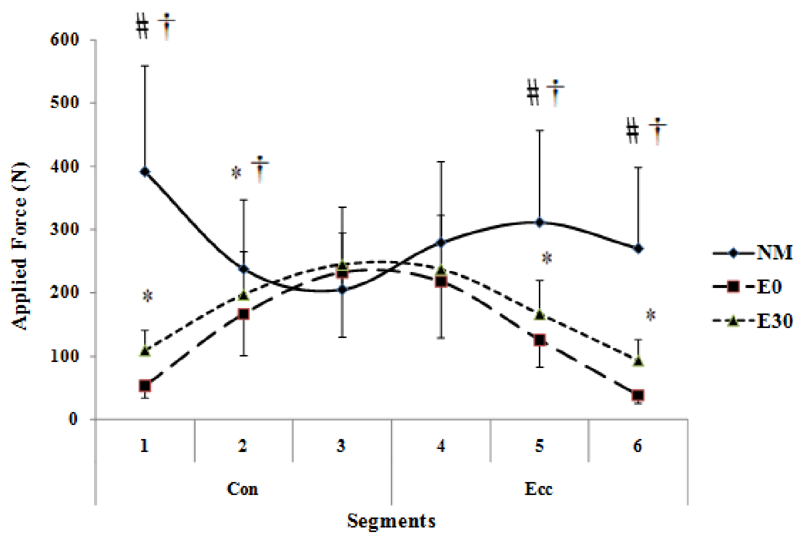

Figure 5.3 Mean ± SD of Applied Force (N) within various segments of motion for the 3 exercise modes. The value of every segment includes the average of 1^{st} + 5^{th} + 8^{th} repetitions, # = NM is significantly higher than E30, * = E30 is significantly higher than E0, † = NM is significantly higher than E0.

5.3.2 EMG. The results addressing the main effects (phases, repetitions and training modes) were listed in Table 5.2. Analysis of variance demonstrated statistically significant difference among six segments (p = *.00*), three repetitions (p = *.00*) and three modes of exercise (p = *.00*). Interaction effects also created a significant values for segments × repetitions (p = *.027*), segments × training mode (p = *.022*), and segments × repetitions × training mode (p = *.025; all* $p < .05$). However, there was no interaction effect for repetitions × training modes (p = *.19*).

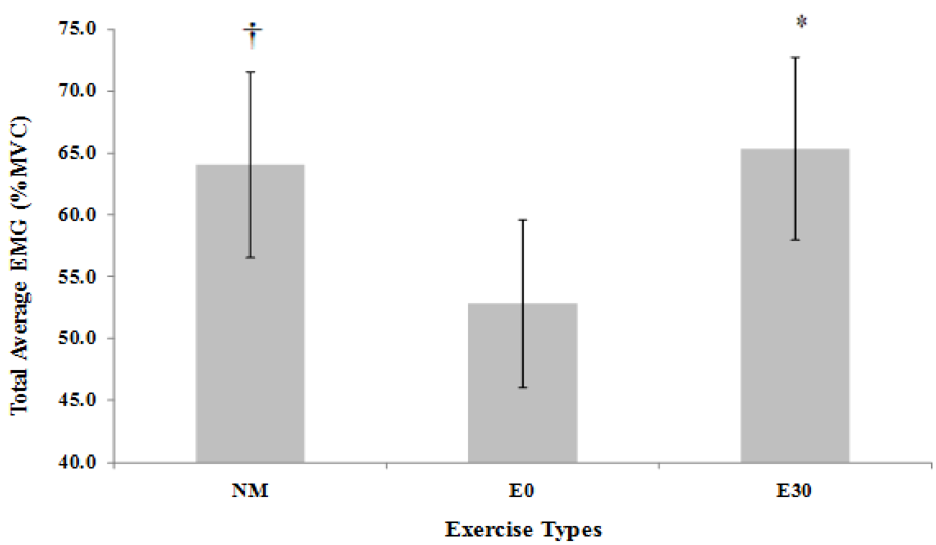

Figure 5.4 Total average EMG ± SD (% MVC) within various exercise modes. The value of every column includes the average of 3 repetitions and 6 segments. * = E30 is significantly higher than E0. † = NM is significantly higher than E0.

