CHAPTER VI

Acute Neuromuscular and Hormonal Responses to Resistance Exercise Using Variable External Resistance Loading (Nautilus Machine versus Elastic Resistance)

6.0 Abstract

In the past two decades Variable Resistance training (VRT) such as Nautilus Machine (NM) and Elastic Resistance (ER) has gained tremendous popularity among athletes. However, the use of ER in high intensity training protocols has been controversial due to providing low external force. Purpose: to quantify and compare the acute responses in frequency and amplitude of electromyogram signals (EMG) and the concentration of serum Growth Hormone (GH), Testosterone (T) and Lactate (LC) following fatiguing knee extension exercise with ER and NM. Methods: In a counterbalance cross-sectional study, nine male (21.08 ± 6.2 yrs) recreationally active subjects completed 5 sets of 10-RM knee extension exercises by ER and NM with three weeks elapse between experiments. Blood sampling, Maximum Voluntary Contraction (MVC) and EMG were recorded before, immediately, 15, 30, and 60-min after termination exercises. Results: The average of applied forces in NM was significantly higher than ER (509.88 ± 59.66 N vs 266.73 ± 58.56 N) through the 5 sets of dynamic exercises. However, the average force and mean amplitude of MVC as well as the blood concentration of GH, T and LC demonstrated no significant difference between the two types of exercise either in pretest or during recovery period (all $p > .05$). The serum T showed a significant decrease 60-min after NM compared with pretest (16.2 ± 2.5 vs 22.5 ± 3.2 nmol/L, $P = .01$); while, GH increased significantly 15-min and 30-min after NM (0.1 ± 0.05 vs 3.9 ± 2.1) and ER (0.2 ± 0.1 vs 3.8 ± 2.1 mIU/L, *all p < .01*) exercises. The concentration of blood lactate also increased significantly immediately after termination of both exercises and remained elevated up to 30 min post training (*all p < .005*). Conclusion: Despite considerably less total work completed during ER than NM, similar neuromuscular and anabolic hormonal responses were observed. This could be attributed to higher degree of freedom of lower leg segment

during ER (compared with restricted-unidirectional NM lever arm) which might have stimulated proprioceptive pathway and/or changed motor unit activation pattern and in turn facilitated anabolic hormonal secretion. The data supported this idea that in contrary to the classical thought, the exercise intensity should not be defined as magnitude of the load employed but as the rate of the work performed.

6.1   Introduction

In the preceding chapter, comparing electromyographic activity, magnitude of applied force and torque production between NM and ER device, some controversial evidences were observed which made it difficult to judge about effectiveness of a training protocol using ER device. On the one hand, E30 produced an equal total muscle activity compared with NM across 8 RM knee extension exercise, on the other hand, significantly lower magnitude of applied load was recruited during E30 exercise. Furthermore, equal EMG activity was produced by E30 compared with NM in the 2nd to 5th segments, while, considerably greater magnitude of torque was generated by NM compared with E30 at the 1st, 2nd, 5th and 6th segments of motion. Overall, some part of the data suggested E30 as a modified form of ER device which can provide adequate muscle activity for high intensity training protocols, however other findings (e.g. significantly less EMG and applied force by E30 compared with NM in the 1st and 6th segments) recommended that caution should be exercised before accepting E30 as an inclusive mode of training for high intensity training protocols.

These controversial findings about application of ER device for high intensity resistance training are in line with previous documented research studies. In fact, some investigators have rejected the idea of utilizing ER device for high intensity training protocols "due to provide inadequate external force" (Ebben and Jensen, 2002; Hodges, 2006; Newsam *et al.,* 2005; Treiber *et al.,* 1998). While, proponents of ER (Matheson *et al.,* 2001; Muhitch, 2006) suggest that an ER device is a suitable alternative to the use of conventional resistance training equipment, if a similar external force is provided by the ER device. Nevertheless the efficacy of ER as an appropriate resistance training device

does not have widespread acceptance. Accordingly, the use of ER in the development of strength has been primarily limited to rehabilitation settings. The question that needs to be addressed is: "whether using an ER device can result in similar acute neuromuscular and anabolic hormonal responses as NM?"

The combined study of acute neuromuscular and hormonal responses has been used extensively to compare resistance training protocols of various intensities (Bosco *et al.,* 2000; McCaulley *et al.,* 2009) and types of muscle contraction (Durand *et al.,* 2003; Morrissey *et al.,* 1995). The relatively short term responses at the outset of a resistance training program may potentially provide insight to the longer term adaptations. We are unaware of any published research that has focused on the neuromuscular and hormonal responses to VRT such as ER and the NM. On this basis, the present investigation (the 3rd study) was conducted to elaborate further detail about effectiveness of ER device in causing acute neuromuscular and anabolic hormonal responses. It is worth mentioning that in this study we used E30 as a modified form of ER device which makes performing high intensity training protocols possible (e.g. 8 RM). In addition, in the two previous experiments (1st and 2nd study) it was explicitly confirmed that E30 provided significantly higher muscle activation, applied force and torque values compared with E0.

It was hypothesized that since muscles had undertaken similar efforts (indicated from equal EMG activity) within performing 8 RM knee extension exercise by E30 and NM, the equal level of muscle activation could cause similar responses in magnitude of MVIC and submaximal isometric force production following training protocols using E30 compared with NM exercises. In addition, it was hypothesized that equal acute responses would be detected in electromyographic activity (frequency and amplitude of electromyogram

signals) and anabolic hormones secretion following training protocols in contribution of E30 and NM exercise.

The purpose of this investigation therefore was to investigate the acute responses of electromyogram signals (EMG) and the responses of growth hormone (GH), testosterone (T) and plasma Lactate concentration (LC) following intensive resistance training protocols employing ER and NM devices. Investigating the acute neuromuscular and anabolic hormonal responses following training protocols using the two types of exercise would offer valuable information about dose-response relationship and effect of each type of training (Folland and Williams, 2007; McCaulley *et al.,* 2009). The data can be used to optimize training protocols in contribution of theses training devices in late rehabilitational stages as well as recreational and athletic setting.

