ACUTE EFFECTS OF LOCAL VIBRATION ON MUSCLE PERFORMANCE AT DIFFERENT DURATIONS AND FREQUENCIES

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Approval of the Graduate School of Social Sciences

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ABSTRACT

ACUTE EFFECTS OF LOCAL VIBRATION ON MUSCLE PERFORMANCE AT DIFFERENT DURATIONS AND FREQUENCIES

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The purpose of the present study was to investigate the acute effects of local vibration on muscle performance at different durations and frequencies. Fifteen male handball players participated in the study voluntarily. University's Ethics Committee approved the study and the informed consent forms were filled by all participants.

Different vibration durations, (10 sec, 1 min, 10 min), different frequencies (40 and 80 Hz), dominancy (dominant and non-dominant) and conditions (vibration and no-vibration) were independent variables of study. Dependent variables were maximum isometric strength measures under different situations. One way Repeated measures ANOVA, Bonferoni adjusted paired sample t-tests and Two way Repeated ANOVA was used for statistical analyses.

Result of this study demonstrated that local vibration (LV) induced significantly higher muscle activity than no vibration (NV) condition. Strength improvements were obtained in quadriceps muscles of dominant and non-dominant legs for 40 Hz and 80 Hz. When 40 Hz vibration was applied to dominant leg with different durations (10 sec, 1 min, 10 min), significantly higher strength measures were found than no vibration. When 80 Hz vibration was applied to dominant leg with different durations (10 sec, 1 min, 10 min), only 10-sec vibration duration revealed significant increase in strength measures. When 40 Hz vibration was applied to non-dominant leg with different durations, (10 sec, 1 min, 10 min) significantly higher strength measures were found than no vibration. When 80 Hz vibration was applied to non-dominant leg with different durations (10 sec, 1 min, 10 min), 10-sec and 1 min vibration durations revealed significant increase in strength measures. However, no significant difference was obtained when the different vibration durations were compared between 40 Hz and 80 Hz.

Keywords: Local vibration, Maximum voluntary contraction, Isometric strength.

ÖZ

FARKLI SÜRE VE FREKANSLARDA UYGULANAN BÖLGESEL TİTREŞİMİN KAS PERFORMANSI ÜZERİNDEKİ AKUT ETKİSİ

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Bu çalışmanın amacı farklı süre ve frekanslarda uygulanan bölgesel titreşimin kas performansı üzerindeki akut etkisini incelemektir. On beş erkek hentbol oyuncusu çalışmaya gönüllü olarak katılmıştır. Üniversite Etik Komitesi çalışmayı onaylamıştır; tüm katılımcılar gönüllü katılım formu doldurmuştur.

Titreşim süreleri (10 sn, 1 dk ve 10 dk), frekanslar (40 Hz ve 80 Hz), baskınlık (baskın olan ve olmayan) ve titreşim durumu (titreşimli ve titreşimsiz) çalışmanın bağımsız değişkenlerini oluşturmaktadır. Farklı şartlardaki maksimum izometrik kuvvet değerleri ise bağımlı değişkenleri oluşturmaktadır. Tek yönlü tekrarlayan varyans analizi, Bonferoni'ye uyarlanmış eşleştirilmiş T-test ve iki yönlü tekrarlayan varyans analizi kullanılan istatistiksel analizlerdir.

Çalışma sonuçları, titreşim uygulaması yapılarak elde edilen kuvvet değerlerinin, titreşim uygulaması yapılmayanlara göre anlamlı ölçüde arttığını göstermiştir. Baskın olan ve olmayan bacaklardaki kuadriseps kuvvet değerleri titreşim uygulamasıyla beraber 40 ve 80 Hz'lik frekanslarda anlamlı artış göstermiştir. Baskın olan bacağa 10 sn, 1 dk ve 10 dk süreleriyle 40 Hz'lik titreşim uygulandığında elde edilen kuvvet değerlerinin titreşim uygulanmayan kuvvet değerlerine göre anlamlı artış gösterdiği bulunmuştur. Baskın olan bacağa 10 sn, 1 dk ve 10 dk süreyle 80 Hz'lik titreşim uygulandığında sadece 10 sn süreyle uygulanan titreşim sonucu elde edilen kuvvet değerlerinin titreşim uygulanmayan kuvvet değerlerine göre anlamlı artış gösterdiği bulunmuştur. Baskın olmayan bacağa 10 sn, 1 dk ve 10 dk süreyle 40 Hz'lik titreşim uygulandığında elde edilen kuvvet değerlerinin titreşim uygulanmayan kuvvet değerlerine göre anlamlı artış gösterdiği bulunmuştur. Baskın olmayan bacağa 10 sn, 1 dk ve 10 dk süreyle 80 Hz'lik titreşim uygulandığında, 10 sn ve 1 dk süreyle uygulanan titreşim sonucu elde edilen kuvvet değerlerinin, titreşim uygulanmayan kuvvet değerlerine göre anlamlı artış gösterdiği bulunmuştur. 40 ve 80 Hz frekanslardaki farklı titreşim süreleri birbirleriyle karşılaştırıldığında ise anlamlı fark bulunmamıştır.

Anahtar Kelimeler: Bölgesel Titreşim, Maksimum İstemli Kasılma, İzometrik Kuvvet.

To my father, Mehmet YILDIRIM

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Vibration is defined as mechanical oscillations about an equilibrium point (Griffin, 1990). The oscillating motion is not stable but greater or smaller than some average value and repeats after a certain period. Amount of vibration people are exposed to has increased noticeably as a result of the increase in mode of travel and the use of small tools. Typical exposures include driving automobiles, vehicles and other industrial trucks. The vibration motions of engines, electric motors, or any mechanical device in operation are typically unwanted but people from spaceship to horse riding are exposed to vibration.

In a typical daily life, a worker may use industrial trucks; a farmer may drive a tractor; military staff may travel in many types of tracked and wheeled vehicles across the rough nature or they may fly in aircraft or travel in ships and boats

(Mansfield, 2005). These exposures are largely whole body vibration exposures. Human response to vibration is a multidisciplinary topic involving physiology, athletics, engineering, biomechanics, biology and psychology. A little known information is that vibration is also common in many sports such as skiing, skating and sailing. In skiing, for instance, it has been established that skiers are exposed to vibration frequencies of at least 30 Hertz (Babiel, Hartman, Spitzenpfeil, & Mester, 2001).

Vibration can be categorized as whole body vibration (WBV) or local vibration (LV). WBV occurs when the whole body is vibrated while standing, seated or lying. So, WBV occurs when the entire body is suffering motion and the effect of notice is not localized to any particular point of contact (Griffin, 1994). Local vibration, also called direct vibration, segmental vibration, hand-arm vibration, happens when the specific body part or muscle gets in touch with the vibrating surface (Griffin, 1990).

There are diverse experiences or opinions on the vibration about its' benefits or dangers. Frequency and amplitude are two important considerations for vibration. Frequency is the number of cycles in per second and called hertz (Hz). Amplitude is the maximal displacement of the object from the equilibrium point and can be expressed in millimeter (mm).

Vibration use can be good or bad depending on frequency, amplitude, duration and way of application. In one aspect, vibration is bad for a worker who is exposed to vibration during an employment period (Bovenzi, Welsh, Della Vedova, & Griffin, 2006; Dupuis & Zerlett, 1987; Griffin, 1990; Martinho Pimenta, & Costelo Branco, 1999a-b). But in another aspect, vibration is used as a treatment for an injured person (Lundeberg, Abrahamson, Bondesson, &

Akher, 1988; Cafarelli & Kostka, 1981; Cafarelli & Layton-Wood, 1986). On the further side, vibration is also used to improve strength performance in athletics. Total time spent under the vibration to elicit a training effect has been hundreds of times less than the exposure times in working places. Some previous studies established that if vibration exposure continues for 30 minutes or more, performance decrease is unavoidable (Kouzaki, Shinohara, & Fukunaga, 2000).

Researchers and scientists who realized the intense exposure of vibration started to conduct studies about the effects of vibration on humans. Initial studies were commonly conducted as a WBV on a vibrating platform or vibrating seat. Some questions aroused about how much vibration is reaching to the targeted body parts. Body fat, size, muscle mass, bones, skin, joints, ligaments and tendons affect the level of vibration transmission from person to person (Griffin, 1990). So LV or direct vibration which is applied to the directly specific body parts has advantage over WBV.

Vibration is also used as an exercise intervention. Vibration training can recruit nearly all muscle fibers. On the other hand, resistance training can only recruit 40%-60% of muscle fibers. Vibration training achieves these high recruitment levels by creating stretch reflex in muscles (Latash, 1988). This is known as a tonic vibration reflex (TVR) and means that during vibration training, muscles are contracting at incredibly high frequencies. Although vibration has been researched for many years in work environments, the potential benefits for sportsmen have only recently begun to be properly recognized.

Research on vibration as a strength enhancement or specific training modality in sports is relatively new and vibration area needs future studies to understand physiological mechanism (Cardinale & Erskine, 2008; Kin-işler, 2007). One of the pioneer studies which was conducted by Russian scientists, to identify the effect of mechanical vibration on strength improvement in training of gymnasts. Gymnastic beams, bars and rings were vibrated while gymnasts performing the exercises. Performing these exercises concurrently exposed to vibration lead faster strength improvement than traditional methods (Nazarov & Spivak, 1987).

Previous studies are mainly interested in whole body vibration (WBV). But there are many criticisms in the literature about WBV. First, situation of the vibration source that is further away from targeted muscle may not be influential to elicit the vibration training effect (Luo, McNamara, & Moran, 2005a). Second, the vibration amplitude and frequency on a targeted muscle may be unquantifiable because of the long way of transmission (Luo et al., 2005a; Zange, Haller, Müller, Liphardt & Mester, 2009). For example if a scientist is applying a WBV from a platform and analyzing the quadriceps strength. Vibration is affected from bones, ligaments, tendons, muscles and body fluids until reaching the targeted body parts and they may change the effect of vibration from person to person. Even one of the studies revealed that WBV does not potentiate the stretch reflex (Hopkins et al, 2009).

Observations of different persons reveal that there are large physical differences between participants of the selected population in vibration transmission. As vibration transmission can be highly affected from large physical differences, conducting a study with same group or similar group in experimental and control groups prevents disadvantages. On the other hand, local vibration is applied on the muscle belly or tendon of the targeted muscle (Luo et al, 2005b). So the attenuation of vibration by transmission is much less for local vibration. In addition to that, vibration amplitude and frequency on the targeted muscle may be more quantifiable.

Although some studies reported the positive effects of WBV in sportive performance and rehabilitation (Delecluse, Roelants, & Verschueren, 2003; Rittweger, Beller, & Felsenberg, 2000), some others claimed that repetitive and long lasting exposure to WBV can be very dangerous to health (Armstrong, Lawrence, Radwin, & Silverstein, 1987; Cronin, Oliver, & McNair, 2004). Instead of WBV, mechanical perturbations of small amplitude and localized on a specific body segment can be considered as safe. Short duration of local vibration has the advantage that only a part of the body is exposed to the vibration stimulus in a little period of time (Aström, Lindkvist, Burström, Sundelin & Karlsson, 2009). So stress given to the head and brain can be minimized in contrast to WBV.

Literature provides different studies related to local vibration; some of them yield conflicting results. Gabriel, Basford and Kai-nan (2002) applied 1-min local vibration (60 Hz, 1mm) and they found improvement in strength. Kin-işler, Açıkada, and Arıtan (2006) applied the local vibration (4mm) for ten seconds in different frequencies. While they found an improvement for 6, 12 and 24 Hz, 48 Hz showed decrement in isometric strength. In another study, Gomez et al (2003) applied the upper body limb vibration with low frequency (7.5 Hz) and 0.38 cm displacement. But they found no improvement in grip strength. Warman, Humphries and Purton (2002) applied a local vibration (50 Hz, 5mm) for 30 seconds and they found no improvement in isometric strength. In a similar study, Humphries, Warman, Purton, Doyle and Dugan (2004) applied same frequency and amplitude for 5 seconds and they found again no improvements in maximum voluntary isometric contraction. The only consensus is that 30 minutes or till the exhaustion vibration exposure resulted in decrease in strength performances (Bongiovanni, Hagbarth, & Stjernberg, 1990; Jackson & Turner, 2003; Kouzaki, Shinohara, & Fukunaga, 2000; Samuelson, Jordfeldt, & Ahlborg, 1989).

Studies about vibration are contradictory in the literature. There is no study which tested the different durations of the vibration for two different frequencies as well as the dominancy and comparing them with neutral strength measurements.

Therefore, this study explain the effects of local vibration with two different frequencies and three different durations on quadriceps isometric muscle strength performance and compare the vibration and non-vibration conditions in handball players. Another important purpose of this study is to determine the type and duration of vibration exposure for isometric strength improvement.

1.2 Purpose

The purpose of the present study was to investigate the effects of local vibration applied with different frequencies and different durations on maximal quadriceps isometric skeletal muscle contraction in the dominant and non-dominant legs.

1.3 Research Questions

1. What is the isometric strength difference for dominant limb between
    a. non-vibration and 10-sec vibration application for 40 Hz
    b. non-vibration and 1-min vibration application for 40 Hz
    c. non-vibration and 10-min vibration application for 40 Hz

2. What is the isometric strength difference for dominant limb between

   a. non-vibration and 10-sec vibration application for 80 Hz

   b. non-vibration and 1-min vibration application for 80 Hz

   c. non-vibration and 10-min vibration application for 80 Hz

3. What is the isometric strength difference for non-dominant limb between

   d. non-vibration and 10-sec vibration application for 40 Hz

   e. non-vibration and 1-min vibration application for 40 Hz

   f. non-vibration and 10-min vibration application for 40 Hz

4. What is the isometric strength difference for non-dominant limb between

   d. non-vibration and 10-sec vibration application for 80 Hz

   e. non-vibration and 1-min vibration application for 80 Hz

   f. non-vibration and 10-min vibration application for 80 Hz

5. What is the isometric strength differences between 40 Hz and 80 Hz for dominant limb

a. 10-sec vibration application

b. 1-min vibration application

c. 10-min vibration application

6. What is the isometric strength differences between 40 Hz and 80 Hz for non-dominant limb

d. 10-sec vibration application

e. 1-min vibration application

f. 10-min vibration application

1.4 Significance of the Study

Local vibration has been used in athletic settings in recent years. Different and contradicting results of these studies may be because of different frequencies, amplitudes and durations of vibration. So this study will contribute the literature by adding the two different frequencies and three different vibration durations and comparing them with the neutral muscle performances for dominant and non-dominant limbs.

1.5 Delimitations

1. Participants consisted of 18-26 years old collegiate male handball players.

2. Vibration applications were the same for all subjects.

3. One participant who had discomfort during the measurements was excluded from the study.
4. All measurements were performed using the same vibration device and isokinetic dynamometer for all participants.
5. Different vibration durations and frequencies were applied in random order.

1.6 Limitations

1. Participants of this study were not selected randomly.
2. Participants were limited to those handball players attending the college team trainings regularly.
3. Participant group was composed of only male handball players

1.7 Assumptions

1. The participants gave their best performance during the strength tests.
2. The participants joined the tests at fully recovered state.
3. The participants did not participate in any extra strength training during repeated tests.

1.8 Definition of Terms

The followings are definitions of terms that were operationally defined throughout this study.

Vibration: Mechanical oscillations about an equilibrium point which is often generated by an electric motor with an unbalanced mass on its driveshaft.

Local Vibration (LV): Specific segment of the body is in contact with the vibrating surface.

Whole Body Vibration (WBV): is that all parts of the body are moving together in the same direction at any point in time.

Frequency: The number of cycles that occur in one second.

Amplitude: is a maximum displacement of the system from the equilibrium position.

Oscillation: Regular periodic variation in value about a mean.

Tonic Vibration Reflex (TVR): Length changes that are detected by muscle spindles.

Body Mass Index (BMI): A controversial statistical measurement which compares a person's weight and height (kg/m^2).

Peak Torque to Body Weight (PT/BW): The maximum torque that can be obtained from a maximum muscle contraction and this measure is normalized with body weight

CHAPTER 2

LITERATURE REVIEW

Vibration is generally divided into two main application types: Whole Body Vibration (WBV) and Local vibration (LV). The related researches have been reviewed in this part.

Vibration training studies should be interpreted carefully as the vibration parameters of frequency, amplitude and durations are very different. In addition to that application point and vibration type also demonstrates scattered variety.

2.1 Vibration Training

Rittweger (2010) reviewed the vibration as an exercise modality, especially in sport about its mechanism and potential. After his evaluations he realized that vibration is regarded as dangerous but studies started to investigate the benefits of vibration recently. His main interest was the evaluation and the discussion of the physical principles of forced oscillations regarding vibration as an exercise modality. Acute physiological responses to local vibration (LV) and whole body vibration (WBV) exercise are reviewed with the training effects

As a conclusion, evidence proposes that acute vibration exercise seems to elicit a specific warm-up effect, and that vibration training seems to develop muscle power. On the other hand, the potential benefits of vibration over traditional resistive training are still uncertain.

Luo, McNamara and Moran (2005a) searched the effect of additional vibration application into conventional resistance training. They specified the absence of portable vibrator capable of directly stimulating muscle tendon in the literature. So the aim of their study was the development of a vibration unit. They also intended to investigate the desired amplitude and frequency ranges of diverse vibration characteristics used in previous researches. Strapping force, joint angle and day-to-day repeatability on vibration characteristics were examined. Muscle EMG activity was applied to identify the optimum vibration amplitude and frequency. In addition to that, the repeatability of these EMG responses and effect of joint angle were tested. The unit had a capacity to produce an amplitude between 0,2-2 mm and frequency between 30–200 Hz. They tested the biceps curl with 30,65 and 100 Hz frequencies and 0,5 and 1,2 mm amplitudes. Test day, strapping force and joint angle had no significant effect on selected vibration characteristics. Two amplitudes and all three frequencies significantly enhanced EMG activity, with 1,2 mm and both 65 and 100 Hz resulting in significantly greater improvements. Joint angle had no significant effect on EMG results and day-to-day repeatability of EMG response was shown to be high.