Based on the data presented in Table 5.2, the first line of data for comparison is the Total Average of EMG values (average of 3 Rep × 6 Phases) that represented the overall value for each mode of exercise. The Pair sample *t-test* among Total Average EMG exhibited no significant difference between E30 and NM (p = .54). This is despite of the fact that, E30 and NM both exhibited significantly higher value compared with E0 (p = .00 *and* p = .02 respectively*;* all $p < .05$).

The second line of the data is referring to the comparison of the repetitions (Average of 6 phases). This examination is divided in two parts. The first, comparison includes comparing the 1st, 5th and 8th repetitions within each modes of training. The data indicated that examining the three repetitions within each exercise types (intra-exercise examination) displayed a trend in which, higher muscle activation obtained while moving toward last repetitions of the 8 RM (Figure 5.5). The second examination includes comparing similar repetitions between the three modes of exercise (Table 5.2). The data indicated that E30 and NM both show a significantly higher value compared with E0 (all $p < .05$). However as far as the E30 and NM concern, the data indicated that although in the 1st repetition E30 displayed significantly higher value than NM, while repetitions were completed toward the 8th repetition, NM gained higher value than E30. Based on this slop, at the last repetition NM displayed significantly higher value than E30.

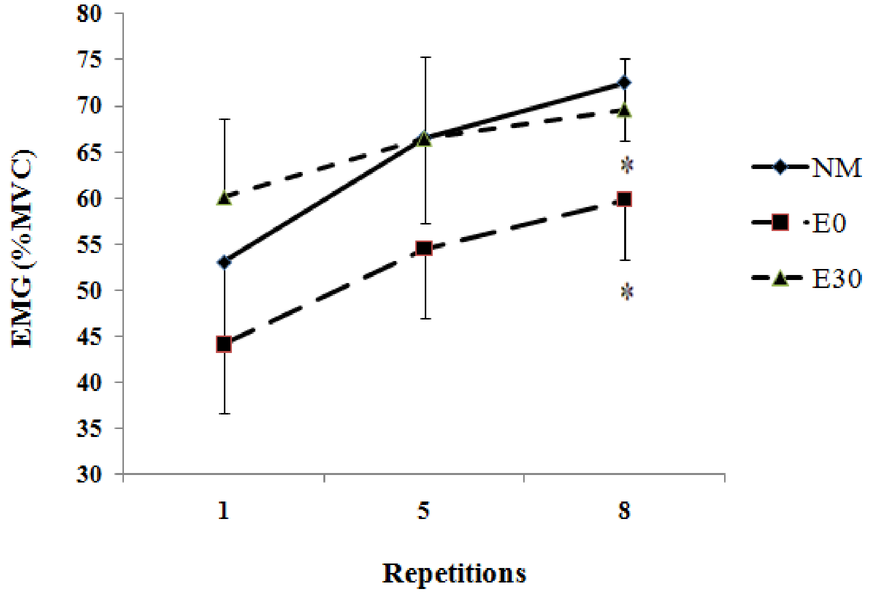

Figure 5.5 Mean ± SD of EMG (%MVC) within various the3 repetitions for the three modes of exercise. The value of each repetition includes the average of 6 segments. * = EMG level in the 8th repetition is significantly higher than the 1st repetition.