6.2 Methods

6.2.1 Subjects

Nine recreationally active male students (age: 21.08 ± 6.2 yrs, weight: 74.58 ± 7.2 kg, height: 172 ± 6 cm) participated in the study which was approved by the Human Ethics Committee of the Sports Centre, University of Malaya. All participants provided their informed consent following explanation of the possible risks and discomfort and subsequently completed a Medical Screening Questionnaire. None of the participants had a history of taking medications and there were no reports of musculoskeletal injuries or metabolic disease. In addition, subjects had not participated in any resistance training program or competitive sport in the past 12 months. All subjects refrained from vigorous

physical activity during their involvement in the study. Subjects must have beed healthy, age 18 to 30 years. The subjects must have not undertaken resistance training in the past 12 monthes. 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.

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, ten subjects were required to participate in the study, and with a crossover study design, one half undertook the ER training first and the other half undertook the NM first.

6.2.2 Preliminary Testing Session

Subjects attended a pre-experimental session to be informed about the possible discomforts and risks associated with the data collection (Komi and Tesch, 1979). Anthropometric measurements such as height, body mass and foreleg length were acquired from the subjects. The percentage of body fat was assessed using a four-site (thigh, triceps, suprailiac, and abdomen) equation (Jackson and Pollock, 1978). For more familiarization subjects were then required to practice 10- RM trials with both modes of exercises. 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 (a custom made leather shin pad). In addition, 30% of initial length of elastic device was reduced to create more external resistance throughout the entire range of motion, particularly at the beginning concentric phase (Hodges, 2006). During each exercise mode the external load was either added or removed so that the subject was always

able to just finish the required ten repetitions were selected for this study (Treiber *et al.,* 1998). The test-re-test reliability for NM and ER 10-RM dynamic trials was 0.93 and 0.85. Moderate intensity (10-RM) was selected for this study because commonly strength and hypertrophic exercise protocols employ this intensity (Kraemer and Gordon, 1991; Kraemer *et al.,* 1998; McCaulley *et al.,* 2009). Furthermore, Since muscle mass and volume of training have been manifested as the effective parameters in hormonal responses, leg extensor muscles have been selected to complete 5 sets of NM and ER trainings (Bosco *et al.,* 2000; Linnamo *et al.,* 2005). It is worth noting that to avoid any biomechanical interference the nautilus knee extension chair (Nautilus, Vancouver, WA) was used for both modes of exercise. In addition, all subjects were provided with the same diet for the day prior to testing.

6.2.3 Testing Procedure

Subjects attended the first experimental session at 8:00 a.m. after an 8-hour fast. Twenty minutes resting time was allocated during which time a flexible indwelling catheter was inserted into the antecubital vein and the baseline blood samples collected. Warm up was performed comprising static stretching and 5 minutes biking on an ergometer with selected pace. Following the warm up, the subjects were allowed to rest for 5 minutes. In the meanwhile, a 2-D electrogoniometer (Noraxon**,** Scottsdale, Arizona, USA) was strapped on the lateral side of the knee. A pair of pre-gelled silver/silver chloride surface electrodes (Meditrace, Canada) were located parallel to the direction of the muscle fibers (20mm interelectrode distance) on Vastus Lateralis (VL), Vasrus Medialis (VM), and Rectus Femories (RF) based on recommendation of SENIAM (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 location of the

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electrodes was carefully marked on the skin to ensure the same position of the electrodes on subsequent day.

The baseline measurement of maximal force was assessed using knee extension Maximal Voluntary Isometric Contraction (MVC) technique based on the method reported by Arendt-Nielsen and Mills (1988). Three trials of unilateral MVC were performed with right leg. Each trial lasted 5 seconds with 2 minutes rest intervals to prevent fatigue. The other muscle performance test was a 5 second submaximal isometric contraction at 50% of preexercise MVC load to measure changes in EMG signals at a constant level of external force. The lever arm of the isokinetic dynamometer (Biodex, USA) was equipped with a force transducer (Noraxon, Scottsdale, Arizona, USA) which was connected to the ankle throughout a custom made leather ankle cuff. The net knee extension force was measured for each subject at 1.05 rad (120°) knee flexion (with 0 being knee straight). Data acquisition package of Myoresearch-XP (Noraxon, Scottsdale, Arizona, USA) was used to synchronize the data form electrogoniometer, force cell and EMG system. The EMG recording was made with a sample rate of 1000 Hz using an eight channel TeleMyo™ 2400T G2 EMG system (Noraxon, Scottsdale, Arizona, USA). The EMG signals were passed through a build-in preamplifier leads (Input impedance of 500 MΩ common mode rejection ratio of 130 dB). Receiver unit collected the telemetry signals, filtered (10 Hz to 500 Hz) it and save the data on a computer. The maximal EMG was used as a reference value which the rate of muscle activation within dynamic exercises was reported as a percentage of it.

The participants then performed five sets of 10-RM (ER or NM) through the assigned range of motion (80º to 180º of knee extension) with 90 s rest period between sets (Kroon and Naeije, 1991). The initial 10-RM load was assigned based on the load that subjects had

carried out during preliminary testing trials. All repetitions were completed based on the rhythm of a metronome at the velocity of 4 second per repetitions (2 s lifting (extension) and 2 s lowering (flexion) the external resistance). The assigned range of motion was limited by using two pieces of rubber band strapped horizontally at each extremities of range of motion. Therefore, when the participant`s foreleg would touch the rubber band, he would end from the corresponding phase of contraction start the next. Immediately after completion of the 5th set, a blood sample was collected followed by isometric MVC plus EMG. The similar procedure of testing comprises of blood sampling, MVC and EMG was recorded at 15, 30, and 60-min after termination of dynamic exercises (Linnamo *et al.,* 2000; Raastad *et al.,* 2000). In addition, blood sampling was continued up to the 3rd, 5th, and 7th day to measure the plasma CK (Ahmadi *et al.,* (2007). All blood samples were analyzed for GH, T and CK. The samples were stores on Vacutainer tubes on the ice and then centrifuged for 10 min at 3000 rpm. Serum plasma was stored at $-20\ °$ C until assayed. GH and T were determined using a sensitive radioimmunoassay (RIA) by reagent kit from Diagnostic Products Corporation (Los Angeles, CA).

The rate of muscle soreness after fatiguing experiments was evaluated based on the method reported by Takahashi et al., (1994). In this method subjects were asked rate their muscle soreness subjectively using a scale of 1 (normal) to 5 (very sore) each day for 4 days after each experiment. One day after completion of each mode of exercise, subjects underwent another MRI scanning exactly similar as pretest measurement.