Luo, McNamara and Moran (2005b) reviewed the literature about the acute and chronic effect of vibration on neuromuscular performance, vibration characteristics and exercise protocols on the enhancement in neuromuscular performance. They emphasized that vibration has been used to increase the effect of strength training in recent years. Although there was a need for strictly controlled studies on the vibration training effect, existing findings proposed that vibration may have a beneficial acute and/or chronic training effect on strength and power enhancement. These benefits are depending on vibration characteristics (application type, amplitude and frequency) and exercise protocols (training type, intensity and volume).

Luo and friends (2005b) stated that vibration load which is determined by amplitude and frequency should be in an optimal range to elicit strength and power enhancement.

According to them most effective muscle activation occurred in the range of 30-50 Hz frequency but it was not obvious for amplitude range. Nonetheless it can be said that smaller amplitudes may be inadequate to obtain an enhancement. Another important factor affecting the vibration training effect was direct-indirect vibration application type which may have an influence on the magnitude of amplitude and frequency. Luo and associates (2005b) had a suggestion that utilization of a greater exercise intensity and volume with vibration training may facilitate a larger enhancement in strength and power. Moreover elite athletes may have greater benefit from vibration training than non-elite athletes. Thus, further studies are necessary to have consistent results.

2.2 Tonic vibration reflex

Tonic vibration reflex (TVR) is a critical term defined as high-frequency muscle vibration leads to a slow reflex increase in muscle contraction (Bishop, 1974; Latash 1998). This reflex is caused by vibratory activation of muscle spindles (Ribot-Ciscar, Rossi-Durand and Roll, 1998) and these spindles are caused to fire once for each cycle of the vibration (Bishop, 1974). Although TVR is caused the muscle contraction in agonist side, antagonist muscles are relaxed (Eklund & Haghbart, 1966). Furthermore, 30-min tonic vibration showed decrease in strength performance (Kouzaki, Shinohara, & Fukunaga, 2000).

Tonic vibration reflex are stronger and increase more rapidly under isometric than under isotonic conditions (Eklund & Haghbart, 1966). Same authors also stated that vibration decreases voluntary power in spastic patients (Haghbart & Eklund, 1968). But it was still questioning whether TVR is beneficial for the athletes as their activities usually include multi-joint movements (Issurin, Liebermann, & Tenenbaum, 1994). One of the previous study showed that maximum voluntary contraction decreased significantly after prolonged tonic vibration (Kouzaki, Shinohara, & Fukunaga, 2000). So laboratory controlled studies are benefitted with a fixation of some parameters. Also duration of the vibration exposure is critical for improvement in performance

2.3 Whole Body Vibration

Whole body vibration (WBV) studies related with the strength improvement have commonly been conducted when a person sits or stands on a vibrating platform or vibrating surface. WBV is vibration that affects the entire body parts of the exposed person (Mansfield, 2005). Most of the exposures are associated with the daily transportation routine where drivers or traveler are influenced (Griffin, 1990). Moreover, workers are vulnerable to vibration in their working hour (Armstrong, Lawrence, Radwin, & Silverstein, 1987) and they are faced to serious health problems (Bovenzi, Welsh, Della Vedova, & Griffin, 2006; Griffin, 1990). Vibration can influence the comfort, performance and health based on the divergent duration, frequency and amplitude (Mansfield, 2005). Despite the presence of negative effects, vibration is also benefitted in rehabilitation (Lundeberg, Abrahamson, Bondesson, & Ahker, 1988; Cafarelli & Kostka, 1981; Cafarelli & Layton-Wood, 1986) and athletic settings (Bosco et al, 1998; Delecluse, Roelants, Diels, Koninckx, & Verschueren, 2005; Mester, Spitzfeil, Schwarzer, & Seifriz, 1999; Stewart, Cochrane, & Morton, 2009) to enhancement in performance. It is also revealed that WBV improves the flexibility (Cochrane & Stannard, 2005; van den Tillaar, 2006)

In a different study which was concentrated on cardiovascular outcomes of vibration revealed that vibration had positive effects on metabolic system. Despite the exhaustive vibration (26 Hz frequency, 1cm amplitude) heart rate, oxygen uptake, blood pressure, jump performances and strength measures had advantage over cycle ergometry training. So elderly can be benefitted from vibration training with lesser difficulty when compared to traditional training (Bogaerts, Verschueren, Delecluse, Claessens, & Boonen, 2007). Actually, there is a popularized tendency to use vibration training in older population in recent times (Bogaerts et al, 2007; Cardinale & Rittweger, 2006; Gusi, Raimundo, & Leal, 2006; Kawanabe, Kawashima, Sashimoto, Takeda, Sato, & Iwamoto, 2007; Rees, Murphy, & Watsford, 2009).

Some studies from extensive literature have suggested that short-term WBV training produces neuromuscular improvement similar to that of power and strength training. Cochrane, Legg and Hooker (2004) studied whether short-term WBV exposure makes enhancement for power, speed, and agility with the examination of the related test performances in non-elite athletes. Twenty-four sport science students were randomly allocated to two groups: WBV training or control. Each group was composed of equal number of men and women (8 men and 4 women). Countermovement jump (CMJ) height, squat jump (SJ) height, sprint speed over 5-10-20 m, and agility (505, up and back) were performed before and after 9 days of either control or WBV training. No significant differences were found between WBV and control groups for CMJ, SJ, sprints, and agility. Cochrane and associates (2004) concluded that short-term WBV training did not enhance performance in non-elite athletes. Torvinen, Sievanen, Jarvinen, Pasanen, Kontulainen and Kannus (2002) reached similar result at the end of 4-min vibration application. Moreover, reduced extensor activation was also seen at the end of the 11-week WBV training period (De Ruiter, Van Raak, Schilperoort, Hollander & De Haan, 2003). However, single bout of 4-min vibration had significant improvement in strength and balance after two minutes of vibration intervention but this improvement disappeared after 60 minutes of vibration intervention (Torvinen, Kannus et al, 2002). It was also stated that WBV enhances neuromuscular activity (Rittweger, Mutschelknauss, & Falsenberg, 2003). Some similar studies also stated that WBV yielded increased muscle strength (Trans et al, 2009; Paradisis & Zacharogiannis, 2007; Roalents, Delecluse, Goris, & Verschueren, 2004; Rittweger et al, 2002).

Effect of WBV in strength training was tested in team handball and water polo players (Bosco et al, 1998). Vibration exposure was applied for ten consecutive days between duration of 90-120 seconds. While control group getting no vibration experimental group was applied vibration with the frequency of 26

Hz and amplitude of 10 mm. At the end of the treatment strength performance and jumping ability were enhanced significantly. They speculated that some neural adaptations would have affected the training outcomes as: stretch reflex potentiation, motor unit synchronization, synergistic muscle contraction, antagonist muscle inhibition, golgi tendon inhibition and fiber type conversion.

National level female volleyball players (N=6) were tested to examine the acute effects of WBV on the mechanical behavior of skeletal muscle (Bosco, Colli, et al 1999). One of the legs was assigned as experimental and the other was control. Ten sets of 1 minute vibration (25 Hz, 10 mm) were applied on a vibrating platform with a 100-degree leg flexion. Results demonstrated that significant improvement was achieved in average force and power of the vibrated leg.

Mester and associates (1999) examined the effects of WBV training on the performance of an elite alpine skier. Their main interest was whether vibration training would be helpful over 21 days and 36 training sessions. Vibration apparatus was developed for the skiers with a 24-Hz frequency and 2,5-mm amplitude. Strength measures showed improvement at the beginning but then returned to normal level. Very high and sharp increase was handled at the last period of the training sessions up to 43%. Jump performance was also improved 23%. They concluded that vibration can be helpful attachment to strength training in developed strength and power results.

Another similar study tested the effects of WBV on strength parameter was conducted by the Schlumberger, Salin and Schmidtbleicher (2001). Their participants performed one-legged squats with a barbell accompanied by vibration whereas; the other leg was performed only squat exercise. Training period was three times in a week for six weeks. Contradicting with the previous results, vibration had no superiority over traditional method for performance increase. It might be the disadvantage of whole body vibration. Because WBV can affect the central nervous system and the vibrated leg could have caused a crossover effect in the other leg.

2.4 Local Vibration (LV)

Local vibration has the advantage that only a part of the body is exposed to the vibration stimulus. So stress given to the head and brain can be minimized when compared to exposure of whole body. The related studies about the LV will be reviewed according to application limb.

2.4.1 Local Vibration Applications in Upper Limb

Luo, McNamara and Moran (2005a) pointed out the need for portable vibrator which is capable of directly stimulating muscle tendon. So the aim of their study was to develop such a unit. In addition to that the essential aspect of this study was to offer testing the most effective frequency and amplitude trials and compare them with previous studies. For this purpose, the effects of strapping force, joint angle and day-to-day repeatability, muscle electromyography (EMG) activity, the repeatability of these EMG responses and effect of joint angle were investigated.

Amplitude range was 0.2-2 mm and frequency range was 30-200 Hz for the unit. Selected values for amplitude were 0.5 and 1.2 and selected frequencies were 30, 65 and 100 Hz. EMG measurements on the biceps were recorded during the experiment to evaluate the muscle response. Results showed that test day, strapping force and joint angle had no significant effect. On the other hand, two amplitudes and three frequencies significantly enhanced EMG activity. Most significant enhancements were seen for 1.2 mm amplitude and for both 65 and 100 frequencies.

Issurin and Tenenbaum (1999) tested vibratory stimulation during bilateral biceps curl exercises of explosive strength effort in elite (n=14) and amateur (n=14) athletes. Participants performed two separate series of three sets of exercises randomly. The second set of each series was administered with vibration of 44 Hz and peak to peak oscillation of 3 mm transmitted through the two-arm handle to the arm muscles. The acute effect was evaluated as the difference between the mean and peak power output in vibration and non-vibration conditions. Likewise, the residual effect was taken to be the difference between the power values of the third (after vibratory stimulation) and the first (before vibratory stimulation) sets.

Repeated-measures ANOVA showed that vibration stimulation and non-vibration stimulation resulted in a significant immediate effect for mean power and for maximal power. There was a significant effect for maximal power between elite and amateur athletes. The increase in explosive strength effort attributed to vibratory stimulation was 10.4% and 10.2% for maximal and mean power respectively in the elite group, and 7.9% and 10.7% respectively in the amateur athletes. But, vibration stimulation resulted in an insignificant residual effect.

Curry and Clelland (1981) studied the effects of the asymmetric tonic neck reflex and high-frequency muscle vibration on isometric wrist extension strength. Hand-held vibrator with a frequency of 120 Hz and amplitude of 1.5 mm was used for vibration stimulation. One hundred fifty right-handed adults

(81 men and 69 women) between the ages of 18 and 40 were assigned to one of five groups randomly. Results of two control group showed any confounding effects of fatigue, experimental learning, or weight of the vibrator in contact with the skin surface overlying the wrist extensor muscle bellies. Individual and combined effects of the asymmetric tonic neck reflex (ATNR) and vibration were evaluated from measurements taken from three experimental groups. Vibration of the extensor surface of the forearm with the head in neutral resulted in significant improved strength. The combination of active head rotation toward the extending wrist and vibration of the extensor surface resulted in a greater increase in strength.

Kin-Isler, Acikada and Aritan (2006) examined the effects of vibration, applied with different frequencies at different joint angles, on maximal isometric muscle contraction. Forty male right-handed university students (ages between 19–30 years) were randomly and equally assigned to one of the four different vibration stimulation groups as 6 Hz, 12 Hz, 24 Hz and 48 Hz. Vibration was applied perpendicularly to the muscle belly of the upper arm with an amplitude of 4 mm. Subjects performed three consecutive isometric MVC with and without vibration for six seconds with one-minute interval at 90, 120 and 150 degrees of elbow angles in random order. During MVC with vibration tests vibration was applied for 10 seconds before the contraction begins and continued throughout the MVC.

ANOVA ($4 \times 3 \times 2$) with repeated measures showed a significant joint angle effect, contraction type effect, and significant frequency × contraction type interaction. It can be concluded that vibration stimulation resulted in increased isometric MVC. While vibration application with 6, 12 and 24 Hz resulted in increased isometric MVC, 48 Hz of vibration on the other hand resulted in decreased isometric MVC. Moreover, the length of the contracting muscle did not affect the vibration load that was applied with different frequencies.

Diverse vibration frequencies were also studied by Martin and Park (1997). They investigated the effects of six different vibration frequency (40, 80,100, 120, 150 and 200 Hz) and two different amplitudes (0.2 and 0.3 mm) on changes in the TVR and motor unit synchronization in the finger and wrist flexor muscles using electromyographic (EMG) activity. Ten healthy subjects (mean age = 22.6) participated the study as paid volunteers. Vibration was applied to the distal tendons of the hand flexor muscles at selected frequencies and amplitudes. Three different grip forces (0, 10 and 20%) of the MVC were applied. Each participant completed 36 trials (3 contractions x 6 frequencies x 2 amplitudes). EMG results demonstrated that motor unit synchronization mechanisms contribute to the modulation of the amplitude of the TVR as vibration frequency enhances. In spite of the decrease in harmonic synchronization, subharmonic synchronization increases as vibration frequency increases. Martin and Park (1997) suggested that synchronization process pressures muscle fatigue as it forces the motor units results in decrease in contraction efficiency and high frequency (>150 Hz) tends to stimulate less motor unit synchronization.

Before this study, same authors (Park and Martin, 1993) conducted another study. Their aim was to quantify the changes in TVR and to refine the understandings of the underlying neurophysiological mechanisms. Method section of the study was the same with the previous one. At the end of the measurements, they concluded that TVR increases with the initial muscle contraction and enhances with vibration frequency up to 100 and 150 Hz but decreases beyond this frequency. In addition to that, muscle and tendon stress decreases with high frequency.

Ribot-Ciscar, Butler and Thomas (2003) proposed that it is possible to improve the weak triceps brachii of people with chronic cervical spinal cord injury by exciting the paralyzed or submaximally activated fraction of muscle. Ribot-Ciscar and associates examined whether elbow extensor force was enhanced by vibration of the triceps or biceps brachii tendons at rest and during isometric MVCs. Experiments were performed on eight volunteers who had sustained a spinal cord injury (SCI). 80-Hz vibration stimulation was applied on either the triceps or the biceps brachii tendons for 9 seconds. Surface EMG data were taken from triceps and biceps brachii muscles.

Their results showed that biceps vibration always evoked a TVR in biceps at rest, but extension force did not improve with biceps vibration during triceps MVCs. Triceps vibration induced a TVR in half of the triceps muscles at rest. On the other hand, biceps tendon vibration during elbow extensor MVCs resulted in no improvements. Thus only triceps brachii tendon vibration increases the contraction strength of some partially paralyzed triceps brachii muscles.

Griffin, Garland, Ivanova and Gossen (2001) examined whether vibration would change the modulation of motor unit firing rate throughout fatiguing isometric contractions. They applied three different scenarios related with fatigue, vibration, performance and firing rates. Their result showed that the motor unit discharge rate during vibration did not always improve. Fatigue decreased the added increment of force imposed by vibration. As a conclusion, motor unit firing rate is preserved in submaximal isometric contractions with periodic vibration and vibration did not affect the result of the fatiguing protocol.

Another study related with fatigue, MVC and local vibration was conducted by McBride, Porcari, and Scheunke (2004). They examined whether vibration during fatiguing resistance exercise would alter associated patterns of muscle activity. They applied a cross-over design with and without vibration. Eight male participants with a mean age of 21 took part in the study and they performed resistance training with a vibrating dumbbell or non-vibrating dumbbell in a random order. Vibration was applied with a 44-Hz frequency and 3-mm amplitude during a one-arm biceps curl for a 10 repetition maximum EMG was taken from the biceps brachii muscle at 12 different time points during a MVC after each set of the dumbbell exercise. Pre (5 minutes before the resistance exercise), T1–T10 (immediately following each set of resistance exercise), and post (15 minutes after the resistance exercise) were measured. Vibration had an overall trend of lower maximum EMG in comparison to non-vibration condition. They concluded that EMG patterns observed with vibration may show a more capable and effective recruitment of high threshold motor units during fatiguing contractions. This outcome may demonstrate the usage of vibration with resistance exercise as an effective tool for strength training.

Casale, Ring and Rainoldi (2009) examined whether high frequency vibration can induce some conditioning effects and whether these effects are central or peripheral. Ten healthy males aged from 25 to 50 years joined the study. A 300 Hz vibration was applied over the muscle belly of the right biceps brachii by means of a cup-shaped transducer with 2 mm amplitude. Vibration was applied for 5 consecutive days with 30 min duration. EMG was measured in basal condition, before vibration and two days after the 5-day vibration application period. Isometric MVCs were taken for 3 (set) x 3 sec with 5 min rest interval.

It can be concluded that no statistically significant differences were found between pre and post vibration conditioning when involuntary stimulus-evoked contraction and 30% MVC were used. Thus, 300 Hz vibration did not induce any peripheral changes as demonstrated by the lack of differences when fatigue was electrically induced. Differences were found only when the muscle was voluntarily fatigued at 60% MVC suggesting a modification in the centrally driven motor unit recruitment order, and interpreted as an adaptive response to the reiteration of the vibratory conditioning.