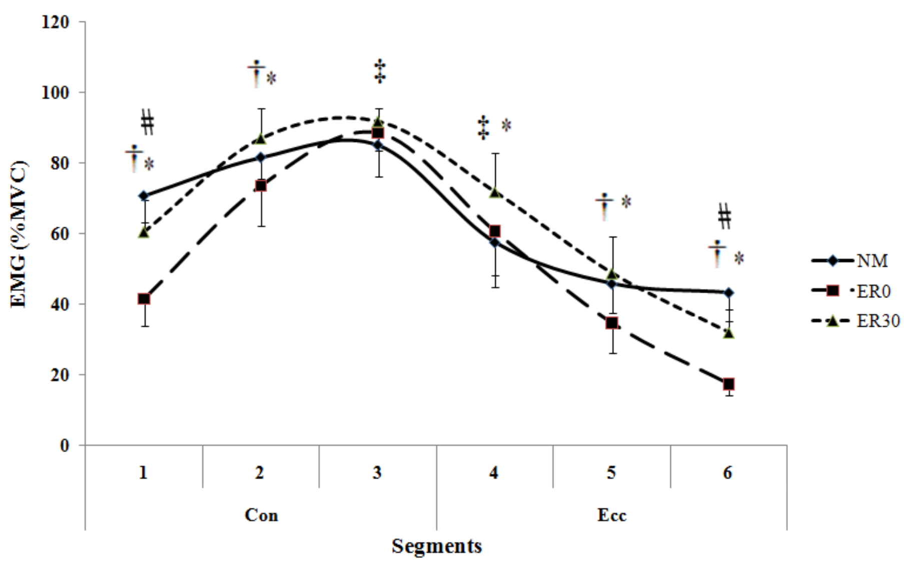

Figure 5.6 Mean ± SD of EMG (%MVC) within various segments of motion for the 3 exercise modes. The value of every segment includes the average of 1st + 5th + 8th repetitions. † = NM is significantly higher than E0%. ‡ = E30 is significantly higher than NM. # = NM is significantly higher than E0 and E30. * = E30 is significantly higher than E0.

Table 5.2. The EMG values within various levels of exercise modalities.

	EMG (% MVC)								
	NM Total Average of 3 Rep × 6 seg			E0 Total Average of 3 Rep × 6 seg			E30 Total Average of 3 Rep × 6 seg		
	64.1 * (7.5)			52.8 (6.8)			65.4 ‡ (7.4)		
	Average of all 6 phases			Average of all 6 phases			Average of all 6 phases		
	rep 1	rep 4	rep 8	rep 1	rep 5	rep 8	rep 1	rep 5	rep 8
	53.1 * (8.2)	66.6* (9.3)	72.5 *† (6.3)	44.1 (7.5)	54.5 (7.5)	59.8 (6.5)	60.1 ‡♦ (8.5)	66.4‡ (8.8)	69.6‡ (5.6)
Mean (±SD) of EMG values of every segments (N=16)									
1	49.4 * (6.4)	70.7*† (15)	92.3*† (6.5)	33.7 (6.3)	41.4 (8.1)	49.8 (11.6)	56.2‡♦ (8.3)	55.8‡ (12.7)	69.8‡ (11.7)
2	62.5* (12.2)	88.5 * (9.3)	93.9* (3.7)	57.5 (15.8)	76.2 (11.3)	87.3 (11.9)	80.2 ‡♦ (15.2)	84.8 ‡ (11.9)	95.9‡ (3.7)
3	77.5 (16.2)	87.1 (9.5)	90.8 (7.6)	79.7 (10.4)	91.4 (4.6)	94.7 (3.7)	88.1‡♦ (9.5)	93.5 ♦ (4.1)	93.6 (4.2)
4	48.1 (12.4)	60.4 (12.7)	64.1 (15.5)	50.3 (12.6)	63.9 (16.4)	67.9 (12.7)	62.5‡♦ (14.1)	74.9 ‡♦ (13.0)	78.9‡♦ (12.4)
5	40.8* (9.6)	45.8 * (10.2)	50.8* (7.8)	28.2 (7.4)	34.8 (10.9)	41.1 (10.1)	41.8 ‡ (9.9)	52.2 ‡ (12.2)	52.6 ‡ (11.2)
6	39.8*† (8.4)	46.6*† (8.9)	43.4 *† (8.8)	15.3 (4.7)	19.2 (6.9)	17.8 (3.0)	31.8 ‡ (6.9)	37.2 ‡ (11.0)	27.3 ‡ (7.1)