6.2.4 Statistical Analyses

7 Statistical   analyses   were   computed   using   SPSS   software   (Version 15.0, SPSS, Inc, Chicago, IL). A two way repeated measure ANOVA (2×5) was used

to identify the effect of training mode (ELASTIC and NAUTILUS) and the time course of testing (before × IP × 15 min × 30 min × 60 min) on the EMG, applied force and blood parameters. If significant results were obtained from main effects of ANOVA, a series of pair sample *t-tests* were used to compare identical time course of intervals between ELASTIC and NAUTILUS. Significance was defined as $P < .05$. Test–retest reliability was evaluated by intraclass correlation coefficient (ICC).

7.2 Results

Statistical analyses were computed using SPSS software. Test–retest reliability was evaluated by intraclass correlation coefficient (ICC). The ICC of force production for NM and ER during the 10-RM dynamic trials was 0.93 and 0.85, respectively.

7.2.1 The changes in force and EMG within 5 sets of dynamic contraction. The data addressing the magnitude of external force employed during each mode of training are presented in Table 6.1. The average of applied forces during NM was significantly higher than ER ELASTIC (362 ± 34.2 N vs 266.7 ± 44.6 N, F $(1,8) = 27.20$, $p = .00$) throughout the 5 sets of dynamic exercise (Figure 6.1, all $P = .00$). However, the mean amplitude (F $(1,8) = 0.68$, $P = .43$) and median frequency (F $(1,8) = 0.05$, $P = .82$) of EMG signals during dynamic contractions showed no significant difference between the two modes of training (Figures 6.1 and 6.2).
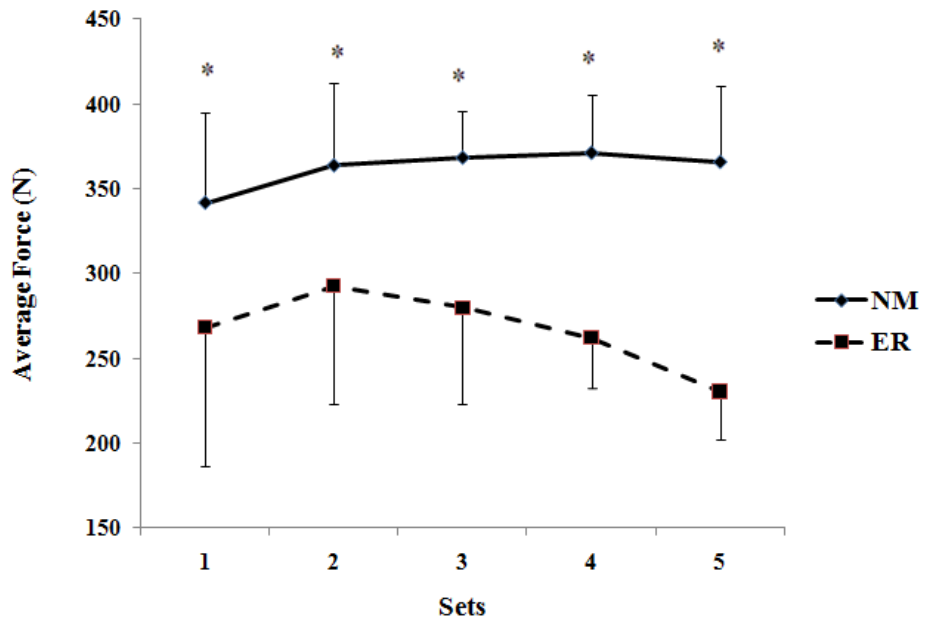
Figure 6.1 Average of external force employed during dynamic exercises. NM = Nautilus Machine; ER = Elastic Resistance. * = significantly greater magnitude of external force lifted during NM in compared with ER (p < 0.001).

Table 6.1. The EMG measures during 5 sets of dynamic exercises.

Variables	Groups	1st set	2nd set	3rd set	4th set	5th set
Average force (N)	NM	341 ± (75)*	363 ± (42)*	368 ± (48)*	371 ± (78)*	365 ± (43)*
	ER	268 ± (42)	292 ± (83)	279 ± (45)	262 ± (97)	230 ± (64)
MA VM (µV)	NM	78.45± (14.8)	85.71 ± (17.9)	81.45 ± (16.4)	74.8 ± (6.7)	87.4± (22.4)
	ER	73.6± (25.8)	83.5± (18.2)	88.8± (24.0)	81.9 ± (23.2)	91 ± (11.6)
MA VL (µV)	NM	77.3± (11.0)	85.5± (19.0)	85.1± (6.9)	77.8 ± (16.46)	101.4± (19.7)
	ER	60.4± (14.5)	84.7 ± (10.8)	87.8 ± (22.8)	92.42± (27.91)	97.46± (17.26)
MA RF (µV)	NM	108.5 ± (24.7)*	88.5 ± (29.0)	90.41 ± (14.6)	83.69± (21.4)	109.42 ± (24.12)
	ER	77.7 ± (27.8)	74.5 ± (35.2)	77.95 ± (27.36)	86.01 ± (14.36)	88.64 ± (24.6)
MDF VM (Hz)	NM	54.6 ± (14.1)	58.4 ± (13.3)	60.7± (19.37)	61.0± (17.58)	58.7 ± (12.9)
	ER	58.47± (4.30)	61.8 ± (15.5)	58.2 ± (6.6)	55.5± (6.64)	55.6 ± (11.35)
MDF VL (Hz)	NM	61.1 ± (11.08)	59.2 ± (13.3)	55.6± (10.2)	58.7± (10.9)	57.8 ± (10.5)
	ER	58.6± (12.2)	59.8 ± (11.8)	59.6± (11.8)	58.7 ± (9.9)	55.2 ± (10.7)
MDF RF (Hz)	NM	59.4 ± (8.5)	59.8 ± (11.2)	58.5 ± (7.2)	57.4 ± (9.6)	52.5 ± (8.8)
	ER	64.2 ± (8.2)	63.5 ± (9.5)	61.7 ± (8.8)	59.5 ± (7.3)	54.7 ± (6.6)