Bosco, Cardinale and Tsarpela (1999) evaluated the influence of vibration on the mechanical properties of arm flexors. Twelve international level boxers from Italian national team took part in the study voluntarily. Both limbs of the boxers were tested separately with an extra load equal to 5% of the subjects' weight while performing a maximal dynamic elbow flexion. After the pretests, one of the limbs was randomly allocated to experimental (vibration) group (E), and the other limb was allocated to control group (C). Experimental Group was exposed to vibration training by gripping vibrating dumbbell in standing position with a 30 Hz frequency and 6 mm amplitude. Five sets of 1-min vibration application were performed during arm flexion in isometric conditions with 1 min rest between tests.

The results revealed that vibration training enhanced the average power significantly. Although the root mean square electromyogram (EMGrms) had not changed following the treatment, when divided by mechanical power (P), it showed statistically significant increases.

Bosco and associates (1999) concluded that mechanical vibrations enhanced muscle P and decreased the related EMG/P relationship in elite boxers. In addition to that, EMGrms analysis demonstrated enormous increase in neural activity during vibration up to more than twice the baseline values. As a conclusion, vibration training is able to stimulate the neuromuscular system more than other treatments.

Cochrane, Stannard, Walmsely and Firth (2008) compared the acute effect of vibration exercise with a concentric-only activity on concentric-only muscle action using an upper body isoinertial exercise. Twelve healthy, physically active men participated in the study. Subjects performed four maximal prone bench pull (PBP) efforts before and after a 5-min period of three different interventions: Acute vibration exercise (VBX), arm cranking (AC) and control (exercise without vibration) (NVBX). Warm-up was forbidden prior to the interventions to reduce the likelihood of influencing the outcome of the study.

EMG activity was evaluated from the middle trapezius muscle during PBP. Acute VBX was induced with an electric-powered dumbbell (DB) with 26-Hz frequency and 3-mm amplitude. Vibration exposure lasted for 30 seconds at five different shoulder positions. NVBX was performed the same procedure with WBX but the vibration instrument was turned off. AC cranked for 5 min in lying prone position at a 40° angle and a workload of 25W.

Results demonstrated significant interaction between acute VBX and AC enhanced peak power by 4.8% and 3.0%, respectively, compared to NVBX (−2.7%). On the other hand, EMG activity did not differ among treatments on compared to the control. As a conclusion, concentric-only muscle performance was potentiated by acute VBX. But, VBX did not show greater enhancement over concentric (arm cranking) exercise.

A similar vibration characteristic was studied by Mischi and Cardinale (2009). Their aim was to evaluate activation and coactivation of biceps and triceps muscles during isometric exercise performed with and without vibration stimulation. Twelve healthy volunteers (7 females and 5 males) with a mean age of 22.7 participated in this study. Participants performed five trials of isometric elbow flexion and extension with increasing levels of force in vibration condition and control condition. 28-Hz superimposed vibration was applied. Surface EMG motion of biceps and triceps muscles was measured and evaluated by the estimation of the root mean square (RMS). Results demonstrated that vibration enhanced the EMGRMS activity significantly. In elbow flexion, average EMGRMS of biceps and triceps was, respectively, 26.1% and 18.2% higher than control group. In elbow extension, the EMGRMS of biceps and triceps was 77.2% and 45.2% higher than control group, respectively. The coactivation also increased during vibration exercise. Their conclusion was that vibration exercise at 28 Hz produces an improvement of the activation and the coactivation of biceps and triceps.

Mottram, Maluf, Stephenson, Anderson and Enoka (2006) examined the influence of prolonged tendon vibration on the time to failure when maintaining limb position with the elbow flexor muscles. Twenty-five right-handed healthy men, ages between 18 – 39 (mean = 22) performed the fatiguing contraction by maintaining elbow angle at 90° until failure while supporting a load equal to 20% of MVC force. Diverse levels of vibration were applied to the common tendon of the biceps brachii. The fatiguing contraction was performed on 3 separate days for three groups: no vibration, subthreshold for a tonic vibration reflex (TVR), and suprathreshold for a TVR.

These three groups completed the followings: 1) an assessment of the MVC force for the elbow flexor and extensor muscles, 2) measurement of the EMG-force relation with 5-s isometric contractions at 20, 40, and 60% MVC, 3) TVR determination, and 4) performance of the fatiguing contraction. 100-Hz frequency was used with the wide range of amplitude: 0.01 – 0.41 mm for subtreshold TVR sessions and 0.10 - 0.75 mm for the suprathreshold TVR session.

MVC force did not differ across the three sessions before the fatiguing contraction as expected. Similar decline was observed in MVC force after the fatiguing contraction across conditions, the time to task failure was 3.7 ± 1.4 min for the suprathreshold TVR condition, 4.3 ± 2.1 min for the subthreshold TVR condition, and 5.0 ± 2.2 min for the no-vibration condition. Mean EMG of the elbow flexors was similar during the fatiguing contractions. On the other hand, suprathreshold TVR condition had a greater fluctuation in limb acceleration at task onset. Other two conditions were not different. Mottram and associates also specified that the difference in the SD of limb acceleration between the no-vibration and vibration conditions was correlated with the difference in time to failure for the no-vibration and subthreshold TVR conditions, but not for the no-vibration and suprathreshold TVR conditions.

Their findings indicated that prolonged vibration condensed the time to failure of a sustained contraction when subjects maintained limb position, signifying that peripheral inputs to the motor neuron pool play an important role in sustaining a contraction during tasks that necessitate active control of limb position. Our main concern was to see the effects of vibration on force. This study showed that there was no difference in the rate of change in EMG activity of the elbow flexor muscles across the three vibration conditions.

Poston, Holcomb, Guadagnoli and Linn (2007) examined the effect of mechanical vibration on acute power output in the bench press exercise. Ten male subjects with at least three year experience in resistance training participated in this study. Independent variables were condition (vibration and control) and set (1, 2, and 3) in a within-subject design. Average and peak power outputs were dependent variables. Each participant performed 3(set) x 3(reps) in the bench press exercise with 70% of 1 RM in each of 2 sessions separated by 3 days. While experimental session included vibration the other session served as the control (no vibration) condition. The intervention (vibration or no vibration) was applied between sets 2 and 3. The vibration was applied by a vibrating barbell apparatus held by the subjects while lying supine on a bench with 30 Hz frequency and 1.1 mm amplitude. Peak and average power were calculated during each bench press set to analyze the power differences between vibration and no vibration conditions.

At end of the measurements, it can be commented that results were inconsistent. Vibration treatment showed significant improvement over control group in average power. Moreover, there was also insignificant increase in peak power in the vibration condition.

Although peak and average power output were higher following the vibration intervention compared to control, the sets prior to vibration application demonstrated higher power outputs compared with the control condition. It can be speculated that factors other than the vibration intervention influenced task performance during the vibration condition. Poston and associates suggested that psychological factors related to the novelty of the vibration intervention were concerned. Psychological factors may partially explain the conflicting results of previous researches that interested in vibration as an exercise intervention.

2.4.2 Local Vibration Applications in Lower Limb

One of the recent studies conducted by Christiansen, Kotiya and Silva (2009) investigated the effects of vibration on treatment of osteoporosis. Some studies stated that vibration correlated with bone health (Arpınar, Şimşek, Sezgin, Birlik & Korkusuz, 2005; Bediz, Özgüven & Korkusuz, 2010; Özdurak, Sezgin, Akın & Korkusuz, 2006). Christiansen and colleagues (2009) developed constrained tibial vibration (CTV) as a method for controlled vibration loading of the lower leg of a mouse. Mice were trained constrained tibial vibration loading for 5-week adaptive period. Their hypothesis was that mice subjected to the highest magnitude of dynamic strain would have the largest bone formation response. A slight and local benefit of CTV loading on trabecular bone was observed. On the other hand, they observed significantly lower measures of trabecular structure in both loaded and non-loaded tibias from CTV loaded mice compared to sham and baseline control animals. This result indicated that CTV has negative effect on trabecular bone.

After getting this unexpected result the authors decided to conduct a follow-up study. Mice were subjected to CTV or sham loading, and tibias were scanned before and after the 5-week period using in vivo micro-computed tomography. Results of the two studies were consistent. Trabecular bone volume per total volume in both tibias of CTV loaded and Sham mice was, on average, 36% and 31% lower on day 36 than day 0, respectively, compared to 20% lower in Age-Matched Controls over the same time period. Contrary to the first part of the study, there were no differences between loaded and non-loaded tibias in CTV loaded mice, providing no evidence for a local benefit of CTV. In brief, 5 weeks of daily CTV loading of mice was, at best, weakly anabolic for trabecular bone in the proximal tibia, while daily handling and exposure to anesthesia was associated with significant loss of trabecular and cortical bone.

Thus it can be concluded that direct vibration loading of bone in anesthetized, adult mice is not anabolic.

Another tendon vibration study was conducted on humans with the VB 115 vibration instrument. Lapole and Perot (2010) searched the literature and they were aware of the benefits of WBV. But they wanted to show the effects of local vibration when the WBV is not suitable to apply as vibrating platforms are heavy tools that cannot be easily used by all patients. So they proposed to apply vibrations directly to the achilles tendon at rest with a portable vibrator. They examined whether 14 days of vibration program would enhance triceps surae (gastrocnemius and soleus muscles) force production in healthy subjects.

Twenty-nine healthy and active students (mean age = 21.7) participated in the study voluntarily. 50 Hz vibration was applied during 14 days for 1 hour daily stimulation. The electrical evoked twitch, plantar-flexion MVC, and EMG were quantified before and at the end of the vibration application program. Vibration application program resulted in an increase in MVC associated with greater EMG of the triceps surae force production. Muscle hypertrophy was not found on the twitch parameters and the EMG–torque relationships. Repeated tendon vibration produce an improvement in plantar-flexor activation and thus to greater force developed in MVC. They concluded that local vibration program could be beneficial to persons with hypo-activity.

Plantar flexion was also used in another study conducted by Zange, Haller, Müller, Liphardt, and Mester (2009). One of their aims was to test whether vibration (20 Hz, 3-4 mm) increases ATP consumption of the muscle. Participants were 20 healthy male subjects (mean age = 21). Right calf muscle of the participants was tested. Isometric plantar flexion at 40 % of MVC was performed for 3 minutes. Results showed that ATP consumption increased significantly under vibration application.

Kouzaki, Shinohara and Fukunaga (2000) examined the effect of prolonged tonic vibration applied to a single synergist muscle on MVC and maximal rate of force development on eight untrained subjects (7 men and 1 woman). Participants performed a unilateral isometric knee extension MVC in the seated position. The knee extension MVC force was measured from the surface electromyogram which are placed the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM). The subjects performed three MVCs lasting 3 sec each before and after muscle vibration from proximal portion of RF at 30 Hz for 30 min. Interestingly, MVC and the iEMG of RF decreased significantly after prolonged tonic vibration. In addition to that, VL and VM showed no change. The authors concluded that MVC and maximal rate of force development may be influenced by the attenuated Ia afferent functions of a vibrated single synergist muscle.

It is emphasized in the literature that effect of tendon vibration on afferent response is very crucial (Cordo, Gandevia, Hales, Burke and Laird, 1993). Luo, McNamara and Moran (2008) focused on the muscle-tendon vibration and its effects on the neuromuscular output during and 1.5 and 10 min after a bout of ballistic resistance training. Fourteen male participants with at least two years' experience of resistance training were exposed to two training conditions randomly: exercise with vibration and exercise with sham vibration. The exercises consisted of 3 (sets) x 5 (reps) of knee extensions with a load of 60-70% of 1-RM. Local Vibration with 1.2 mm amplitude and 65 Hz frequency was applied by means of a portable vibrator strapped over the distal tendon of the quadriceps. During and after training, the vibration did not induce significant changes in peak angular velocity, time to peak angular velocity, peak moment, time to peak moment, peak power, time to peak power, or average EMG of the rectus femoris and vastus lateralis. It can be concluded that local vibration, with 1.2 mm amplitude and 65 Hz frequency, does not enhance these neuromuscular variables in ballistic knee extensions during or immediately after training.

Konishi, Kubo and Fukudome (2009) compared the effect of Ia afferent attenuation on the activity of alpha motor neuron during concentric and eccentric action. Eight male gymnasts joined the study. Concentric and eccentric MVC and EMG signals were simultaneously measured before and immediately after the 20-min, 50-Hz vibration stimulation. Vibration stimulation was applied by hand (instead of fixation) to the mid-portion of the infrapatellar tendon.

Their results demonstrated that the application of prolonged vibration stimulation to the infrapatellar tendon attenuated the strength of knee extension and the average EMG values of vastus lateralis and vastus medialis in both concentric and eccentric action.

They also compared the MVC and the EMG activity to see the superiority between eccentric and concentric actions. The results demonstrated that the decrease of maximal eccentric strength in response to the prolonged vibration stimulation was significantly larger than that of concentric action. Moreover, the average EMG values of the VL were also significantly reduced in eccentric contraction over concentric contraction. They assumed that the application of prolonged vibration to muscles was considered to attenuate Ia afferents and the same protocol of vibration stimulation was applied in both condition of eccentric and concentric actions, in addition, the result suggested that the attenuation of Ia afferents had a greater deactivation effect on the alpha motor neuron of the VL during eccentric action than during concentric action. It can be also interpreted from the results, only the VL might have different neural control during maximal eccentric action from that of the other quadriceps muscles. In brief, deactivation effect on the alpha motor neuron of the VL during eccentric action was greater than that of concentric action.

Luo, McNamara and Moran (2007) wanted to learn the effect of direct vibration during two sub-maximal isometric loading conditions on EMG output. Sixteen male participants performed isometric knee extensions under four conditions in random order.

Four loading conditions were 10% and 30% of 1RM with and without vibration. Direct vibration stimulation with a 1.2 mm amplitude and 65 Hz frequency was applied to the distal end of the quadriceps using a portable vibrator. Only the dominant leg was tested to an angle of 150° for 20 seconds in each experiment condition. EMG root-mean-squared (EMGrms) outputs of the rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM) were evaluated.

RF, VL and VM EMGrms outputs for both the 10% 1RM and 30% 1RM loading conditions were significantly enhanced with vibration in comparison to no vibration. But, 10% and 30% 1RM loads did not show any significant difference.

Bakhtiary, Safavi-Farokhi and Aminian-Far (2007) interested in reduction effect of delayed onset muscle soreness (DOMS) in sportive performance. They proposed that vibration training (VT) may improve muscle performance. So they investigated the effect of VT on controlling and preventing DOMS after eccentric exercise. For this purpose, fifty healthy non-athletic male and female volunteers with a 20.6 mean age were assigned randomly into two experimental, VT (n=25; 12 male and 13 female) and non-VT (n=25; 13 male and 12 female) groups. 50 Hz vibration device was used to apply vibration on the middle line of each of the left and right quadriceps, hamstring and calf muscles for 1 min before 30-min downhill treadmill walking with a 10° decline and 4 km/h speed. On the other hand, the subjects in the non-VT group did not receive any vibration before downhill treadmill walking.

Isometric MVC of left and right quadriceps muscles in 100° of knee flexion in sitting position, pressure pain threshold (PPT) on the 5, 10 and 15 cm above the left and right patellae and on the middle line of calf muscles of both lower limbs were measured before and the day after treadmill walking. The level of muscle soreness and the serum level of creatine kinase (CK) were also measured 24 hours after treadmill walking.

Strength results showed that isometric MVC force in the right and left quadriceps showed a significantly higher decrease in the non-VT group compared with the VT group. Besides the decreased isometric MVC force, the results also demonstrated a reduced PPT and significantly increased mean of DOMS and CK levels in the non-VT group, compared to the VT group. As a conclusion, VT may help to protect the force and to prevent the muscle damage and also VT before eccentric exercise may prevent and control DOMS.

Fattorini, Ferraresi, Rodio, Azzena and Filippi (2006) evaluated the influence of localized muscle vibration associated to an arousal state on motor performances of healthy subjects. Fifteen male and 6 female volunteers divided into three groups: 1) muscular contraction (VC), 2) relaxed muscle condition

(VR), and 3) no treatment (NV). There was no vibration or traditional strength training for NV group.

Ten minutes of sinusoidal mechanical vibration with 100 Hz frequency and 0.005-0.015 mm amplitude was applied on the quadriceps muscle of VC and VR groups. The transducer was positioned against the distal end of the quadriceps muscle. All three groups completed pre and post isometric and isotonic tests 7 days before and 14 days after the 21-day training period. However, pre and post isokinetic tests were performed by VC group only. Both legs were tested randomly in all measurements. VC and VR group were exercised to maintain an isometric contraction by setting the difficulty level at about 20% of MVC. Angular velocity values were 30, 60, 90, 120, 180,240°/s and range of motion was about 80° for isokinetic tests.

In their study (Fattorini et al, 2006), force development (FD) was defined as the force value reached at 30, 50, 100 and 200 ms after the onset time. To avoid momentary phenomenon, they defined the onset time when force reached 5% of its maximum.

Isometric MVC results did not change significantly in pre and post tests for both legs in any of the subjects participating to the experimental research. Results revealed that the time of force development showed a significant decrease only in VC group.

As there was a fatiguing protocol in isotonic test, the fatigue resistance increased greatly in VC group, increased slightly in VR group but there was no significant change in NV group.

In isokinetic tests, conditioning protocol did not produce any significant modification in the force-velocity relationship, or at any of the tested angular velocities, in left versus right in VC group. However, at several angular velocities, significantly less time was required to reach the force peak. Fattorini and associates commented on their results as plastic changes in proprioceptive processing, initiating to an enhancement in knee joint control.

Cronin, Nash and Whatman (2008) investigated dynamic knee joint range of motion (ROM) and jump performance following a single bout of (1) passive hamstring stretching, (2) hamstring vibration or a vibration-stretching combination. Ten competitive level male athletes volunteered to participate in this study.