NOTE. Mean (±SD) values for various segments (seg) of contraction (1-6), Average of 6 phases for every repetition (rep) and Total Average of 3 Repetitions for every mode of exercises. *= NM is significantly higher than E0. ‡= E30 is significantly higher than E0. †=NM is significantly higher than E30. ♦ = E30 is significantly higher than NM (all $p < 0.05$).

The third level of data is referring to the EMG value obtained for each phase of contraction. The data are also graphically presented in figure 5.6. These results indicated that in the early concentric and late eccentric phases (i.e. 1^{st} and 6^{th}) NM generated significantly higher muscle activation than both elastic modalities. E30 also attained a significantly higher value than E0 (all $p < .05$). In the mid-concentric and mid-eccentric phases (i.e. 2^{nd} and 5^{th}) E30 and NM showed significantly higher muscle activity than E0. In the 5^{th} segment E30 also demonstrated significantly higher EMG value than NM. Finally, in late concentric and early eccentric phases (i.e. 3^{rd} and 4^{th}), E30 demonstrated a significantly higher EMG than NM in both segments and compared with E0 only at the 4^{th} segment (all $p < .05$).

5.3.3 Torque. The data addressing the magnitude of torque production by each mode of exercise device were presented Table 5.3. Analysis of variance demonstrated statistically significant difference among six segments ($p = .00$) and three modes of exercise ($p = .00$). Interaction effects also created a significant values for segments × training mode ($p = .00$; *all* $p < .05$). The Pair sample *t-test* of Total average torque values among three modes of training exhibited a significant trend in which NM > E30 > E0 ($p = .00$; Figure 4.7). Examining the pattern of and magnitude of torque elicited by each modes of training (Figure 5.8) also indicated that NM has produced significantly higher torque compared with E0 and E30 through all segments of ROM. The results also indicated that E30 generated significantly higher resistive torque compared with E0 at the 1^{st}, 2^{nd}, 5^{th} and 6^{th} segments (all $P < .05$).

Table 5.3. The magnitude of torque elicited within various levels of exercise modalities.

Resistive Torque (N.m)			
	NM Total Average of 6 segments	E0 Total Average of 6 segments	E30 Total Average of 6 segments
	122*† (58)	41 (17)	54‡ (20)
Mean (±SD) of Resistive Torque for every segment of motion (N=16)			
1	170*† (79)	22 (9)	46‡ (15)
2	102*† (51)	59 (26)	69‡ (27)
3	88*† (42)	54 (27)	57 (24)
4	120*† (59)	51 (23)	55 (22)
5	134*† (68)	44 (17)	59‡ (21)
6	116*† (59)	16 (6)	39‡ (15)

Note: Mean (±SD) of elicited torque by each mode of training within various segments of ROM (1-6). The Total Average torque was calculated as values of 6 segments for each mode of exercises. The value of each segment is the average of three repetitions (1^{st}, 5^{th} and 8^{th}) in that respective exercise type. *= NM is significantly higher than E0. ‡= E30 is significantly higher than E0. †=NM is significantly higher than E30 (all $p < 0.05$).