Note: Mean (±SD) average of external force (N), Mean Amplitude (MA, µV) and Median Frequency (MDF, Hz) during performing 5 sets of dynamic exercises. NM = Nautilus Machine; ER = Elastic Resistance. VM = Vastus Medialis. VL = Vastus Lateralis. RF = Rectus Femoris. * = NM is significantly greater than ER ($p < 0.001$).
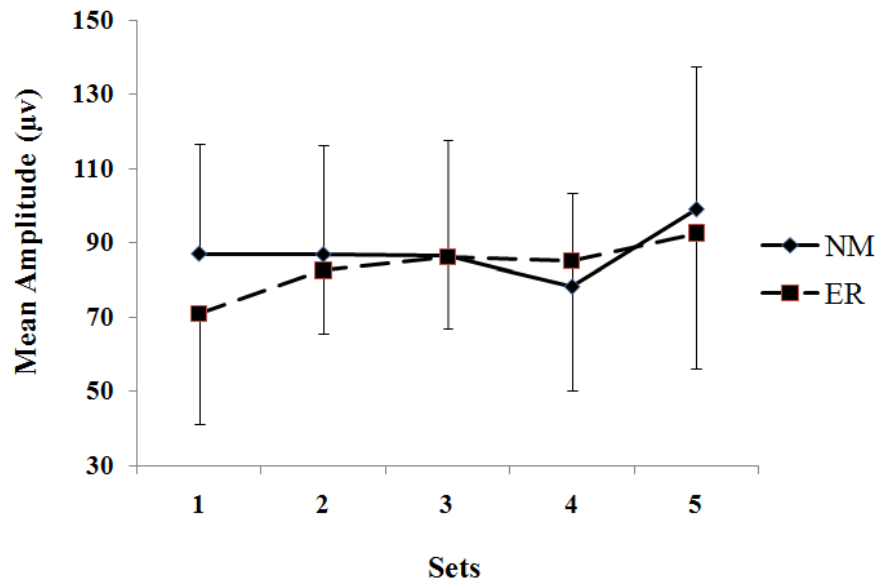
Figure 6.2 Average of Mean Amplitude of EMG for each set during dynamic exercises. The data for each mode of exercise includes the average values of the three muscles examined. NM = Nautilus Machine; ER = Elastic Resistance.
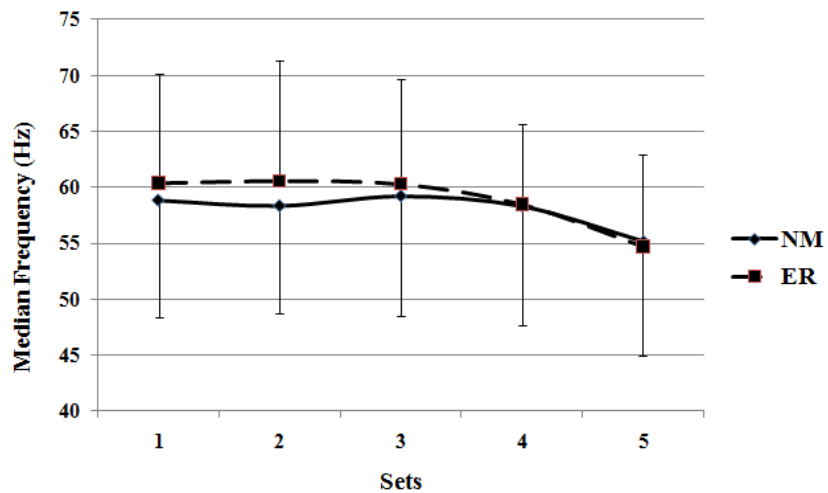

Figure 6.3 Average of Median Frequency of EMG for each set during performing dynamic exercises. The data for each mode of exercise includes the average values of the three muscles examined. NM = Nautilus Machine; ER = Elastic Resistance.

6.3.2 The changes in force and EMG signals during MVC. The results addressing changes in maximal force production (F (1,8) = 0.31, *P = .59)* and mean amplitude of EMG signals (F (1,8) = 0.004, *P = .95*) during MVC test before and after each mode of exercise are presented in Table 6.2. Using independent sample *t*-test, no significant difference was observed between ER and NM for maximal force production (Figure 6.4) and mean amplitude (Figure 6.5) values. On the other hand, one way analysis of variance revealed that neither of training modalities resulted in any significant alteration in maximal force production and mean amplitude of EMG signals (all p < .05). Nonetheless, both modes of training resulted in an insignificant decrease in rate of muscle activation and force production immediately after (IP) dynamic contractions. Either of above parameters showed a trend to return to the baseline measure in the recovery period; although, the recovery after ER training is slower than NM exercise.
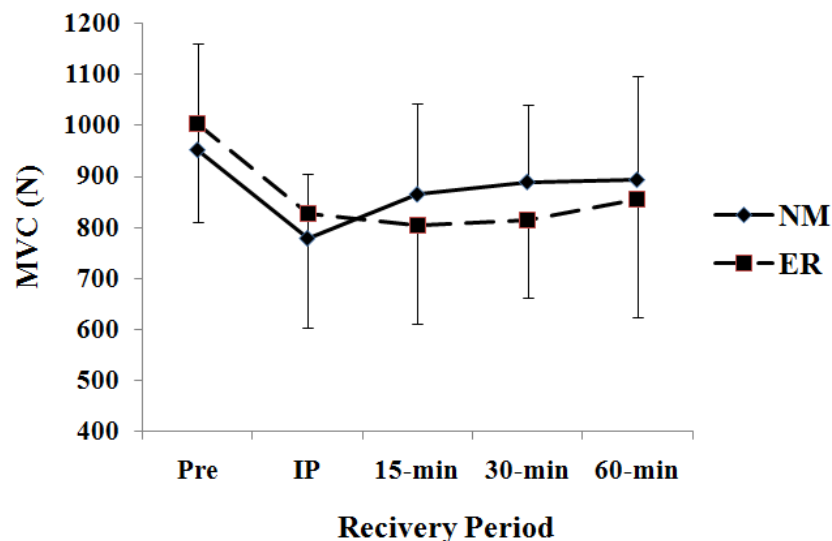

Figure6.4 Average of external force lifted during MVC trials in recovery period. NM = Nautilus Machine; ER = Elastic Resistance.

Table 6.2. The magnitude of maximal force and the EMG measures within MVC and submaximal isometric tests.