Knee joint dynamic ROM and jump performance were evaluated before, immediately following and 10min following stretching and vibration of the hamstring muscles. In arandom order, all participants completed three interventions: (1) 3×30s static stretches, (2) 3×30s bouts of vibration (3mm amplitude, 34 Hz frequency) and (3) a combination of the stretching and vibration protocols on hamstring muscles.

Results showed that vibration or combination of stretching and vibration did not influence dynamic knee joint ROM or jump performance. However, stretching intervention showed an increase in dynamic knee joint ROM between the pre and immediate after assessments in the (mean change 3° or 2%). It can be concluded that there was no statistically significant interaction between intervention and time for any of the jump performance evaluations.

Cronin, Nash and Whatman (2007) examined the influence of four different segmental vibratory stimulation (VS) loads on dynamic range of motion

(ROM) of the hamstrings. Ten male club level athletes participated in the study voluntarily. Four different vibration stimulation with selected amplitudes (3-3-3-5 mm) and frequencies (14-24-34-44 Hz) were provided respectively. A two factor repeated measures ANOVA (intervention (4) × time (2)) with post hoc comparisons was used to decide whether any vibration setting produced a significantly greater ROM change.

Results indicated that a significant enhancement in dynamic ROM was found for three out of the four vibration loads. Vibration stimulation with 5mm amplitude and 44 Hz frequency load resulted in greatest ROM improvement; however, this was not significantly different to the improvements observed for the other three loading parameters. As a conclusion, this study demonstrated that VS had comparatively better results than previous traditional stretching methods.

Bongiovanni and Hagbarth (1990) examined the effects of high-frequency muscle vibration on weak or moderate voluntary contractions and on MCVs of (i) non-fatigued muscles, (ii) muscles fatigued by sustained MVCs and (iii) muscles deprived of gamma-fiber innervation by partial anesthetic nerve block on human foot dorsiflexor muscles. Five healthy subjects (aged 33-63 years) including the authors took part in the study. The motor outcome of the voluntary dorsiflexion efforts was evaluated by measuring the firing rates of single motor units in the anterior tibial (TA) muscle, the mean voltage EMG activity from the pretibial muscles and foot dorsiflexion force. Vibration was applied over the tendons of the ankle dorsiflexor muscles with the amplitude of 1.5 mm and the frequency of 150 Hz.

Results demonstrated that superimposed vibration improved EMG activity and contraction force on weak or moderate contraction. A partial anesthetic block similar to muscle fatigue resulted in a reduction of MVC motor unit firing rates which could be worked against muscle vibration. In prolonged MVCs performed during the block, motor unit firing rates stayed at a relatively constant low level during the contraction period. Bongiovanni and Hagbarth (1990) concluded that in sustained MVCs, fatigue processes occur extrafusal and intrafusal muscle fibres, intrafusal fatigue causess to a reduction of the voluntary drive transported to the alpha-motoneurones by the gamma-loop and vibration-induced activity in group Ia afferents can act as a replacement for the reduced drive.

At the end of their review of similar literature, Jackson and Turner (2003) reached the notion that prolonged vibration of the rectus femoris decreases maximal voluntary knee extension performance in the ipsilateral leg. Ten male subjects with the mean age of 26 took part in the study. Local mechanical vibration (1.5-2 mm amplitude; 30 and 120 Hz frequency) was applied to the right rectus femoris (RF) for 30 minutes In their design, measurements of maximal voluntary isometric knee extension contractions with the ipsilateral (right) leg and the contralateral (left) leg were performed before and after vibration treatment. Results demonstrated significant reductions in maximal force and maximum rate of force generation happened in both the ipsilateral and contralateral limbs following 30 minutes of continuous vibration at both 30 Hz and 120 Hz but 30 Hz caused the bigger decrease in ipsilateral limb. On the other hand, despite the fact that the level of neural activation of the vibrated muscle (right RF) was reduced following 30 Hz vibration, there were no significant differences in a synergistic muscle (right vastus lateralis) or in either contralateral muscle. They concluded that the prolonged vibration of the vibrated leg attenuates isometric MVC in not only the vibrated leg but also the contralateral leg.

Humphries, Warman, Purton, Doyle and Dugan (2004) interested in effects of vibration on the contractile ability of skeletal muscle tissue. They examined the effects of a superimposed muscle/tendon vibration at almost 50 Hz frequency and 5 mm displacement on muscular activation and maximal isometric contraction. Sixteen participants with a mean age of 22 were recruited for this study. Maximal isometric force data were gathered from rectus femoris of the dominant leg with and without vibration. A superimposed 50 Hz vibration was applied during the contraction phase for the maximal isometric leg extension. No significant difference was found between the vibration and no-vibration conditions for peak normalized EMGRMS (84.74% vs 88.1%) values, peak isometric force, peak rate of force development, rate of force development at times 0.05, 0.01, 0.1, 0.5 seconds, and rate of force development at 50, 75, and 90% of peak force. They suggested that the 50-Hz vibration stimulation during the contraction did not improve force production for maximal isometric contractions.

Samuelson, Jorfeldt and Ahlborg (1989) investigated how vibration affects endurance during knee extension with and without superimposed vibrations. Fourteen males (mean age = 20) performed maximal isometric and sustained knee-joint extension efforts in sitting position three times with each leg, with or without vibration. Both legs were tested in a random order. The frequency of the vibration was 20 Hz and the amplitude was 1,8 mm. They assign the endurance as the time in seconds that it took for the exerted force to decrease by 10% of the initial value. The mean endurance time was 15.8 sec and 22.5 sec with and without vibration, respectively. They concluded that vibration may decrease the endurance of maximal isometric contraction.

Warman, Humphries and Purton (2002) interested in the effect of 50-Hz superimposed vibration stimulation on muscular strength for isometric, isotonic and concentric isotonic contractions. 28 recreational athletes (mean age = 22.8) participated in this study. Vibration was applied to the rectus femoris (RF) for 30 seconds and vibration stimulation continued during contraction.

Significant improvement was obtained only in concentric isotonic strength during and after the vibration stimulation. No significant improvements in isometric and isokinetic strength were apparent. EMG output presented significant improvements during stimulation in mean activation of RF for the isometric, isokinetic, and concentric isotonic contractions. Synchronous collection of vibromyography (VMG) during stimulation also showed a significant decrease in mean VMG activity of RF for the isometric, isokinetic, and concentric isotonic contractions. They concluded that significant enhancement in muscular strength and activation for concentric isotonic contractions performed during an applied vibration suggests that the optimal timing of a vibratory stimulation would be while the participant is contracting isotonically.

Cafarelli and Layton-Wood (1986) studied the effect of vibration on force sensation in fatigued muscle. They tried to determine how progressive fatigue adapts the effect of vibration on force sensation. Nine subjects performed maximum voluntary contraction (MVC) of the right knee extensors to provoke fatigue in seventeen experiments with and without vibration. Perturbations in force feeling were accomplished by applying high-frequency vibration (160 Hz, 2mm) to the patellar tendon of the fatigued muscle. Decrease to the 50% of MVC or stopping the exercise willingly was accepted as fatiguing point. Their results demonstrated that force sensation is changed by the effects of fatigue on contractile capacity. In addition to that fatigue attenuates the effect of vibration and fatigue has no effect on increased intensity of force sensation propose that sensory outputs of fatigue may not distinctive initiator in muscle receptors but also exist in central nervous system.

In another similar study, Rothmuller and Cafarelli (1995) designed a study to determine whether local vibration produced any confirmation that a peripheral pathway also plays a role in the increase in coactivation during progressive fatigue. 10 male subjects who had low to average physical activity level participated in the study. Isometric maximum voluntary contractions (iMVCs) were applied (1) prior to fatigue and below the (2) 85%, (3) 70% and 50% of the initial iMVC. Vibration instrument (1500 Hz, 1.5 mm) was placed on patellar tendon of the extensor muscles of dominant leg. Vibration treatment resulted in greater amount of antagonist coactivation. Vibrating the patellar tendon of the extensor muscles increase biceps femoris coactivity, but does not change the rate at which coactivation improves during fatigue. Authors explained this situation as agonist coactivation is controlled by a central mechanism.

CHAPTER 3

MATERIALS AND METHODS

This study was designed to investigate the effects of local vibration applied with different frequencies and different durations on maximal quadriceps isometric skeletal muscle contraction in the dominant and non-dominant legs.
The chapter begins with the (1) Overall Design of the Study, and covers (2) Participants, (3) Vibration Instrument, (4) Physical and Physiological Measurements, (5) Experimental Protocol and (6) Statistical Analyses.

3.1 Overall Research Design

A Crossover Randomized Control Trial design was selected. The crossover design refers to a study in which each of the participants is given all of the study interventions. The order in which the participants receive each of the study interventions is determined randomly.

This design was chosen to examine the possible differences among different vibration durations, different frequencies, dominancy and conditions with and without vibration. Each participant was tested fourteen times in seven visits. All tests were performed in the Medical Center of the Middle East Technical University at Ankara. These tests composed of physical tests, vibration applications and strength tests for leg extensors. Significance of changes was compared by statistical methods.

3.2 Participants

At the beginning of the study there were 16 male handball players. One subject withdrew from the study due to discomfort during isometric strength tests and 15 male handball players completed all the tests. The average age, body mass, height and body mass index (BMI) (standard deviation) of the participants were 20.8 (2.1) years, 79.2 (11.3) kg, 178.3 (8.5) cm and 25.0 (1.3) kg/m^2, respectively. Inclusion criteria included at least three year experience in handball. Participants showed no evidence of neuromuscular disease, injury, fracture of lower extremity or any serious health problems.

The exact nature of the studies' aim was explained to each voluntary participant. Middle East Technical University's Ethics Committee approved the study (11.01.2010; B.30.2.ODT.O.AH.00.00/126/72-943) and a written consent was obtained from all participants.

3.3 Vibration Instrument

A portable muscle-tendon vibrator (VB 115 Techno Concept, France) which is strapped onto the skin over the quadriceps muscle belly (Humphries, Warman, Purton, Doyle & Dugan, 2004; Jackson & Turner, 2003) was used (Figure 3.3). Vibration amplitude was 3.5 mm and selected frequencies were 40 and 80 Hz High frequency level, 80 Hz was decided considering the comfort of the subjects. Luo, McNamara and Moran (2005a) applied the 30, 65 and 100 Hz frequencies in their local vibration study. They stated that 100 Hz frequency caused discomfort to most of the subjects during tests. However, their low frequency level, 30 Hz did not produce significant benefit for muscle contraction. So 40 Hz was selected as a low frequency level and 80 Hz was selected as a high frequency level. Ten seconds, 1 minute and 10 minutes vibration durations were selected as short, medium, and long durations, respectively. Participants were informed and they were familiarized to the system before the experiment about vibration.

Figure 3.3 The vibration instrument.

3.4 Physical and Physiological Tests

Physical characteristics of participants were evaluated by body mass index (BMI). Strength measures were assessed by peak torque to body weight measures. Physical and physiological measurements were explained in following parts.

3.4.1 Body Mass Index (BMI)

Body weight was measured in kilograms by the Seca 767 electronic column scale (Seca gmbh & co. Hamburg, Germany) and the height was measured by the Harpenden Stadiometer (Holtain ltd. Crosswell, United Kingdom). BMI (kg/m^2) is the ratio of body weight to height square (Heyward & Stolarczyk, 1996).

3.4.2 Isometric Strength Measures

Participants were assessed on an isokinetic dynamometer (Biodex Medical Inc, Shirley, System3, NY). Isometric strength data was recorded with the Biodex System Dynamometer to assess the strength of the quadriceps muscles (Figure 3.4.2). Isometric contraction is accepted as trustworthy and it is easy to control under laboratory conditions (Klausen, 1990).

Participants were placed in a comfortable upright seated position on the dynamometer chair and were secured using pelvis and torso straps in order to minimize extraneous body movements. Their arms were across the chest and their back was in straight position during the experiments. The lateral femoral epicondyle was used as the bony landmark for matching the axis of rotation of the knee joint with the axis rotation of the dynamometer resistance adapter. Values for the isometric variables measured were automatically adjusted by the Biodex Advantage Software Rev. 3.27.

Figure 3.4.2 Isokinetic dynamometer, Biodex System 3

At the beginning of the measurements of strength performance, the participants warmed up on a bicycle ergometer for 5 minutes and then stretched their body parts for 5 minutes. Before all test trials, participants were instructed to perform their maximum efforts and they did 5-sec isometric knee extension at 120^{o} with their dominant and non-dominant limbs. The dominant leg was defined as the preferred kicking leg (Luo, McNamara and Moran, 2008). Peak torque to body weight (PT/BW) was chosen for strength measures.

3.5 Experimental Protocol

We applied a specific protocol using different combinations of duration (10, 60, 600 seconds), frequency (40 and 80 Hz), condition (vibration and no vibration) and dominancy (dominant and non-dominant). Prior to the experiments, randomization was applied for each subject to prevent the potential for an order effect. All subjects came to the laboratory for eight visits. In their first visit, they were familiarized with the isometric strength tests and vibration exposure. They were also explained and trained to perform maximal effort isometric contractions of knee extensors.

During the test day, participants performed warm-up and stretching exercises for ten minutes. After being ready for the testing, they performed maximal effort isometric contraction of the knee extensors for 5 sec from a knee joint angle of 120^{0} (Luo, McNamara and Moran, 2008). Players were encouraged to perform their best efforts during the tests. All experiments were finished with 10-min cool down period to provide relaxations for participants.

Vibration exposure was applied in three different durations and two different frequencies for dominant and non dominant legs (3x2x2= 12 measurements). Also strength measures for Dom and Non-Dom were taken without vibration (2 measurements). Each participant completed fourteen tests (Table 3.5) in random order. Participants joined fourteen tests in seven different days and there are at least two days break in consecutive tests. Two measurements were taken in a single test day; one from right leg and the other measurement from left leg. Same leg was not tested twice in a day. All tests were conducted on weekdays between 12:00-13:30 and 16:00-19:00.

Table 3.5 Amplitude, frequency, vibration durations and dominancy characteristics of tests

Test No	Amplitude (mm)	Frequency (Hz)	Vibration durations (Sec)	Dominancy (D/ND)
1	0	0	0	D
2	3.5 mm	40	10	D
3	3.5 mm	40	60	D
4	3.5 mm	40	600	D
5	3.5 mm	80	10	D
6	3.5 mm	80	60	D
7	3.5 mm	80	600	D
8	0	0	0	ND
9	3.5 mm	40	10	ND
10	3.5 mm	40	60	ND
11	3.5 mm	40	600	ND
12	3.5 mm	80	10	ND
13	3.5 mm	80	60	ND
14	3.5 mm	80	600	ND

3.6 Statistical Analyses

The statistical analyses were performed using the computer program PASW 18 SPSS. The mean of the peak torque to body weight measures (PT/BW) were used for comparisons as dependent variables. One way Repeated Measures ANOVA within subject design was used, where independent variables are durations (No vibration, 10-sec, 1-min, 10-min vibration).

Bonferoni adjusted paired sample t-tests were also used to compare the vibration and non-vibration conditions. Significance level was set at an alpha level of $p \leq 0.05$.

Two way Repeated ANOVA (3X2) was also conducted to compare the vibration durations (10-sec, 1-min and 10-min vibration) for two different frequencies (40 and 80 Hz)

CHAPTER 4

RESULTS

This chapter begins with the brief information about the participants and proceeds with the results of the study about strength parameters under different vibration durations and frequencies for dominant and non-dominant lower limbs.

4.1 Participants

The average age, body mass, height and body mass index (BMI) (standard deviation) of the participants were 20.8 (2.1) years, 79.2 (11.3) kg, 178.3 (8.5) cm and 25.0 (1.3) kg/m^2, respectively.

4.2 Overall Results of the Study

For 40-Hz and 80-Hz vibration frequencies, two separate one-way repeated ANOVAs were performed to search for a difference between different vibration durations in terms of isometric maximum voluntary contraction PT/BW scores of the dominant quadriceps. The analysis for 40-Hz vibration resulted in that isometric maximum voluntary contraction PT/BW scores of the dominant quadriceps increased significantly (p=.05) with different vibration durations (10-sec, 1-min, and 10-min) (see Table 4.3.3). The analysis for 80-Hz vibration yielded that isometric maximum voluntary contraction PT/BW scores of the dominant quadriceps increased significantly (p=.006) with only 10-sec vibration (Table 4.4.2).

For 40-Hz and 80-Hz vibration frequencies, two separate one-way repeated ANOVAs were performed to search for a difference between different vibration durations in terms of isometric maximum voluntary contraction PT/BW scores of the non-dominant quadriceps. The analysis for 40-Hz vibration resulted in that isometric maximum voluntary contraction PT/BW scores of the non-dominant quadriceps increased significantly (p=.004) with different vibration durations (10-sec, 1-min, and 10-min) (see Table 4.5.2). The analysis for 80-Hz vibration indicated that isometric maximum voluntary contraction PT/BW scores of the non-dominant quadriceps increased significantly (p=.018) with 10-sec and 1-min vibration (Table 4.6.2).

Two-way repeated ANOVA was conducted to examine whether isometric maximum voluntary contraction PT/BW scores of the dominant quadriceps differ between 40-Hz and 80-Hz with different vibration durations. Results indicated that three different vibration durations did not differ significantly between 40-Hz and 80-Hz in terms of isometric maximum voluntary contraction PT/BW scores of the dominant quadriceps.

The same analysis was performed for non-dominant quadriceps and it was found that three different vibration durations did not differ significantly between 40-Hz and 80-Hz in terms of isometric maximum voluntary contraction PT/BW scores of the non-dominant quadriceps.