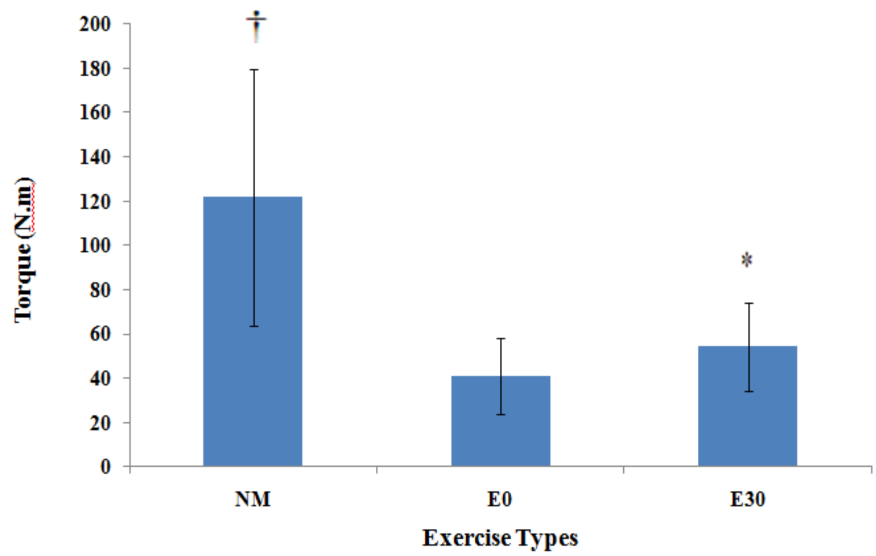

Figure 5.7 Total average torque ± SD (N.m) within various exercise modes. The value of every column includes the average of 3 repetitions and 6 segments.* = E30 is significantly higher than E0. † = NM is significantly higher than E0 and E30.

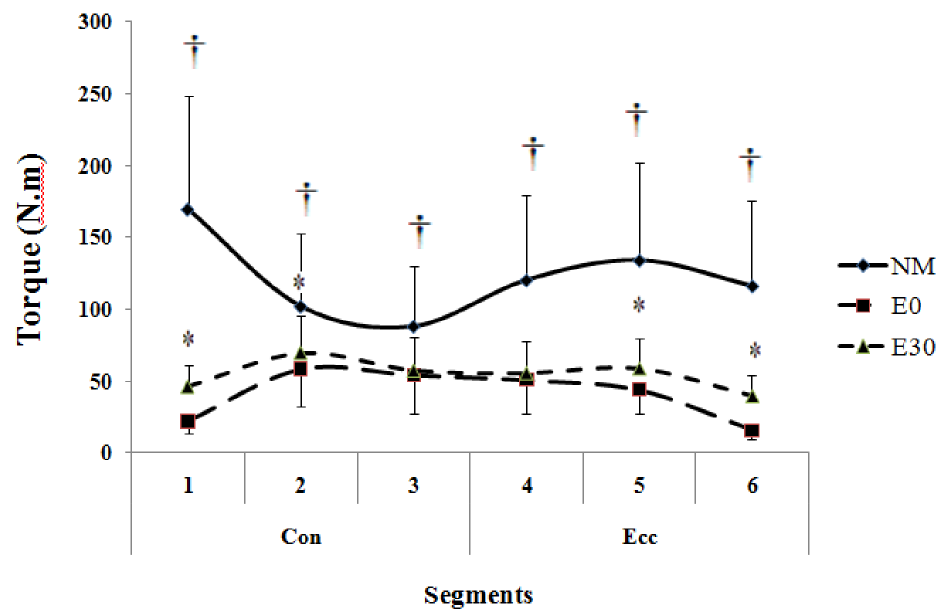

Figure 5.8 Mean ± SD of torque (N.m) within various segments of motion for the 3 exercise modes. The value of every segment includes the average of 1st + 5th + 8th repetitions, † = NM is significantly higher than E30 and E0, * = E30 is significantly higher than E0.

5.4 Discussion

The aim of this study was to compare the pattern of electromyography activity and applied force among three modes of resistance training (NM, E0 and E30) within performing high intensity knee extension exercises. In the present study no equalization of external force was performed across the exercise devices. Instead, subjects completed 8 RM knee extensions by each type of training. The rationale for selecting this method was based on the fact that: (i) no scientific method has been documented for equalizing the magnitude of external force; and (ii) the repetition maximum strategy is known as a popular method for prescribing high resistance training protocols. Undertaking 8 RM was believed to make the research outcomes more applicable to athletic conditioning.