Variables	Groups	Before	IP	15-min	30-min	60-min
Average force MVC (N)	NM	951 ± (219)	778 ± (129)	865 ± (163)	888 ± (157)	892 ± (198)
	ER	1003 ± (189)	827± (227)	804 ± (192)	812 ± (153)	856 ± (333)
MA VM (MVC, µv)	NM	96.44 ± (4.7)	94.22 ± (3.9)	99.04 ± (2.1)	99.35 ± (0.1)	98.97 ± (1.0)
	ER	98.08 ± (2.0)	95.88± (2.1)	99.16 ± (1.9)	97.94 ± (3.8)	98.38 ± (1.5)
MA VL (MVC, µv)	NM	92.85 ± (4.1)	93.45 ± (3.1)	88.84 ± (8.2)	91.47 ± (9.2)	91.79 ± (8.9)
	ER	96.63 ± (4.5)	91.29 ± (5.0)	91.29 ± (3.0)	88.62 ± (7.9)	90.51 ± (7.8)
MA RF (MVC, µv)	NM	96.54 ± (4.6)	91.13 ± (7.6)	93.81 ± (4.7)	95.59 ± (5.5)	93.99 ± (7.6)
	ER	96.66 ± (3.8)	92.60 ± (6.4)	89.40 ± (8.4)	94.42 ± (7.2)	96.75 ± (4.0)
MDF VM (SMIT, Hz)	NM	49.58 ± (6.7)	60.09 ± (17.0)	63.07± (15.4)	64.47 ± (15.9)	61.75 ± (14.5)
	ER	56.64 ± (8.7)	54.63 ± (6.3)	61.08 ± (9.7)	61.06 ± (7.1)	58.77 ± (5.9)
MDF VL (SMIT, Hz)	NM	58.39 ± (8.8)	55.55 ± (17.9)	63.78 ± (10.9)	60.44 ± (7.5)	57.32 ± (10.1)
	ER	56.47 ± (12.1)	56.28 ± (13.5)	58.37 ± (9.8)	58.99± (6.1)	54.43 ± (9.8)
MDF RF (SMIT, HZ)	NM	57.09 ± (9.0)	58.82 ± (9.1)	62.48 ± (7.6)	64.07 ± (7.0)	61.52 ± (9.1)
	ER	61.01 ± (6.4)	58.71 ± (8.8)	59.55 ± (8.7)	64.36 ± (8.1)	62.93 ± (8.5)
GH (mlU/L)	NM	0.17± (0.45)	1.12 ± (0.49)	3.89 ± (0.98)	3.41 ± (2.15)	3.52 ± (1.76)
	ER	0.23± (0.46)	1.46± (0.64)	3.79± (2.31)	3.97± (1.89)	1.34± (0.57)
Testosterone (nmol/L)	NM	22.17± (3.8)	20.18 + (2.9)	20.29± (2.4)	18.16± (2.4)	16.16± (1.9)
	ER	21.97± (3.6)	20.47± (4.5)	20.86± (4.6)	18.46± (5.8)	16.23± (4.3)
LACTATE (mmol/L)	NM	2.82± (0.52)	6.42± (2.63) ‡	7.56± (3.73) ‡	6.91± (1.59) ‡	4.78± (2.73)
	ER	1.19± (0.76)	7.65± (1.74) ‡	6.34± (2.45) ‡	5.73± (2.92) ‡	3.45± (1.61)

Note: Mean (±SD) average of MVC (N), Mean Amplitude (MA, µV) and Median Frequency (MDF, Hz) within performing MVC (Maximal Voluntary Contraction) and SMIT (submaximal Isometric Test at 50% of MVC) tests. Each value includes the average of three muscles analyzed (Vastus Medialis, Vastus Lateralis, Rectus Femoris). NM = Nautilus Machine; ER = Elastic Resistance. ‡ = significantly higher than pretest value ($p < 0.001$).
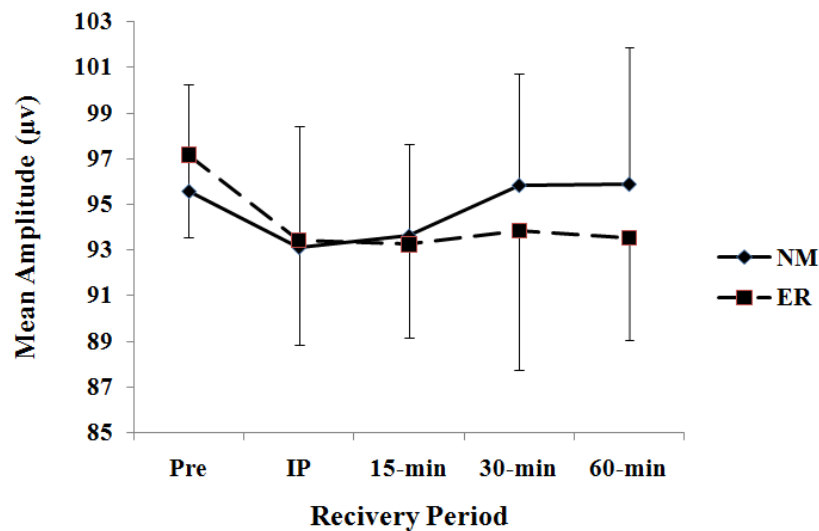
Figure 6.5 Mean Amplitude of EMG for MVC during time intervals in recovery period. The data for each mode of exercise includes the average values of the three muscles examined. NM = Nautilus Machine; ER = Elastic Resistance.