4.3 Dominant Leg Isometric Maximum Voluntary Contraction PT/BW Scores for 40 Hz

A one-way repeated ANOVA was conducted with the factor being vibration durations and the dependent variable being the dominant leg isometric maximum voluntary contraction (iMVC) PT/BW scores at 40 Hz. One-way repeated-measures ANOVA indicated a significant time effect, Wilks' λ =.53, F(3,12) = 3.49, p=.05, η_p^2 =. 47. The mean dominant leg iMVC PT/BW scores and standard deviations (SD) for 40 Hz were presented in Table 4.3.1.

Table 4.3.1 Mean Dominant Leg iMVC PT/BW Scores and SDs for 40 Hz

Vibration Durations	Mean	SD	N
No Vibration	343.5	72.3	15
10-sec Vibration	370.3	69.4	15
1-min Vibration	373.1	63.7	15
10-min Vibration	372.3	73.5	15

Paired sample t-tests were applied to assess which means differ from each other. Three pair-wise comparisons were conducted for 40 Hz among four different vibration durations: 1) no vibration - 10-sec vibration, 2) no vibration - 1-min vibration and 3) no vibration - 10-min vibration. Pair-wise comparisons were evaluated according to Holm's sequential Bonferroni procedure to avoid Type I error (Green, Salkind and Akey, 2000). Holm's sequential Bonferroni levels were presented in Table 4.3.2 and these levels will be used for rest of the pair-wise comparisons.

Table 4.3.2 Significance levels according to Holm's Sequential Bonferroni Procedure

Number of comparisons	Significance level
1 comparison	0.05 (0.05/1)
2 comparisons	0.025 (0.05/2)
3 comparisons	0.017 (0.05/3)
4 comparisons	0.0125 (0.05/4)
5 comparisons	0.01 (0.05/5)
6 comparisons	0.0083 (0.05/6)

The smallest p-value was for the comparison between "no vibration" and "1-min vibration" and its p-value of 0.006 was less than alpha level, (0.05/3 = 0.017) and, therefore difference between two means was significant. The next smallest value (0.011) was also significant at the 0.025 (0.05/2) level between "no vibration" and "10-sec vibration" conditions. Third value (0.018) was also significant at the 0.05 (0.05/1) level. Difference in isometric MVC PT/BW was given at Figure 4.3.

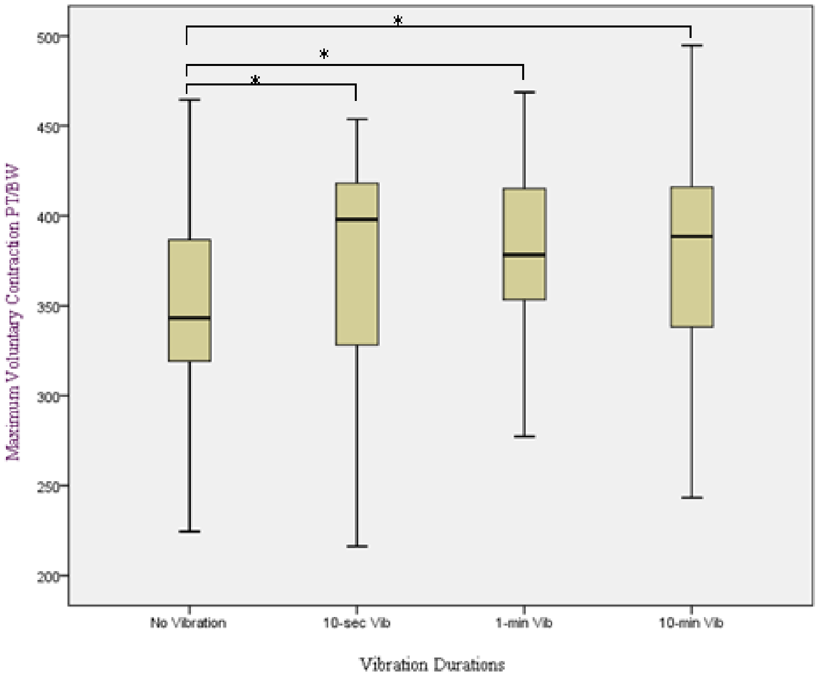

Figure 4.3 Dominant Leg Maximum Voluntary Contraction PT/BW for Different Vibration Durations at 40 Hz

Significant mean difference was found between no vibration (M = 343.5, SD = 72.3) and 1-min vibration (M = 373.1, SD = 63.7) for the dominant leg iMVC PT/BW at 40 Hz. 1-min vibration improved the dominant leg iMVC PT/BW than no vibration [t (14) = -3.21, $p<0.0083$]. Significant mean difference was also found between no vibration (M = 343.5, SD = 72.3) and 10-sec vibration (M = 370.3, SD = 69.4) for the dominant leg iMVC PT/BW at 40 Hz. 10-sec vibration improved the dominant leg iMVC PT/BW more than no vibration [t (14) = -2.92, $p<0.025$]. Significant mean difference was found between no vibration (M = 343.5, SD = 72.3) and 10-min vibration (M = 372.3, SD = 73.5) for the dominant leg iMVC PT/BW at 40 Hz. 10-min vibration improved the dominant leg iMVC PT/BW better than that of no vibration [t (14) = -2.68, $p<0.05$]. Dominant leg mean differences of iMVC PT/BW between pairs of different vibration durations for 40 Hz are presented in Table 4.3.3.

Table 4.3.3 Dominant Leg Mean Differences of iMVC PT/BW between pairs of different vibration durations for 40 Hz

Pairs		Mean Diff	Std Error	P
No Vibration	10-sec Vibration	-26.8	9.2	.011
No Vibration	1-min Vibration	-29.6	9.2	.006
No Vibration	10-min Vibration	-28.8	10.7	.018

4.4 Dominant Leg Isometric Maximum Voluntary Contraction PT/BW Scores for 80 Hz

A one-way repeated ANOVA was conducted with the factor being vibration durations and the dependent variable being the dominant leg iMVC PT/BW scores at 80 Hz. One-way repeated-measures ANOVA indicated a significant time effect, Wilks' λ =.36, $F(3,12) = 7.00$, p=0.006, η_p^2 =. 64. The mean dominant leg iMVC PT/BW scores and standard deviations (SD) for 80 Hz were presented in Table 4.4.1.

Table 4.4.1 Mean Dominant Leg iMVC PT/BW Scores and SDs for 80 Hz

Vibration Durations	Mean	SD	N
No Vibration	343.5	72.3	15
10-sec Vibration	384.7	67.5	15
1-min Vibration	363.8	64.0	15
10-min Vibration	374.3	70.5	15

Three pair-wise comparisons were conducted for 80 Hz among four different vibration durations: 1) no vibration - 10-sec vibration, 2) no vibration - 1-min vibration and 3) no vibration - 10-min vibration. The smallest p-value was for the comparison between "no vibration" and "10-sec vibration" and its p-value of 0.000 was less than alpha level, (0.05/3 = 0.017) and, therefore difference between two means was significant according to Holm's sequential Bonferroni procedure. The next smallest value (0.029) was not significant at the 0.025

level between “no vibration” and “10-min vibration” conditions, and therefore none of the remaining comparisons were significant. Difference in isometric MVC PT/BW was given at Figure 4.4.1.

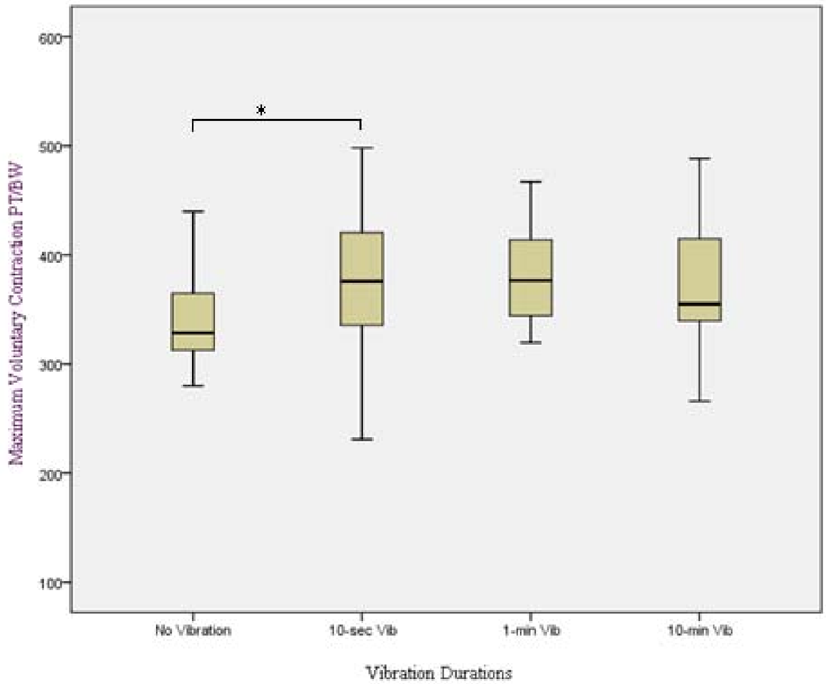

Figure 4.4.1 Dominant Leg Maximum Voluntary Contraction PT/BW for Different Vibration Durations at 80 Hz

Significant mean difference was found between no vibration (M = 343.5, SD = 72.3) and 10-sec vibration (M = 384.7, SD = 67.5) for the dominant leg iMVC PT/BW at 80 Hz. 10-sec vibration improved the dominant leg iMVC PT/BW compared to that of no vibration [t (14) = -4.92, $p<0.017$]. Dominant leg mean differences of iMVC PT/BW between pairs of different vibration durations for 80 Hz are presented in Table 4.4.2.

Table 4.4.2 Dominant Leg Mean Differences of iMVC PT/BW between pairs of different vibration durations for 80 Hz

Pairs		Mean Diff	Std Error	P
No Vibration	10-sec Vibration	-41.2	8.4	.000
No Vibration	1-min Vibration	-20.3	10.5	.073
No Vibration	10-min Vibration	-30.8	12.6	.029

4.5 Non-dominant Leg Isometric Maximum Voluntary Contraction PT/BW Scores for 40 Hz

A one-way repeated ANOVA was conducted with the factor being vibration durations and the dependent variable being the non-dominant leg iMVC PT/BW scores at 40 Hz. One-way repeated-measures ANOVA indicated a significant time effect, Wilks' λ =.34, $F(3,12) = 7.68$, $p=0.004$, η_p^2 =. 66. The mean non-dominant leg iMVC PT/BW scores and standard deviations (SD) for 40 Hz were presented in Table 4.5.1.

Table 4.5.1 Mean Non-dominant Leg iMVC PT/BW Scores and SDs for 40 Hz

Vibration Durations	Mean	SD	N
No Vibration	335.1	92.3	15
10-sec Vibration	370.6	86.2	15
1-min Vibration	369.8	85.3	15
10-min Vibration	377.3	71.4	15

Paired sample t-tests were applied to assess which means differ from each other for the non-dominant leg. Three pair-wise comparisons were conducted for 40 Hz among four different vibration durations: 1) no vibration - 10-sec vibration, 2) no vibration - 1-min vibration and 3) no vibration - 10-min vibration for non-dominant leg. The smallest p-value was for the comparison between "no vibration" and "10-min vibration" and its p-value of 0.001 was less than alpha level, (0.05/3 = 0.017) and, therefore difference between two means was significant. The next smallest p-value 0.001 was also significant at the 0.025 (0.05/2) level between "no vibration" and "1-min vibration" conditions. Third smallest p-value was for the comparison between “no vibration” and “10-sec vibration” and its p-value of 0.008 was less than alpha level, (0.05/1 = 0.05) and, therefore difference between two means was significant. Difference in isometric MVC PT/BW was given at Figure 4.5.

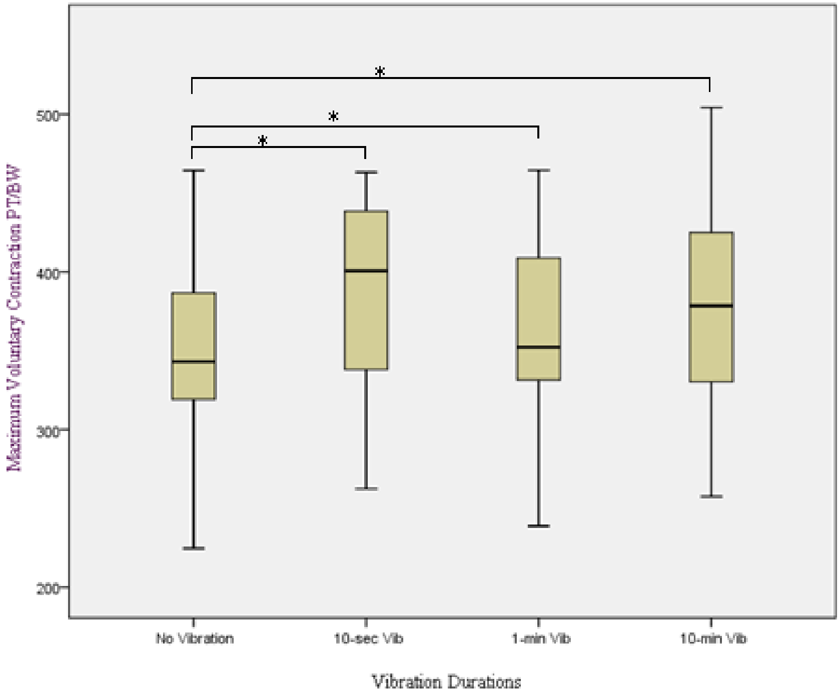

Figure 4.5 Non-dominant Leg Maximum Voluntary Contraction PT/BW for Different Vibration Durations at 40 Hz

Significant mean difference was found between no vibration (M = 335.1, SD = 92.3) and 10-min vibration (M = 377.3, SD = 71.4), t (14) = -4.38, $p<0.0083$ for non-dominant leg iMVC PT/BW at 40 Hz. Significant mean difference was also found between no vibration (M = 335.1, SD = 92.3) and 1-min vibration (M = 369.8, SD = 85,3), t (14) = -4.10, $p<0.01$ for non-dominant leg iMVC PT/BW at 40 Hz. Third significant mean difference was found between no vibration (M = 335.1, SD = 92.3) and 10-sec vibration (M = 370.6, SD = 86.2), t (14) = -3.11, $p<0.0125$ for non-dominant leg iMVC PT/BW at 40 Hz.

In sequence, 10-min vibration, 1-min vibration and 10-sec vibration had more improvement on dominant leg iMVC PT/BW than no vibration. Non-dominant leg mean differences of iMVC PT/BW between pairs of different vibration durations for 40 Hz were shown in Table 4.5.2.

Table 4.5.2 Non-dominant Leg Mean Differences of iMVC PT/BW between pairs of different vibration durations for 40 Hz

Pairs		Mean Diff	Std Error	P
No Vibration	10-sec Vibration	-35.6	11.4	.008
No Vibration	1-min Vibration	-34.7	8.5	.001
No Vibration	10-min Vibration	-42.2	9.6	.001

4.6 Non-dominant Leg Isometric Maximum Voluntary Contraction PT/BW Scores for 80 Hz

A one-way repeated ANOVA was conducted with the factor being vibration durations and the dependent variable being the non-dominant leg iMVC PT/BW scores at 80 Hz. One-way repeated-measures ANOVA indicated a significant time effect, Wilks' λ =.45, $F(3,12) = 4.95$, $p=0.018$, η_p^2 =. 55. The mean non-dominant leg iMVC PT/BW scores and standard deviations (SD) for 80 Hz were presented in Table 4.6.1.

Table 4.6.1 Mean Non-dominant Leg iMVC PT/BW Scores and SDs for 80 Hz

Vibration Durations	Mean	SD	N
No Vibration	335.1	92.3	15
10-sec Vibration	362.9	81.3	15
1-min Vibration	379.4	53.0	15
10-min Vibration	357.3	57.4	15

Paired sample t-tests were applied to assess which means differ from each other for the non-dominant leg. Three pair-wise comparisons were conducted for 40 Hz among four different vibration durations: 1) no vibration - 10-sec vibration, 2) no vibration - 1-min vibration and 3) no vibration - 10-min vibration for non-dominant leg.

The smallest p-value was for the comparison between "no vibration" and "1-min vibration" and its p-value of 0.004 was less than alpha level, (0.05/3 = 0.017) and, therefore difference between two means was significant. The next smallest value (0.024) was also significant at the 0.025 level between "no vibration" and "10-sec vibration" conditions. However, remaining comparison was not significant. Difference in isometric MVC PT/BW was given at Figure 4.6.