The results for the Total Average EMG demonstrated an equal overall muscle activity (throughout 8 repetitions) between E30 and NM, but a significantly higher activity for E30 compared with E0 (Figure 5.4). The data support the idea of using additional elastic bands and, in particular, reducing the resting length of elastic units as effective strategies for improving the level of muscle activation by the ER device. The findings are in agreement with the results reported by Hodges (Hodges, 2006). He found that reducing 30 % of the resting length in elastic material could increase the amount of the load applied to the joint up to 272 % in the concentric and 430 % in the eccentric phase during internal and external shoulder rotation exercise.

The effectiveness of these strategies becomes even more evident when the pattern of muscle activity is compared across the three types of training. As depicted in Figure 5.6, significantly higher EMG was achieved by E30 compared with E0 in the 1st, 2nd, 5th and 6th segments. Furthermore, E30 generated muscle activation equal to that of NM in the 2nd to

5th segments and showed significantly higher value than NM in the 3rd and 4th segments. Such results suggest E30 as a modified form of ER device which can partially overcome a chronic drawback of ER exercise which regularly fails to elicit adequate muscle activation throughout the ROM, particularly at the beginning of the concentric phase (Lim and Chow, 1998; Matheson *et al.,* 2001).

Despite the above findings, significantly less EMG and applied force by E30 compared with NM in the 1st and 6th segments indicates that caution should be exercised before accepting E30 as an inclusive mode of training for high intensity training protocols. In fact, despite reducing 30% of initial length, E30 could not provide adequate external resistance to meet the force generating capability of quadriceps muscle at these two particular segments. This finding is in accordance with the results reported by Hodges (Hodges, 2006). He demonstrated that even shortened elastic tubing provides less average resistance and consequently lower neuromuscular adaptation than that of traditional free weights at the beginning of concentric and end of eccentric segments of motion. These results point to the need for more studies to elucidate if reducing the higher percentage of initial elastic device length (e.g. 40 % or 50 %) would result in more muscle activity and provide elastic force in these segments of motion.

A unique aspect of the data in the present study is observing equal Total Average EMG between E30 and NM, despite considerably less external load (33.46 %) being employed by E30 (Figures 5.2 and 5.4). This result propounds the question "how could less external force in E30 elicit a similar rate of muscle activation compared with NM?" This discrepancy was also evident across a whole range of motion (Figures 5.3 and 5.6) where a higher applied force within NM exercise was not reflected in EMG values. The reason behind this relatively a higher EMG for E30 is unclear. However, since distal extremity of the lower leg (ankle) had higher degree of freedom during knee extension by ER device (compared with restricted-unidirectional NM lever arm) more control over the movement was required to keep the lower leg motion aligned on the sagittal plane (McCaw and Friday, 1994). In advocating this idea, Richards and Dawson (2009) indicated that performing exercises in a multiaxial direction could potentially change the rate of muscle activation via altering motor unit recruitment. Overall, the data supported the idea of Bosco and colleague (2000) regarding the concept of exercise intensity. They stated that contrary to the classical thought which has defined the exercise intensity as a magnitude of the load employed, it must instead be defined as the rate of the work performed.

Regarding the effects of reducing the initial length of elastic material on the pattern of muscle activation, it is worth remembering that E30 generated a significantly higher EMG value compared with E0 across the whole ROM, except in the 3rd segments, which equal EMG observed between the two modes of training. Based on similar findings, Hodges (Hodges, 2006) concluded that after reducing the initial length of elastic material, a shift occurs in the distribution of muscle tension from late concentric to early concentric and from an early eccentric to a late eccentric range of motion. Accordingly, E30 exhibited significantly higher EMG than E0 in the 1st (48 %) and the 6th (84.31 %) phases. These data show the importance of reducing the initial length as an essential strategy to develop muscle activation by ER devices.