6.3.3 The Changes in EMG Signals during Submaximal Isometric Test (SMIT). The magnitude of force during SMIT was a constant value (50% of MVC) during pre- and posttest measurement. However, the electromyographic parameters could be changed due to influence of training modalities. The data addressing the mean amplitude and median frequency discharge $(F (1,8) = 0.95, P = .35)$ during SMIT are presented in Table 6.2. Based on the present data, the rate of mean amplitude $(F (1,8) = 0.067, P = .80)$ and median frequency discharge demonstrated no significant difference between ER and NM exercises either in pretest or posttest resting period (Figures 6.6 and 6.7). In addition, ANOVA testing indicated that neither of training protocols resulted in any significant changes in median frequency discharge during SMIT. This is despite of the fact that both modes of exercise a nonsignificant decline was observed in frequency immediately after dynamic contractions which was followed by a return slope to pretest value until 60 min of resting period. However, as presented in Figure 6.6 statistically greater mean amplitude was found

immediately after, 15-min and 30-min after dynamic exercises (all $P < .05$). It is worth noting that NM did not display any significant different for mean amplitude in the IP and 60 min post-training.
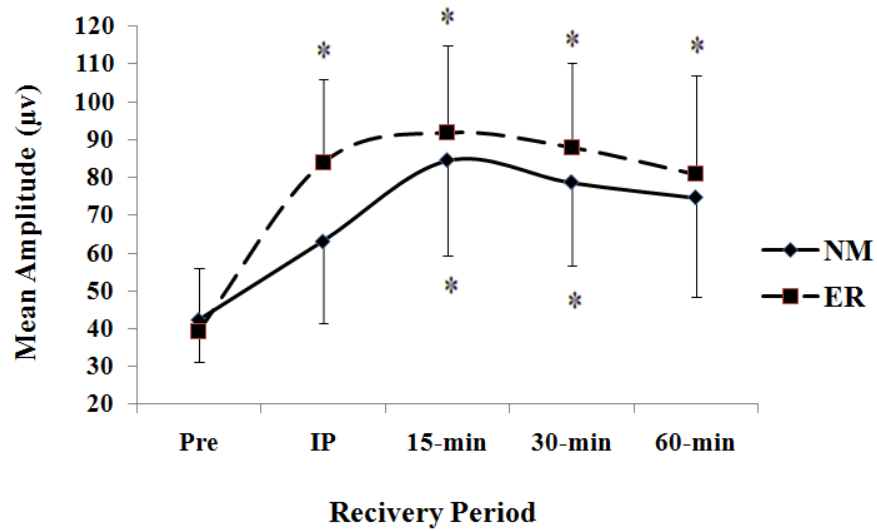

Figure 6.6 Mean Amplitude for submaximal isometric contraction (50% of MVC) during time intervals in recovery period. The data for each mode of exercise includes the average values of the three muscles examined. NM = Nautilus Machine; ER = Elastic Resistance. * = significantly higher mean amplitude for the three muscles in compared with pretest value ($p < .05$).
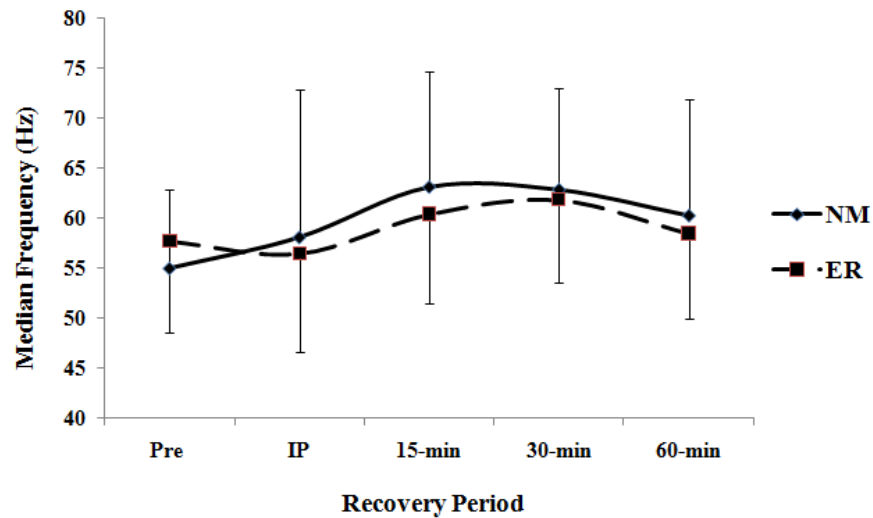
Figure 6.7 Median frequency (±SD) for submaximal isometric contraction (50% of MVC) during time intervals in recovery period. The data for each mode of exercise includes the average values of the three muscles examined. NM = Nautilus Machine; ER = Elastic Resistance.

6.3.4 Hormones. The data addressing the concentration of serum GH (F $(1,8)$ = 0.002, P = .96) and T (F $(1,8)$ = 0.10, P = .75) in blood are presented in Table 6.2. These data are graphically demonstrated in figure 6.8 and 6.9 for GH and T, respectively. The independent sample t-test revealed no statistical difference between two modes of exercise (NM and ER) in pretest as well as posttest values regarding blood concentration for GH and T (all P < .05). On the other hand, ANOVA testing displayed significantly less serum T level 60-min after NM exercise compared with pretest values (P = .01). In addition, statistically higher rate of GH was apparent in 15-min and 30-min after NM (p = .027; p = .004) and ER (p = .005; p = .012) compared with the pretest level (all p < .05).
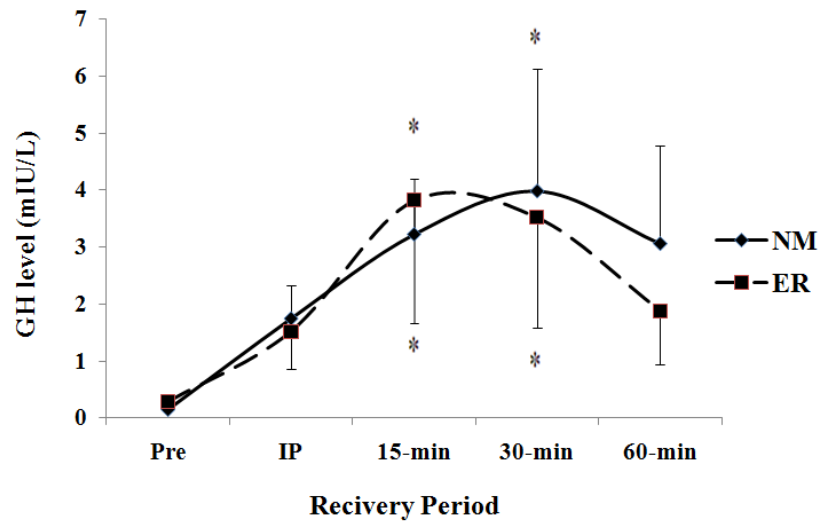
Figure 6.8 Concentration of serum GH during time intervals in recovery period. * = Significantly higher serum GH level in compared with pretest values. NM = Nautilus Machine; ER = Elastic Resistance (P < .05).
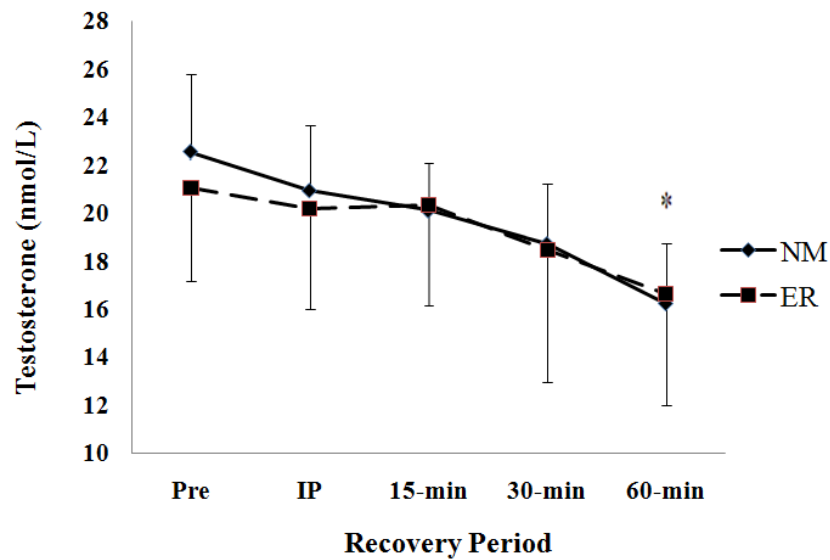