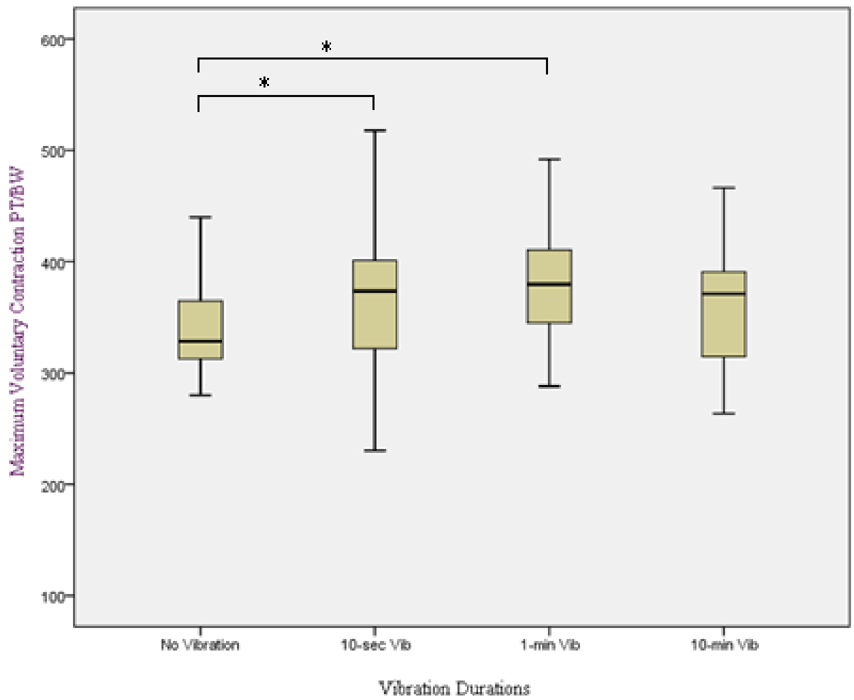

Figure 4.6 Non-dominant Leg Maximum Voluntary Contraction PT/BW for Different Vibration Durations at 80 Hz

Significant mean difference was found between no vibration (M = 335.1, SD = 92.3) and 1-min vibration (M = 379.4, SD = 53.0) for non-dominant leg iMVC

PT/BW at 80 Hz. 1-min vibration had more improvement on non-dominant leg iMVC PT/BW than no vibration, t (14) = -3.39, $p<0.0083$. Significant mean difference was also found between no vibration (M = 335.1, SD = 92.3) and 10-sec vibration (M = 362.9, SD = 81.3) for non-dominant leg iMVC PT/BW at 80 Hz. 10-sec vibration had more improvement on non-dominant leg iMVC PT/BW than no vibration, t (14) = -2.53, $p<0.025$. Non-dominant leg mean differences of iMVC PT/BW between pairs of different vibration durations for 80 Hz were shown in Table 4.6.2.

Table 4.6.2 Non-dominant Leg Mean Differences of iMVC PT/BW between pairs of different vibration durations for 80 Hz

Pairs		Mean Diff	Std Error	P
No Vibration	10-sec Vibration	-27.9	11.0	.024
No Vibration	1-min Vibration	-44.3	13.1	.004
No Vibration	10-min Vibration	-22.3	13.9	.131

4.7 Comparison of 40 Hz and 80 Hz Frequencies on Dominant Leg Maximum Voluntary Contraction for Different Vibration Durations

A two-way repeated measures ANOVA was conducted to evaluate the effect of different frequencies (2) and vibration durations (3) on strength parameters. The dependent variable was iMVC PT/BW scores. The within subject factors were different frequencies with two levels (40 Hz and 80 Hz) and time with three levels (10-sec, 1-min and 10-min vibration applications). The Time main and Frequency x Time interaction effects were tested using the multivariate criterion of Wilks' Lambda. The Time main effect was not significant, Wilks' λ =.91, F(2,13) = .64, p=0.55, η_p^2 =. 09, as well as the Frequency x Time interaction effect, Wilks' λ =.71, F(2,13) = 2.72, p=0.10, η_p^2 =. 30. The univariate test associated with the Frequency main effect was also non-significant, Wilks' λ =.99, F(1,14) = .12, p=0.73, η_p^2 =.01. As there were no significant main and interaction effect pair-wise comparisons were not applied. The mean dominant leg iMVC PT/BW scores and standard deviations for 40 and 80 Hz were presented in Table 4.7.

Table 4.7 Mean Dominant Leg iMVC PT/BW Scores and SDs for 40 and 80 Hz

Frequency	Vibration Durations	Mean	SD	N
40 Hz	10-sec Vibration	370.3	69.4	15
	1-min Vibration	373.1	63.7	15
	10-min Vibration	372.3	73.5	15
80 Hz	10-sec Vibration	384.7	67.5	15
	1-min Vibration	363.8	64.0	15
	10-min Vibration	374.3	70.5	15

4.8 Comparison of 40 Hz and 80 Hz Frequencies on Non-dominant Leg Maximum Voluntary Contraction for Different Vibration Durations

A two-way repeated measures ANOVA was conducted to evaluate the effect of different frequencies (2) and vibration durations (3) on strength parameters for non-dominant leg. The dependent variable was iMVC PT/BW scores. The within subject factors were different frequencies with two levels (40 Hz and 80 Hz) and time with three levels (10-sec, 1-min and 10-min vibration applications).

The Time main and Frequency x Time interaction effects were tested using the multivariate criterion of Wilks' Lambda. The Time main effect was not significant, Wilks' λ =.85, $F(2,13) = 1.16$, $p=0.34$, η_p^2 =. 15, as well as the Frequency x Time interaction effect, Wilks' λ =.74, $F(2,13) = 2.25$, $p=0.15$, η_p^2 =. 26. The univariate test associated with the Frequency main effect was also non-significant, Wilks' λ =.95, $F(1,14)$ = .73, p=0.41, η_p^2 =. 05. As there was no significant main and interaction effect pair-wise comparisons were not applied. The mean non-dominant leg iMVC PT/BW scores and standard deviations for 40 and 80 Hz were presented in Table 4.8.

Table 4.8 Mean Non-dominant Leg iMVC PT/BW Scores and SDs for 40 and 80 Hz

Frequency	Vibration Durations	Mean	SD	N
40 Hz	10-sec Vibration	370.6	86.2	15
	1-min Vibration	369.8	85.3	15
	10-min Vibration	377.3	71.4	15
80 Hz	10-sec Vibration	362.9	81.3	15
	1-min Vibration	379.4	53.0	15
	10-min Vibration	357.3	57.4	15

CHAPTER 5

DISCUSSION

The purpose of the present study was to investigate the effects of local vibration applied with different frequencies and different durations on maximal quadriceps isometric skeletal muscle contraction in the dominant and non-dominant legs.

This chapter discusses the effects of different vibration durations on strength performance and compares strength measures among different vibration durations for low and high frequencies. Following the wide-ranging literature review, six main research questions and their sub-questions were constructed. These research questions and their sub-questions are discussed in this chapter in relation to statistical results.

Subjects of this study were 16 male handball players from Middle East Technical University. Three year experience in handball and absence of neuromuscular disease, injury, fracture of lower extremity or any serious health problems were inclusion criteria.

Result of this study demonstrated that local vibration (LV) induced significantly higher muscle activity than no vibration (NV) condition. Strength improvements were obtained in dominant quadriceps and non-dominant quadriceps for 40 Hz and 80 Hz. However, no significant difference was obtained when the vibration durations were compared between 40 Hz and 80 Hz.

5.1 Comparison of Vibration and Non-vibration Conditions

Local vibration (LV) induced significantly higher muscle activity than no vibration (NV) condition. Three different vibration durations enhanced MVC for dominant and non-dominant quadriceps muscle at 40 Hz when compared to NV condition. On the other hand, 80-Hz frequency had partial significant results. 10-sec vibration for dominant quadriceps and 10-sec and 1-min vibration for non-dominant quadriceps significantly enhanced the iMVC when compared to NV condition at 80 Hz.

Improvement in performance, in the current study can be explained by muscle spindle activation and TVR. It is extensively accepted that vibration improves neuromuscular output of Ia afferent stimulation and it facilitates the recruitment of more motor units during strength exercises (Bongiovanni & Hagbarth, 1990; Bosco, Colli, et al, 1999; Cardinale & Bosco, 2003; Issurin, 2005; Issurin & Tenebaum, 1999; Issurin et al, 1994). Sensitivity of muscle spindle primary endings was enhanced by voluntary contraction (Fattorini et al, 2006).

These results are consistent with some previous studies. Luo et al (2008) studied the influence of 10% 1-RM and 30% 1-RM on EMG response to vibration training with sub-maximal isometric contractions. They applied the vibration (65 Hz, 1.2 mm) on distal tendon of quadriceps. Likewise in the present study, direct vibration (local vibration) induced higher muscle activity on quadriceps muscle. However, same group of investigators (Luo et al, 2007) designed similar study with the same frequency and amplitude (65 Hz, 1.2 mm). They applied the 60-70% 1-RM ballistic knee extension. Luo and associates (2007) stated that muscle activity was not enhanced by superimposed direct vibration (local vibration) during maximal effort ballistic knee extension. Same researchers (Moran, McNamara, & Luo, 2007) found similar non-significant results with almost same training load (70% 1-RM) on dynamic biceps curl. Luo et al (2008) commented that type of contraction (ballistic or non-ballistic) was not the reason for non-improvement. The insignificant result would be resulted in connection with sub-maximal isometric exercise. Significant result of the current study would be resulted from maximal voluntary contraction (Issurin et al, 1994; Lieberman & Issurin, 1997). It is confusing that 10% 1-RM and 30% 1-RM on EMG response reached to enhancement in muscle activity (Luo et al, 2008)

Their frequency level, 65 Hz was almost the average of frequencies in current study. On the other hand, the difference was that Luo and associates applied the 1.2 mm amplitude while the current study applied 3.5 mm amplitude. In the comparison of 0.5 mm and 1.2 mm amplitudes, latter amplitude demonstrated significant enhancement over the former one (Luo et al, 2005a). So higher amplitude values would be the reason for improvements in current study.

The vibration characteristics (40-80 Hz, 3,5 mm) of the present study would be adequate to activate muscle spindle primary endings. So the significant enhancement would have been achieved due to the activation of muscle spindles. It has been suggested that muscle spindle primary endings are very sensitive to vibration (Burke, Hagbarth, Lofstedt, & Wallin, 1976). Also, vibration could induce a sustained discharge of primary afferents and resulted in reflex contraction, named as tonic vibration reflex (Eklund & Hagbarth, 1966).

Significant increase was also found in some previous studies that they revealed vibration induced improvement in maximal dynamic exercises (Issurin & Tenebaum, 1999; Issurin et al, 1994; Lieberman & Issurin, 1997). Present study was applied vibration with amplitude of 3.5 mm and frequency of 40 and 80 Hz directly to the muscle belly. But these previous studies measured the biceps activity by grasping the vibrating handle. So it is inevitable to have attenuation of the vibration stimuli as it travels through the body. Therefore, it is expected that smaller amplitude would have reached to working muscle. Despite this attenuation they managed to have enhancement in maximal dynamic exercises. Actually, amplitude of 0.3 and 0.4 mm in vibration source was already small and it has been smaller in the working muscle. Nevertheless they had a significant improvement in muscle activity.

Small amplitude (0.005-0.0015 mm) with a high frequency (100 Hz) was applied during 20% 1-RM isometric muscle contraction (Fattorini et al, 2006). Ten-minute micro perturbations were applied three times in a day for three consecutive days in left leg only. Pre and post MVC did not show any significant improvement in quadriceps muscle. However, vibration significantly increased the force value reached at 30, 50, 100 and 200 milliseconds in the left leg. In this study (Fattorini et al, 2006), legs were classified as right or left instead of dominant and non-dominant.

Insignificant results of the current study for 10 minutes and 80 Hz could be explained by the prolonged exposure to vibration (Konishi et al, 2009; Kouzaki et al, 2000). In the current study 40 Hz and 80 Hz was selected as low and high frequencies. Jackson and Turner (2003) on the other hand, selected 30 and 120 frequencies as low and high frequencies. Furthermore, amplitude level was between 1.5 and 2 mm, almost half of the value in current study (3.5 mm). Different from the current study, previous study applied 30 minute of vibration duration. They found that prolonged vibration of the right rectus femoris decreased isometric MVC in not only ispilateral leg but also the contralateral legs. In a similar one-legged vibration study (Bongiovanni et al, 1990) found that prolonged vibration (150 Hz) reduced MVC and EMG activity in ispilateral limb. In addition to that, prolonged muscle vibration (30 Hz) also decreased maximal isometric knee extension performance (Kouzaki et al, 2000).

In another similar study, Samuelson, Jorfeldt and Ahlborg (1989) examined the effect of vibration on endurance during maximal isometric contraction until exhaustion. Samuelson and colleagues found the decline in endurance performance of leg extensors under prolonged vibration. They applied the LV with 1.8 mm amplitude which can be accepted at an optimum level (Eklund & Haghbart, 1966). Thus, possible reason for decline in performance can be explained by low frequency level (20 Hz). Significant result of the present study would have been reached due to the two-fold amplitude and double to quadruple frequency level.

Unlike the isometric contraction, Konishi, Kubo and Fukudome (2009) examined the influence of prolonged vibration (50 Hz, 1.5 mm and 20 min) on eccentric and concentric contractions and EMGs of knee extensors. This study has different results with current study. Vibration stimulation reduced the strength of knee extension and EMG values of vastus lateralis and vastus madialis in concentric and eccentric contractions. Twenty minute of vibration duration could cause the reduced strength measures as mentioned in the some previous studies.

The results of the current study are similar to some WBV training studies investigating the effect of resistance load (Roalents et al, 2006). They measured the electromyography (EMG) on quadriceps muscle in accordance with different exercises. Results showed that muscle activity increased during WBV training. Another study conducted by Rittweger and associates (2001) examined the influence of sub-maximal isometric contraction on acute vibration training effect by measuring the oxygen uptake. They found that oxygen uptake during a isometric exercise could be enhanced by WBV.

5.2 Comparison of Different Vibration Durations between High and Low Frequency

The present study showed no significant difference when the vibration durations were compared between 40 Hz and 80 Hz. Although the low level of frequency (40 Hz) produced more significant results than high level of frequency (80 Hz), they did not differ with each other. In the current study 40 Hz and 80 Hz was selected as low and high frequencies. Jackson and Turner (2003) on the other hand, selected 30 and 120 frequencies as low and high frequencies. Furthermore, amplitude level was between 1.5 and 2 mm, while amplitude level was 3.5 mm for current study. One possible reason for non-significant result is small difference between frequency levels. Previous studies stated that discomfort is seen for high frequencies close to 100 Hz (Luo et al, 2005a) and the others stated that 20 Hz is not adequate to activate muscles (Samuelson et al, 1989).

An important reason for disagreement among the results of the extensive literature was that the experiments being compared have been conducted for different purposes and designs. There are too many differences in durations, frequencies, amplitudes and application places.

The differences and complexity of vibration with the diverse range and variability in human response to vibration stimulation is still exciting area for the researchers wishing to comprehend relationship between vibration and its effects. It is hard to find studies used the similar design and vibration characteristics.

5.3 Conclusion

This study assists the following points: 1) Local vibration induced significantly higher muscle activity than no vibration, 2) strength improvements were obtained in dominant quadriceps and non-dominant quadriceps for 40 Hz and 80 Hz, but low frequency revealed more significant results, and 3) different frequencies were not distinguishing for better strength improvement.

5.4 Recommendations

Future studies about vibration training on strength measures are still interesting to reach more general understandings. Further research is encouraged for combined dynamic and static strength parameters. The current study applied specific durations and frequencies; therefore, further study should use wide range of frequency, amplitude and durations for comprehensive evaluations. Participants of the present study were fifteen handball players, further studies should be benefitted from different sports with a larger sample size.

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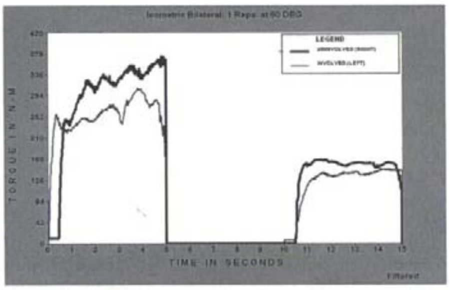
APPENDICES

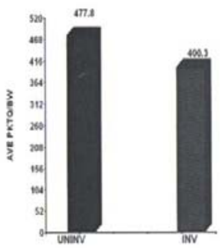
Appendix A: Isometric Strength Evaluation Sheet

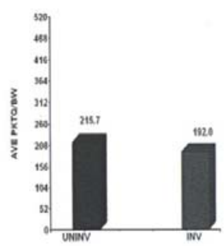
Comprehensive Evaluation

Name:		Session:	30.03.2010 20:48:35		
ID:	Ahmetpes15	Involved:	None	Protocol:	Isometric Bilateral
Birth Date:	(dd.MM.yyyy)	Clinician:		Pattern:	Extension/Flexion
Ht:		Referral:		Mode:	Isometric
Wt:	77.1	Joint:	Knee	Contraction:	AWAY/TOWARD
Gender:	Male	Diagnosis:			



		ʹŞAAWAY 60 DEG			¼ŞATOWARD 60 DEG		
# OF REPS (60 DEG): R 1 - L 1		UNINV	INV	DEFICIT	UNINV	INV	DEFICIT
		Right	Left		Right	Left	
PEAK TORQUE	N-M	366.6	307.1	16.2	165.5	147.3	11.0
AVG PEAK TQ	N-M	366.6	307.1		165.5	147.3	
AVE PKTQ/BW	%	477.8	400.3		215.7	192.0	
RELAXATION TIME	SEC	5	5		5	5	
CONTRACTION TIME	SEC	5	5		5	5	
COEFF. OF VAR.	%	0.0	0.0		0.0	0.0	
AGON/ANTAG RATIO	%	45.1			48.0		





Comments:

PEAK TORQUE:	Highest muscular force output at any moment during a repetition. Indicative of a muscle's strength capabilities.
PEAK TQ/BW :	Represented as a percentage normalized to bodyweight and compared to an established goal
COEFF. OF VAR.:	Statistical representation of test validity based on reproducibility of preformance. Lower values demonstrate higher reproducibility.
AGON/ANTAG RATIO:	The Reciprocal muscle group ratio. Excessive imbalances may predispose a joint to injury
DEFICITS:	1 to 10% No significant difference between extremities. 11 to 25% Rehabilitation recommended to improve muscle performance balance. > 25% Significant Functional Impairment (-) Negative deficit indicates involved extremity performed better than uninvolved Use positive angles for Extension/Flexion

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Appendix B: Informed Consent Form

GÖNÜLLÜ KATILIM FORMU

"Farklı titreşim sürelerinin kas performansı üzerine etkisinin incelenmesi" isimli bir araştırma yapmaktayız. Bu çalışmanın amacı hentbol oyuncularında değişen titreşim sürelerinin performans ile olan ilişkisini incelemektir. Kuvvet değerlendirilmesi BIODEX izokinetik dinamometre kullanılarak yapılacaktır. Kuvvet ölçümlerinin öncesinde taşınabilir ve titreşim veren "VB 115" adlı bir titreşim cihazı kullanılacaktır. Bu araştırmayı yapmak istememizin nedeni, ölçümlerin sonuçlarına göre sporculara yararlı bilgiler sağlamaktır. ODTÜ Beden Eğitimi ve Spor Bölümü ile ODTÜ Sağlık ve Rehberlik Merkezi işbirliği ile gerçekleştirilecek bu çalışmaya katılımınız araştırmanın başarısı için önemlidir. Ölçümler ODTÜ Sağlık Rehberlik Merkezinde yapılacaktır.