As far as torque production concern, E0 and E30 demonstrated similar ascending – descending torque pattern, though E30 showed flatter torque pattern compared with E0. Regarding that the length of lever arm and angle of RAA and AOA is similar between the two modes exercise, the flatter torque pattern in E30 could be due to greater external force provided by E30 device. Nonetheless, NM and ER exercises demonstrated considerably different patterns of torque production. In NM exercise, the greater magnitude of torque was observed at the beginning of concentric phase (1^{st} segment) and gradually the torque production declined to the end of concentric phase (3rs segment). However, in both modes of ER exercises, the ascending – descending pattern of torque production exhibited an increase from the 1^{st} to the 2^{nd} segment of motion and again fell at the 3^{rd} segment. Across the eccentric phase however, both NM and ER exercises demonstrated nearly similar inverted U shaped torque pattern where the increased torque value from the 4^{th} to the 5^{th} segment was followed by a decline at the 6^{th} segment of motion.

As previously mentioned, completely different research approach was required to resolve the issue that whether ER and NM can accommodate the length tension relationship of the knee extensor muscle or not. Documented studies indicated that some previous investigators have scrutinized this topic, although the data are restricted methodologically and always studied other modalities of VRT training devices rather than NM and ER. One of the most informative studies in this regard was conducted by Folland and Morris (2008). In their investigation, eight variable-cam knee extension machines were studied to determine the extent to which the resistance provided by each machine match joint torque capability. To achieve this aim, knee extensor muscle torque capability was determined isometrically and dynamically at the same five angles. Using isokinetic machine, an inverted ‘‘U’’ shape angle – torque relationship was observed for the knee extensors during isometric and isokinetic torques. The data displayed Maximal torques at 100 - 110° of knee extension (end of the 1^{st} segment) with marked reductions near both extremities of the range of motion. This research also revealed that the torque generating capability of the knee extensor muscle at the beginning of concentric phase is significantly higher than the end of this phase. However, one the limitation of this study was that neither NM knee extension nor ER was studied. In addition, the pattern of torque production was analyzed only across the concentric phase.

Nonetheless, comparing the torque pattern in the study of Folland and Morris (2008) with the calculated pattern in the current study indicated that NM provided more accommodative torque pattern with the torque generating capability of knee extensor muscles. In fact, in the present study, the pattern of torque production by NM demonstrated the highest value at the 1^{st} segment of concentric phase (80 -113° of knee extenison) which is in line with the data reported by Folland and Morris. However, the highest torque value for ER was observed with a delay in the 2^{nd} segment of concentric phase (113 - 146° of knee extension). In addition, the other noticeable discrimination between torque pattern of NM and ER exercises is that, in opposite of NM, ER devices generated greater torque at the end of concentric phase (3^{rd} segment) compared with the beginning of it (1^{st} segment). However, as mentioned previously, more research studies are required to quantify and compare the torque production of the NM and ER exercises with isokinetic dynamometers in detail.

5.5 Conclusion

Equal overall muscle activity (throughout 8 repetitions) between E30 and NM and significantly higher EMG achieved by E30 compared with E0 in the 1^{st}, 2^{nd}, 5^{th} and 6^{th} segments supported the idea of using additional elastic bands and, in particular, reducing the resting length of elastic units as effective strategies for improving the level of muscle activation by the ER device. Despite the promising nature of these findings, significantly less EMG and applied force by E30 compared with NM in the 1st and 6th segments indicates that caution should be exercised before accepting E30 as an inclusive mode of training for high intensity training protocols. In other words, despite reducing 30% of initial length, E30 could not provide adequate external resistance to meet the force generating capability of quadriceps muscle at these two particular segments. These results point to the need for more studies to elucidate if reducing the higher percentage of initial elastic device length (e.g. 40 % or 50 %) would result in more muscle activity and provide elastic force in these segments of motion.