Figure 6.9 Concentration of serum Testosterone during time intervals in recovery period. *= Significantly less serum T level compared with pretest value; NM= Nautilus Machine; ER = Elastic Resistance (*P < .05*).

6.3.5 Blood Lactate (LC). The data for lactate concentration ($F_{(1,8)} = 0.42$, *P =
.53*) are presented Table 6.2 and figure 6.10. The independent sample t-test showed no
statistical significant difference observed between ER and NM exercises in any stages of
testing (*P < .05*). In addition, the data revealed that during both experiments the lactate
contrition increased significantly from pre- to IP and reduced in 15-time. The ANOVA
analyses in both modes of exercise indicated that the concentration of lactate was apparent
to be significantly higher for 15-time and 30-time in compared with pretest values (all *P =
.00*). In the other word, the peak lactate level was observed immediately after termination
of dynamic contractions and a trend of decrease was observed until end of recovery period.
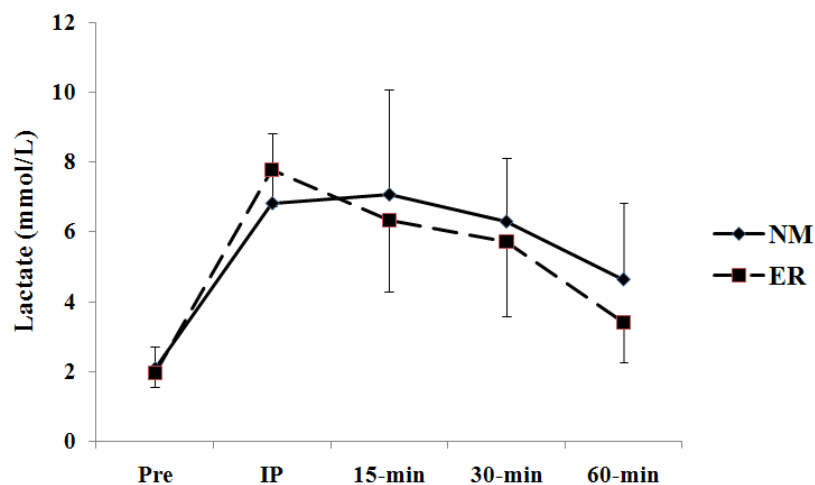

Figure 6.10 Concentrations of blood lactate during time intervals
in recovery period. NM = Nautilus Machine; ER = Elastic
Resistance. * = significantly greater blood lactate concentration
in compared with pretest value (P < .05).

In addition, analysis of variance demonstrated that neither types of training caused
any significant changes in force ($F_{(4,32)} = 1.70$, *P = .17*) and EMG amplitude ($F_{(4,32)} =
1.19$, *P = .33*) of the MVC and EMG median frequency ($F_{(4,32)} = 1.80$, *P = .15*) of the
submaximal isometric contraction test. However, the submaximal isometric test

demonstrated statistically greater EMG mean amplitude in IP, 15, 30 and 60-min after both ELASTIC and NAUTILUS exercises (Table 2, $F_{(4,32)} = 20.75$, $P = .00$).

The results addressing the changes in concentration of blood hormones are presented in Table 2. Serum T decreased significantly 60-min after NAUTILUS ($F_{(4,32)} = 19.19$, $P = .00$), while there was no significant change in serum T following ELASTIC. The GH however showed a significant increase throughout the recovery period after both NAUTILUS and ELASTIC ($F_{(4,32)} = 43.85$, $P = .00$). The concentration of blood LA also significantly increased for both modes of exercise IP and remained high until 30 min after termination of the dynamic contractions ($F_{(4,32)} = 62.65$, $P = .00$).

6.4 Discussion

The present study was designed to address the question of "whether using an ER device can result in similar acute neuromuscular and anabolic hormonal responses as the NM?" The importance of resolving this debate is underlined by the fact that elastic resistance has long been accepted as an affordable, portable and versatile training device compared with other resistance training apparatus (Page and Ellenbecker 2003).

Hughes (1999) reported the resistance of an elastic device (Hygienic Corporation, Akron, Ohio) ranging from of 3.3N (yellow) to 80.1N (silver) when elastic materials were at 18% (minimum) and 250% (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. Accordingly, in the present study to achieve adequate tensile

force for performing 10 RM, 30% of the resting un-stretched length of an elastic device was reduced and various elastic color codes were used in parallel to meet actual 10 RM.