Bu araştırmadan hiçbir şahsi çıkarımız yoktur. Yapılacak olan çalışma sonunda bulunan veriler sporcuların performans ve iyileştirme gibi süreclerinde anlamlı bilgiler sağlayacak ve bilimsel amaçlı olarak kullanılacaktır. Çalışmalar sırasında ve sonrasında herhangi bir risk, rahatsızlık veya stres beklenmemektedir. Çalışmaya katılmak tamamen gönüllülük esasına dayalıdır. Çalışmadan istediğiniz zaman çıkabilirsiniz. Testler karşılığında sizden herhangi bir ücret talep edilmeyeceği gibi, size de herhangi bir ücret ödenmeyecektir.

Araştırma ile ilgili detaylı sorular (şimdi ve proje sırasında) araştırmacı tarafından cevaplanacaktır. Daha fazla bilgi almak için Beden Eğitimi Bölümü başkanı Prof. Dr. Feza Korkusuz (Tel: 210 4950; E-posta: feza@metu.edu.tr) ya da araştırma görevlisi Ahmet Yıldırım (Tel: 210 3835; E-posta: yahmet@metu.edu.tr) ile iletişim kurabilirsiniz.

Yukarıda bahsedilen araştırma prosedürünü anlamış bulunmaktayım. Konu ile ilgili tüm sorularım cevaplanmıştır ve bu çalışmaya katılmayı kabul ediyorum. Bu formun bir örneği şahsıma verilmiştir.

Katılımcı
Adı, soyadı:
Tel:
İmza:

Görüşme tanığı
Adı, soyadı: Emre AK
Tel: 210 36 63
İmza:

Katılımcı ile görüşen araştırmacı
Adı soyadı, unvanı: Ahmet YILDIRIM, Araştırma Görevlisi
Adres: Beden Eğitimi ve Spor Bölümü, Eğitim Fakültesi, ODTÜ, ANKARA
Tel: 210 38 35
İmza:

Appendix C: Approval of Research Procedures

Orta Doğu Teknik Üniversitesi İnsan Araştırmaları Etik Kurulu Başvuru Formu

> **Orta Doğu Teknik Üniversitesi (ODTÜ) bünyesinde yapılan ve/ya ODTÜ çalışanları/öğrencileri tarafından yürütülen ve insan katılımcılardan bilgi toplamayı gerektiren tüm çalışmalar, ODTÜ İnsan Araştırmaları Etik Kurulu incelemesine tabidir. Bu başvuru formu doldurulduktan sonra diğer gerekli belgelerle birlikte ODTÜ İnsan Araştırmaları Etik Kuruluna başvuru yapılmalıdır. Çalışmalar, Etik Kurulun onayının alınmasından sonra aktif olarak başlatılmalıdır.**

1. Araştırmanın başlığı: *Farklı titreşim sürelerinin kas performansı üzerine etkisinin incelenmesi*

2. Araştırmanın niteliği (Uygun olan kutuyu işaretleyiniz)

☐ Öğretim Üyesi Araştırması ■ Doktora Tezi

☐ Yüksek Lisans Tezi ☐ Diğer (belirtiniz) _________

3. Araştırmacının/Araştırmacıların:

Adı-Soyadı: *Ahmet Yıldırım* Bölümü: *Beden Eğitimi ve Spor* Telefonu: *210 3835*

Adresi: *Eğitim Fakültesi, Beden Eğitimi ve Spor Bölümü, 4.Kat. ODTÜ-ANKARA*

E-posta adresi: *yahmet@metu.edu.tr*

4. (Varsa) Danışmanın: Adı-Soyadı: *Feza Korkusuz* Telefonu: *210 4950*

5. Proje Dönemi: Başlangıç *2010 Ocak,* Bitiş *2010 Nisan*

6. Projenin desteklenip desteklenmediği: ■ Desteksiz ☐ Destekli

Desteklenen bir proje ise, destekleyen kurum: ☐ Üniversite ☐ TUBİTAK

☐ Uluslararası (belirtiniz) ______________ ☐ Diğer (belirtiniz) ______________

7. Başvurunun statüsü: ■ Yeni başvuru ☐ Revize edilmiş başvuru ☐ Bir önceki projenin devamı

Bir önceki projenin devamı ise, yürütülen çalışma önceden onaylanan çalışmadan herhangi bir farklılık gösteriyor mu? ☐ Evet ☐ Hayır

8. Çalışma katılımcılara, herhangi bir şekilde yanlı/yanlış bilgi vermeyi, çalışmanın amacını tamamen gizli tutmayı
gerektiriyor mu? ☐Evet ■ Hayır
Evet ise açıklayınız:____
9. Çalışma katılımcıların fiziksel veya ruhsal sağlıklarını tehdit edici sorular/maddeler, prosedürler ya da
manipülasyonlar/uygulamalar içeriyor mu? ☐ Evet ■ Hayır
Evet ise açıklayınız:____
10. Katılımcı sayısı: *15*
11. Kontrol grup kullanılacak mı?: ☐ Evet ■ Hayır
12. Aşağıda sunulan listeden, çalışmanın katılımcılarını en iyi tanımlayan seçenekleri işaretleyiniz.

☐ Üniversite Öğrencileri

☐ Çalışan Yetişkinler

☐ Halihazırda İş Sahibi Olmayan Yetişkinler

☐ Okul Öncesi Çocuklar

☐ İlköğretim Öğrencileri

☐ Lise Öğrencileri

☐ Çocuk İşçiler

☐ Yaşlılar

☐ Zihinsel Engelli Bireyler

☐ Fiziksel Engelli Bireyler

☐ Tutuklular

■ Diğer (belirtiniz) *Hentbol oyuncuları*

13. Aşağıda yer alan uygulamalardan, çalışma kapsamında yer alacak olanları işaretleyiniz.

☐ Anket

☐ Mülakat

☐ Gözlem

☐ Bilgisayar ortamında test uygulamak

☐ Video/film kaydı

☐ Ses kaydı

☐ Alkol, uyuşturucu ya da diğer herhangi bir kimyasal maddenin katılımcılara kullandırılması

☐ Yüksek düzeyde uyarıma (ışık, ses gibi) maruz bırakma

☐ Radyoaktif materyale maruz bırakma

■ Diğer (belirtiniz): *Isokinetik dinamometre ile kuvvet ölçümü – Tendon titreşimi verilmesi*

Bu bölüm ilgili bölümleri temsil eden İA Etik Alt Kurulu tarafından doldurulacaktır.

Proje No: XXXX – XX – XXX (Yıl – Etik Alt Kurul No. – Proje Sıra No.)

Değerlendirme Tarihi: İmza:

Appendix D: Türkçe Özet

Giriş

Titreşim bir denge noktası etrafındaki mekanik salınım olarak tanımlanmıştır (Griffin, 1990). Salınım hareketi sabit değildir; ortalama değerden büyük ya da küçük olacak şekilde belirli bir periyotta tekrarlanır. Günlük hayat içerisinde insanlar da titreşime maruz kalır. Seyahatler ve küçük aletlerin kullanımı arttıkça insanların maruz kaldığı titreşim miktarı da artar. Bunun tipik örnekleri araba, vasıta ya da endüstiyel kamyon kullanmaktır. Makinelerin, elektrik motorlarının ya da mekanik cihazların titreşim hareketi her ne kadar istenmese de insanlar uzay gemisinden at binmeye kadar her yerde titreşime maruz kalırlar.

Günlük hayatta, bir işçi endüstriel kamyon kullanabilir, bir çiftçi traktör sürebilir, askerler çetin doğa koşullarında çok çeşitli taşıta binebilir, uçakla, gemiyle ya da botla seyahat edebilirler (Mansfield, 2005). Bu sırada maruz kalınan titreşimler büyük ölçüde bütün vücudu etlikeyen titreşimlerdir. İnsanların titreşime tepki vermesi, fizyoloji, atletizm, mühendislik, biomekanik, biyoloji ve psikoloji alanlarını da kapsayan çok disiplinli bir konudur. Çok fazla bilinmemesine karşın insanlar kayak, buz pateni, yelkencilik gibi sporlarda da titreşime maruz kalmaktadırlar. Örneğin kayak yaparken kayakçıların en az 30 Hz frekansında titreşime maruz kaldıkları tespit edilmiştir (Babiel, Hartman, Spitzenpfeil ve Mester, 2001).

Titreşim, tüm vücut titreşimi (TVT) ya da lokal titreşim (LT) olarak sınıflandırılabilir. Tüm vüvut titreşimi, titreşim belirli bir bölgeye uygulandığında değil de tüm vücut ayakta, otururken ya da uzanırken titreştiğinde meydana gelir (Griffin, 1994). Lokal titreşim ise direkt titreşim, segmental titreşim, el-kol titreşimi olarak da adlandırılır; vücudun belirli bir bölgesi ya da kası titreşen yüzeyle temas ettiğinde oluşur (Griffin, 1990).

Titreşimin faydalı ya da zararlı oluşu frekansına, genliğine, süresine ve nasıl uygulandığına bağlıdır. Bir açıdan bakacak olursak, gün boyunca titreşime maruz kalan bir işçi için titreşim zararlıdır. (Bovenzi, Welsh, Della, Vedova ve Griffin, 2006; Dupuis ve Zerlett, 1987; Griffin, 1990; Martinho Pimenta ve Costelo Branco, 1999a-b). Fakat diğer bir açıdan, titreşim sakatlık problemi olan insanların tedavi sürecinde olduğu gibi iyi amaçlarla da kullanılmaktadır (Lundeberg, Abrahamson, Bondesson ve Akher, 1988; Cafarelli ve Kostka, 1981; Cafarelli ve Layton-Wood, 1986). Titreşim aynı zamanda atletlerin performanslarını geliştirmek için de kullanılmaktadır. Antreman sırasında maruz kalınan titreşimin toplam süresi, iş yerlerinde maruz kalınan titreşim süresinden yüzlerce kat daha azdır. Bazı çalışmalar 30 dakika ya da daha fazla süre boyunca titreşime maruz kalınması sonucunda performans düşüklüğünün kaçınılmaz olduğunu ortaya çıkarmıştır (Kouzaki, Shinohara ve Fukunaga, 2000).

Titreşimin, sporda kuvvet artırımı ya da özel antrenman uygulaması olarak araştırılması oldukça yeni bir konudur. Rus bilim adamları Nazarov ve Spivak tarafından yürütülen, bu konudaki öncü çalışmalardan biri, mekanik titreşimin cimnastikçilerin antrenmanlarındaki kuvvet artırımı üzerindeki etkisini tespit etmiştir. Cimnastikçiler egzersizleri yaparken cimnastik kirişleri, barları ve halkaları titreştirilmiştir. Titreşim altında yapılan bu egzersizlerin, geleneksel metodlarla yapılan egzersizlere göre kuvvet artırımını hızlandırdığı belirlenmiştir (Nazarov ve Spivak, 1987).

Daha önce yapılan çalışmalar büyük ölçüde tüm vücut titreşimini ele almıştır fakat literatürde tüm vücut titreşimi ile ilgili çok sayıda eleştiri yapılmıştır. Bunlardan biri TVT uygulaması sırasında titreşim kaynağı ile ölçüm yapılması hedeflenen kas arasındaki uzaklık nedeniyle titreşimin etkisinin azalması ve doğru ölçümün yapılamamasıdır (Luo, McNamara ve Moran, 2005a). Titreşim hedeflenen kasa uzun bir yol alarak geldiği için kas üzerindeki genliği ve frekansı tam olarak ölçülememektedir (Luo, McNamara ve Moran, 2005a; Zange, Haller, Müller, Libhardt ve Mester, 2009). Örneğin üst bacak kasının kuvvetini analiz etmek için, platformdan TVT uyguladığımızda, titreşim hedeflenen kasa ulaşana kadar kemiklerden, bağlardan, diğer kaslardan ve vücut sıvılarından etkilenir; böylelikle titreşimin etkisi kişiden kişiye değişebilir.

Literatürde lokal titreşim ile ilgili farklı çalışmalar yer almaktadır; bazı çalışmaların sonuçları birbiriyle çelişmektedir. Gabriel, Basford ve Kai-non (2002) 1 dakikalık lokal titreşim (60 Hz, 1 mm) uygulamış ve kuvvette gelişme bulmuşlardır. Kin-İşler, Açıkada ve Arıtan farklı frekanslarda 10 saniye boyunca lokal titreşim (4mm) uygulamışlardır. İzometrik kuvvette 6, 12, ve 24 Hz frekanslarında gelişme, 48 Hz frekansında ise azalma tespit etmişlerdir. Gomez ve arkadaşları (2003) tarafından yürütülen bir çalışmada kollara 3.8 mm genliğinde, düşük frekanslı (7.5 Hz) titreşim uygulanmıştır ancak uygulama sonucunda pençe kuvvetinde gelişme bulunmamıştır. Warman, Humphries ve Purton (2002) 30 saniyelik lokal titreşim (50 Hz, 5mm) uygulamış ve izometrik kuvvette gelişme bulmamışlardır. Benzer bir çalışmada, Humphries, Warman, Purton, Doyle ve Dugan (2004) aynı frekans ve genlikteki titreşimi 5 saniye süreyle uygulamış ve yine maksimum istemli izometrik kasılmada gelişme bulmamışlardır. Bu konudaki tek fikir birliği, 30 dakikalık ya da tükenene kadar verilen titreşimlerin kuvvet performansında düşüklüğe neden olduğudur (Bongiovanni, Hagbarth ve Stjernberg, 1990;

Jackson ve Turner, 2003; Kouzaki, Shinohara ve Fukunaga, 2000; Samuelson, Jordfeldt ve Ahlborg, 1989).

Literatürde yer alan titreşimle ilgili çalışmalar birbiriyle çelişmektedir. Dominant olan ve olmayan bacaklara üç farklı sürede ve iki farklı frekansta uygulanan ve bunları titreşimsiz değerlerle karşılaştıran başka bir çalışmaya rastlanmamıştır.

Bu nedenle, bu çalışma hentbol oyuncularına uygulanan lokal titreşimin kuadriseps izometrik kas kuvvet performansı üzerindeki etkisini iki farklı frekansta ve üç farklı sürede, titreşimli ve titreşimsiz koşulları birbiriyle kıyaslayarak açıklamaktadır. Çalışmanın bir diğer önemli amacı da izometrik kuvvet gelişimi için titreşimin tipinin ve süresinin belirlenmesidir.

Amaç

Bu çalışmanın amacı farklı frekanslarda ve sürelerde baskın olan ve olmayan bacağa uygulanan lokal titreşimin maksimal izometrik kuadriseps kas kasılması üzerindeki etkisinin incelenmesidir.

Materyal ve Method

Katılımcılar

Başlangıçta çalışma örneklemini 16 erkek hentbol oyuncusu oluşturmaktaydı. Bir oyuncu, izometrik ölçümler sırasındaki rahatsızlığı yüzünden çalışmadan ayrıldı. Geriye kalan 15 erkek hentbol oyuncusu çalışmaya gönüllü olarak katıldı ve bütün testleri tamamladı. Katılımcıların ortalama yaşı, kilosu, boyu ve vücut kitle indeksi sırasıyla: 20.8 (2.1) yıl, 79.2 (11.3) kg, 178.3 (8.5) cm ve

25.0 (1.3) kg/m2'dir. En az üç yıllık hentbol deneyimi olan hentbolcular çalışmaya dahil edilmiştir. Katılımcıların hepsi sağlıklı bireylerdi; hiçbirinin nöromüsküler rahatsızlığı, sakatlığı, alt bacağında kırığı ya da ciddi bir sağlık problemi yoktu. Üniversitenin etik kurulundan çalışma için onay alınmış ve tüm katılımcılardan aydınlatılmış onam formu temin edilmiştir.

Titreşim Ölçümleri

Titreşim ölçümleri için kuadriseps kaslarının üzerine yerleştirilen portatif kas-tendon titreştiricisi (VB 115 Techno Concept, Fransa) kullanılmıştır (Humphries, Warman, Purton, Doyle ve Dugan, 2004; Jackson ve Turner, 2003). Genliği 3.5 cm olan titreşim için 40 Hz ve 80 Hz olmak üzere iki farklı frekans seçilmiştir. Yüksek frekans seviyesi olarak 80 Hz'e, katılımcıların rahatlığı göz önünde bulundurularak karar verilmiştir. Lou, McNamara ve Moran (2005a) lokal titreşim çalışmalarında 30, 65 ve 100 Hz frekanslarını kullanmışlardır. 100 Hz frekansındaki titreşimin katılımcılarda rahatsızlık oluşturduğunu, 30 Hz lik frekansın ise kas kasılması üzerinde önemli bir fayda sağlamadığını belirtmişlerdir. Bu bilgiler göz önünde bulundurularak, bu çalışma için düşük frekans 40 Hz, yüksek frekans da 80 Hz olarak belirlenmiştir. Kısa, orta ve uzun süreler için ise 10, 60, ve 600 sn'lik titreşim süreleri belirlenmiştir. Testlerden önce katılımcılar bilgilendirilmiş ve düzeneğe alışmaları sağlanmıştır.