The results however indicate that, despite implementing similar exercise intensity (10-RM) and observing equal EMG amplitude and frequency discharge between NM and ER (Table 1), a significantly greater load (26.31%) was employed during NM compared with ER (Figure 2). The reason underlying this discrepancy is not clear. However, a potential explanation possibly centres on the need for more control over the movement during ER. Since the ankle had a greater degree of freedom during the ER knee extension (compared with restricted-unidirectional NM lever arm), perhaps relatively greater muscle activation was required to keep lower leg motion aligned in the sagittal plane. In such case, observing a similar EMG response between ER and NM seems to be acceptable with regards to the significantly lower external force employed during ER exercise. This proposition is in line with the findings of Richards and Dawson, (2009) who observed a significant alteration in rate of motor unit recruitment due to performing exercises in a multiaxial direction. It seems a reasonable proposition that such a difference in external force (26.31%) between ER and NM would be reflected in differences in the acute neural and anabolic hormonal responses.

6.4.1 Neuromuscular responses. The maximal voluntary contractile force (MVC) and corresponding average muscle activation did not decrease to any significant extent after both modes of dynamic exercise (Table 2). Bosco *et al.,* (2000) have attributed such changes to intervention of the tonic motor units (ST, slow twitch) which possess a lower action potential. Since fast twitch fibers (FT, fast twitch) are more susceptible to muscle fatigue (Komi and Tesch, 1979), Bosco *et al.,* (2000) suggested a tendency towards

recruitment of ST muscle fibers might attenuate the maximal muscle force and amplitude of signals.

Immediate and prolonged changes in maximal isometric force after exercise-induced muscle damage have been considered as one of the most effective means of evaluating the magnitude and time course of muscle damage (Byrne *et al.,* 2004; Clarkson and Hubal, 2002; Cutlip *et al.,* 2008). In the present study, the Peak MVC decreased the day after both types of exercise (18.19 % vs 17.52 % for NM and ER, respectively); though, the rate of decrease was statistically insignificant. A plausible explanation for insignificant strength loss could be relatively active state of quadriceps muscle which is used during day-to-day locomotion (Howatson and van Someren, 2008). The magnitude of strength loss in knee extensors after exercise-induced muscle damage has been shown to be less (around 35% loss) and recovery has been usually faster than that observed for the elbow flexors (Byrne and Eston, 2002 ; Komi and Viitasalo, 1977).

However, the mean amplitude of the submaximal isometric test demonstrated a significant increase after both ER and NM training (Table 6.2). The data are in accordance with the findings in previous investigations (Bigland-Ritchie *et al.,* 1986; Hakkinen *et al.,* 1988). In fact, since the submaximal isometric test was performed against 50% of MVC, rotation of motor units and inclusion of fresh motor units has resulted in achieving higher mean amplitude. In other words, given that during the pre-test MVC all motor units are activated, recruitment of new motor units immediately after the dynamic exercise is unlikely. Based on Arendt-Nielsen and Mills (1988), recruitment of fresh motor units above 60% of maximal force is improbable.

The median frequency of EMG signals also exhibited a reduction during both the dynamic (Table 1) and submaximal isometric exercise bouts (Table 2). Numerous research studies have shown a reduction in the frequency component of EMG signals after fatiguing dynamic exercise (Komi and Tesch, 1979; Linnamo *et al.,* 2000). This has been attributed to the accumulation of metabolic by-products such as lactate with the implication that this is an indicator of peripheral muscle fatigue. In support of this postulate, the present data demonstrated a significant increase in the concentration of blood lactate following both modes of exercise (Table 2).

6.4.2 Endocrine responses. The rate of hormonal discharge has been shown to be sensitive to the relative stress of exercise (Raastad *et al.,* 2000; Durand *et al.,* 2003; McCaulley *et al.,* 2009). Previous research studies reported a positive relationship between total amount of work (load × repetitions) and the magnitude of increase in anabolic hormonal levels (Hortobagyi *et al.,* 1996; Linnamo *et al.,* 2005). However, the present data surprisingly exhibited equal concentration of serum T and GH, despite the fact that considerably less total work was completed during ER compared with NM (load × 10 reps × 5 sets). The underlying mechanism for these findings is not known. However, perhaps the most plausible explanation was presented by Kumar and colleague (2002) and Richards and Dawson (2009). They found greater adaptive responses following exercises with multiaxial loading patterns. On this basis, they speculated on the presence of an alternative signaling pathway which could be responsible for achieving higher muscle adaptation. In line with this assumption, Durand, *et al.,* (2003) has proposed the inclusion of proprioceptive feedback pathway (Golgi tendon organs and muscle spindles) as one of the major modulators of the hormonal response. Thus it could be speculated that perhaps a higher degree of freedom of the lower leg segment during ER training stimulated a proprioceptive

pathway and/or changed the motor unit activation pattern which resulted in similar discharge of T and GH when compared with NM. Overall, the data supports the conclusion of Bosco *et al.,* (2000) that the intensity should be defined as the rate of work performed rather than the classical view which defines the intensity as the magnitude of load employed.

The time course of hormonal secretion also exhibited a trend towards a decrease in serum T and an increase in GH concentration following both modes of dynamic exercises. The increased serum GH was in accordance with the findings in the previous studies which have suggested a high volume of training (repetitions $\times$ sets) combined with short rest periods between sets as the main cause of GH secretion (Raastad *et al.,* 2000)). Likewise, Linnamo and colleague (2005) have explained that decrease in blood pH following high intensity and moderate volume exercises (5 sets $\times$ 10-RM) was one of the underlying mechanism for increasing GH. With the decrease in pH a significant increase in blood lactate concentration following both modes of training was observed.

The level of serum testosterone however decreased systematically during resting period for both modes of exercise which could be due to reducing production or increasing utilisation of testosterone. Several researchers have attributed the decrement in serum testosterone concentration to an increased role in remodeling muscle tissue following intensive training as well as increases in the blood concentration of other hormones such as SHBG (Hakkinen *et al.,* 1988). However, Bosco *et al.,* (2000) suggested a negative relationship between changes in concentration of serum T and the amplitude of electromyogram signals. In this proposition, the dissipation of testosterone has been suggested to compensate for muscle fatigue via enhancing the neuromuscular efficiency of

FT muscle fibers. They have speculated that perhaps serum testosterone is partially consumed to compensate for disturbances in excitation-contraction coupling through a Ca^{2+} handling mechanism.

In conclusion, based on the observation of similar neuromuscular and anabolic hormonal responses for ER and NM, it can be anticipated that similar longer term training adaptations (muscle strength and muscle hypertrophy) will result from employing either training device. Accordingly, perhaps ER device could be considered as a safe and affordable mode of training for regeneration of muscle strength in athletes in various phases of training schedule.