Fiziksel ve Fizyolojik Testler

Katılımcıların fiziksel özellikleri vücut kitle indeksine göre değerlendirilmiştir. Kuvvet ölçümleri ise azami torkların vücut ağırlığıyla normalize edilmesinden elde edilmiştir.

Vücut Kitle İndeksi

Vücut kitle indeksi metrekareye düşen vücut ağırlığı olarak tanımlanmıştır (Heyward ve Stolarczyk, 1996).

İzometrik Kuvvet Ölçümleri

İzometrik kuvvet verileri Biodeks Sistem Dinamometresi tarafından kaydedilerek kuadriseps kaslarının kuvvetleri değerlendirilmiştir. İzometrik kasılma laboratuar koşulları altında kolay kontrol edilebilir olması açısından ve güvenilir olması açısından kabul edilmiştir (Klausen, 1990)

Prosedür

Ölçümler başlamadan önce tüm katılımcılar ölçümler hakkında bilgilendirilmiş ve deneme ölçümleri yapılarak düzeneğine alışmaları sağlanmıştır. Her ölçüm farklı bir günde en az iki gün arayla yapılmıştır. Her test gününde baskın olan ve olmayan bacaklardan birer ölçüm alınmıştır.

Katılımcılar bisiklet ergometresinde 5 dakika ısınıp, 5 dakikada da germe egzersizleri yaptıktan sonra kuvvet testlerine alınmıştır. Testler için 120˚ lik diz açısı kullanılmış ve 5 sn'lik maksimum izometrik kuadriceps kasılması ölçülmüştür (Luo, McNamara ve Moran, 2008). Testler boyunca katılımcılardan uygulayabilecekleri en yüksek kuvveti uygulamaları istenmiştir.

Her katılımcıdan baskın olan bacak için 7, baskın olmayan bacak için 7 olmak üzere toplam 14 ayrı kuvvet ölçümü alınmıştır. Baskın olan bacağa 10, 60 ve 600 saniyelik sürelerle, 40 ve 80 Hz lik frekanslarda lokal titreşim uygulanarak 6 ölçüm alınmıştır. 7. ölçüm ise titreşim verilmeden alınmıştır. Bu yedi ölçümün hepsi baskın olmayan bacak için de uygulanmış ve toplam 14 ölçüme ulaşılmıştır.

İstatistiksel Analiz

PASW 18 programı kullanılarak tek yönlü tekrarlanan varyans analizi, eşleştirilmiş t-testi ve iki yönlü tekrarlayan varyans analizi yapılmıştır.

Sonuçlar

40 Hz ve 80 Hz ‘lik titreşim frekanslarında, farklı sürelerde uygulanan titreşim altındaki baskın bacaktaki azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları arasındaki farkı incelemek için iki ayrı tek yönlü tekrarlayan varyans analizi yapılmıştır. 40 Hz frekanındaki titreşim, farklı sürelerde (10 sn, 60 sn ve 600sn) baskın bacaktaki azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları arasında anlamlı bir fark oluşturmuştur (p= .05). 80 Hz frekansındaki titreşim ise sadece 10 sn’lik titreşim süresi için baskın bacaktaki azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları arasında anlamlı bir fark oluşturmuştur (p=.006).

40 Hz ve 80 Hz ‘lik titreşim frekanslarında, farklı sürelerde uygulanan titreşim altındaki baskın olmayan bacaktaki azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları

arasındaki farkı incelemek için iki ayrı tek yönlü tekrarlayan varyans analizi yapılmıştır. 40 Hz frekanındaki titreşim, farklı sürelerde (10 sn, 60 sn ve 600sn) baskın olmayan bacaktaki azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları arasında anlamlı bir fark oluşturmuştur (p= .004).). 80 Hz frekansındaki titreşim ise sadece 10 sn'lik ve 60 sn'lik titreşim süreleri için baskın olmayan bacaktaki azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları arasında anlamlı bir fark oluşturmuştur (p=.018).

40 ve 80 Hz frekanslarında farklı sürelerde uygulanan titreşimin baskın olan kuadrisepslerin azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorlarını değiştirip değiştirmediğini incelemek için iki yönlü tekrarlayan varyans analizi yapılmıştır. Sonuçlar 40 ve 80 Hz frekanslarında üç farklı sürede uygulanan titreşimin baskın olan kuadrisepslerin azami torkların vücut ağırlığı ile normalize edilmesiyle elde edilen maksimum istemli izometrik kasılma skorları arasında anlamlı bir farklılık oluşturmadığını göstermiştir. Aynı analiz baskın olmayan bacak için de uygulanmıştır ve yine farklı sürede uygulanan titreşim sonucunda anlamlı bir fark bulunmamıştır.

Tartışma

Performanstaki gelişim, bu çalışmada kas iğciği aktivasyonu ve tonik titreşim refleksi ile açıklanabilir. Titreşimin, nöromüsküler aktiviteleri geliştirdiği, kuvvet egzersizleri sırasında motor ünitelerinin çalışmasını kolaylaştırdığı yaygın bir şelikde kabul edilmektedir (Bongiovanni ve Hagbarth, 1990; Bosco ve ark,1999; Cardinale ve Bosco, 2003; Issurin, 2005; Issurin ve Tenebaum, 1999; Isurin ve ark., 1994). Kas iğciği uçlarının duyarlılığı istemli kasılmayla geliştirilir (Fattaorini ve ark, 2006).

Bu sonuçlar daha önceki çalışma sonuçlarıyla uyuşmaktadır. Luo ve arkadaşları (2008) maksimum kuvvetin % 10'unu ve % 30'unu kullanarak yaptıkları submaksimal izometrik kasılmalı titreşim antrenmanının EMG sonuçlarını inceledikleri bir çalışma yapmışlardır. 65 Hz frekans ve 1.2 mm genlikteki titreşimi kuadrisepsin uç tendonuna uygulamışlardır. Bu çalışmada olduğu gibi lokal titreşim antrenmanı kuadrisepsteki kas aktivitesi yüksek bir şekilde uyarmıştır. Aynı çalışma gurubu (Luo ve ark., 2007) aynı genlik ve frekanstaki bir diğer çalışmalarında, maksimum kuvvetin % 60- 70'ini kullanarak diz ektensiyonu çalışmışlardır fakat kas aktivitesinde artış bulamamışlardır. Moran ve arkadaşları tarafından yürütülen (2007) ve benzer bir antrenman metodu kullandıkları çalışmada titreşimi biseps kasına uygulamış ve anlamlı sonuç bulamamışlardır. Araştırmacılar bu sonucu submaksimal izometrik egzersize bağlamışlardır. (Issurin ve ark., 1994; Lieberman ve Issurin, 1997). Bu çalışmada ise maksimal istemli kasılma anlamlı sonuç bulunmasını sağlamış olabilir.

Maksimum kuvvetin % 10'unu ve % 30'unu kullanarak yaptıkları submaksimal izometrik kasılmalı titreşim antrenmanının EMG sonuçlarının anlamlı olması şaşırtıcı bir sonuç olmuştur (Luo ve ark., 2008). Çalışmada kullandıkları 65 Hz 'lik frekans yaklaşık olarak bu çalışmada kullanılan ferkansların ortalama değeridir. Diğer taraftan çalışmalarda kullanılan titreşimin genlikleri arasında fark bulunmaktadır. Luo ve arkadaşları 1.2 mm genliğinde titreşim uygularken bu çalışmada 3.5 mm genliğinde titreşim uygulanmıştır. 0.5 mm genliği ile 1.2 mm genliği birbiriyle kıyaslandığında, 1.2 mm genlikteki titreşimin daha fazla gelişme sağladığı ortaya çıkmıştır (Luo ve ark., 2005). Bu çalışmada kullanılan yüksek genlik değerleri de gelişmenin nedenlerinden biri olabilir.

Bu çalışmada kullanılan titreşimin özellikleri (40-80 Hz frekans, 3,5 mm genlik) kas iğcik uçlarını aktive etmek için yeterlidir. Anlamlı gelişmenin sağlanması kas iğciklerinin aktive edilmesiyle sağlanmış olabilir. Kas iğcik uçlarının titreşime oldukça duyarlı olduğu öne sürülmektedir (Burke ve ark., 1976). Titreşim, aynı zamanda, sinir uçlarının boşalmasını sağlayarak tonik refleks titreşimi adı verilen, refleks kasılmasını da sağlamaktadır (Eklund ve Hagbarth, 1966).

Anlamlı artış bulan daha önce yapılmış çalışmalardan bazıları maksimal dinamik egzersizlerinde titreşimin gelişmeyi sağladığını ortaya çıkarmıştır (Issurin ve Tenebaum, 1999; Issurin ve ark., 1994; Lieberman ve Issurin, 1997). Bu çalışmada 3.5 mm genliğinde 40 ile 80 Hz'lik frekanslarındaki titreşim doğrudan kasın en kalın kısmına uygulanmıştır. Yapılan önceki çalışmalarda ise biseps aktivitesi, titreşen bir kulpu kavratarak ölçülmüştür. Yani titreşim kasa doğrudan uygulanmamıştır, bu da titreşim kaynağını kavrayan elden, hedeflenen kasa gelene kadar titreşimin etkisinin azalmasına neden olabilmektedir. Böylelikle hedeflenen kasa istenilenden daha küçük genlikte bir titreşim ulaştığı söylenebilir. Titreşimdeki bu azalmaya rağmen maksimal dinamik egzersizlerinde gelişme sağlanmıştır. Aslında, 0.3 mm ve 0.4 mm genliğindeki titreşimler zaten oldukça küçüklerdir ve çalışan kaslarda daha da küçük hale gelmektedirler. Bu kadar küçük genlikli titreşimlerde bile, kas aktivitelerinde önemli gelişme sağlamaktadırlar.

Bu çalışmada 80 Hz'lik titreşim 10 dakika boyunca uygulandığında anlamlı sonuç bulunamamıştır; bu sonuç kasların uzun süre titreşime maruz kalmasından kaynaklanıyor olabilir (Konishi ve ark., 2009; Kouzaki ve ark., 2000). Bu çalışmada düşük frekans olarak 40 Hz, yüksek frekans olarak da 80 Hz belirlenmiştir. Jackson ve Turner (2003), çalışmalarında düşük frekans olarak 30 Hz, yüksek frekans olarak da 90 Hz'i tercih etmişlerdir. Genlik seviyesi de bu çalışmada kullanılan genliğin (3.5 mm) yaklaşık olarak yarısı kadardır ve 1.5 mm ile 2 mm arasındadır. Bu çalışmadan farklı olarak titreşim 30 dakikalık süre boyunca uygulanmıştır. Jackson ve Turner'in yürüttüğü çalışma, sağ rektus femoris kasına uygulanan uzun süreli titreşimin aynı tarafta bulunan bacağın izometrik MVC değerini düşürürken, karşı tarafta bulunan bacağın da izometrik değerini düşürdüğünü ortaya çıkarmıştır. Benzer bir şekilde tek bacakla yapılan başka bir çalışmada (Bongiovanni ve ark., 1990) uzun süreli titreşimin (150 Hz) aynı tarafta bulunan vücut uzuvlarının MCV ve EMG aktivitelerini azalttığı bulunmuştur. Bunlara ek olarak, uzun süreli kas tireşiminin (30 Hz) maksimal izometrik diz ekstensiyon performansını düşürdüğü saptanmıştır (Kouzaki ve ark., 2000).

İzometrik kasılmadan farklı olarak, Konishi, Kubo ve Fukudome (2009) yaptıkları çalışmada uzun süreli titreşimin (50 Hz, 1.5 mm ve 20 dk), iç ve dış merkezli kasılmalar ile diz ekstansörlerinin EMG leri üzerindeki etkisini incelemişler ve farklı sonuçlar bulmuşlardır. Titreşimin, diz ekstensiyon kuvvetinde ve vastus lateralis ile vastus medialis kaslarının konsantrik ve eksantrik kasılmalarındaki EMG değerlerinde azalmaya neden olduğu tespit edilmiştir. Daha önceki araştırmalarda da belirtildiği gibi bu sonuç, 20 dakikalık uzun titreşim süresinin kuvvet ölçümlerinde azalmaya neden olmasından kaynaklanmış olabilir.

Bu çalışmanın sonuçları, Roalents ve arkadaşları tarafından (2006) yürütülen ,direnç yükünün incelendiği bazı TVT antrenman çalışmalarıyla benzerlik göstermektedir. Araştırmacılar farklı egzersizler sırasında kuadriseps kasının EMG değerlerini ölçmüş ve TVT antrenmanının kas aktivitesini artırdığını bulmuşlardır. Rittweger ve arkadaşları (2001) tarafından yürütülen başka bir çalışmada ise titreşim antrenmanının sub-maksimal kasılma üzerindeki etkisini oksijen alımını ölçerek incelemiş ve izometrik egzersizler sırasında oksijen alınımın TVT tarafından geliştiğini bulmuşlardır.

Bu çalışmada, 40 Hz ve 80 Hz frekansındaki titreşimler farklı süreler için karşılaştırıldığında anlamlı bir fark bulunmamıştır. Düşük frekans (40 Hz), yüksek frekansa (80 Hz) göre daha iyi sonuçlar vermesine rağmen her iki frekansın oluşturduğu sonuçlar birbirinden farklı değildir. Bu çalışmada düşük frekans olarak 40 Hz, yüksek frekans olarak da 80 Hz belirlenmiştir. Jackson ve Turner (2003), çalışmalarında düşük frekans olarak 30 Hz, yüksek frekans olarak da 90 Hz ve genlik seviyesini de 1,5 mm ile 2 mm arasında belirlemişlerdir. Bu çalışmanın genlik seviyesi ise 3,5 mm'dir. Frekanslar seviyeleri arasındaki küçük fark, bu çalışmada anlamlı fark bulunmamasına neden olmuş olabilir. Önceki çalışmalar yüksek frekans değeri 100 Hz'e yaklaştıkça, katılımcılarda rahatsızlıkların oluştuğunu (Luo ve ark., 2005), 20 Hz lik frekansın da kasları aktive etmek için yeterli olmadığını ortaya koymuştur (Samuelson ve ark., 1989).

Sonuç ve Öneriler

Lokal titreşim uygulanan kuvvet değerleri, titreşimsiz kuvvet değerlerine göre anlamlı derecede yüksek bulunmuştur. 40 ve 80 Hz arasında ise anlamlı bir fark bulunmamıştır. Titreşim ile ilgili yapılacak çalışmalar çekiciliğini korumaktadır. Bu alanda, İzometrik ve izotonik kuvvet ölçümlerinin birlikte değerlendirileceği çalışmalar yapılması önerilmektedir. Bu çalışmada belirli süreler ve frekanslar kullanılmıştır; sonraki çalışmalarda farklı genliklerin de uygulanması literatüreyeni bilgiler sağlayacaktır. 15 Hentbol oyuncusuyla gerçekleştirilen bu çalışmanın daha farklı spor branşlarında daha geniş örneklemlere uygulanarak tekrarlanması önerilmektedir.

Appendix E: Curriculum Vitae

CURRICULUM VITAE

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Telephone (office)	+90 (312) 210 38 35
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E-mail	yahmet@metu.edu.tr
Date of Birth	June 25th, 1976
Place of Birth	Saray/Konya
Marital Status	Single
Nationality	Turkish
Current Occupation	Research Assistant

Research interests:

Shoulder strength and throwing velocity in handball

Vibration and posture

Isokinetic leg strength, lactate threshold, and anthropometric measures of football players

Endurance level, leg and back strength and other physical features of American football players

Physical activity level of students

Formal Education:

2004 - present	PhD. at Middle East Technical University - Physical Education and Sports Department
2000 - 2003	M.S. at Middle East Technical University - Physical Education and Sports Department
1996 - 2000	B.S. at Middle East Technical University - Physical Education and Sports Department
1995 - 1996	Preparatory at Middle East Technical University – Basic English Dept.

Languages:

Turkish	Native
English	Fluent

Professional Experience:

2001 - present	Middle East Technical University, Research Assistant
1996 - present	Middle East Technical University, Handball Team Coach
2004 - present	Middle East Technical University, Squash Coach
2004 - 2005	Çankaya Sports Club, Handball Team Coach
2000 - 2002	Ankaragücü Sports Club, Handball Team Coach

Professional Activities and Qualifications:

2007	3rd Level Coaching Certificate by the Turkish Handball Federation, Directorate General of Youth and Sports
2007	Squash Coaching Certificate by the Turkish Badminton Federation, Directorate General of Youth and Sports
2005 - 2006	Member of Turkish Handball Federation Technical Council
2001	First Aid Certificate by the Turkish Red Crescent
2001	First Aid Educator Certificate by the Turkish Red Crescent
1999	Tennis Referee Certificate by the Turkish Tennis Federation, Directorate General of Youth and Sports

Teaching Experience:

Undergraduate Courses

4530314	Handball
4530330	First Aid

Computer Skills:

Microsoft Office	All Microsoft Office applications
Program and Software	SPSS MasterScreen CPX gas analyzer Software Biodex isokinetic system, Advantage Software Rev. 3.27

Publications:

Papers Published in Refereed International Journals:

Tansel, R.B., Salcı, Y., **Yıldırım, A.,** Koçak, S., & Korkusuz, F. (2008). Effects of eccentric hamstring strength training on lower extremity strength of 10–12 year old male basketball players. Isokinetics and Exercise Science, 16(2), 81-85.

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International Congress and Presentations:

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Yıldırım, A., & Çiçek, Ş. (2002). Öğretmenlik uygulaması yapan aday beden eğitimi öğretmenlerinin derslerindeki akademik öğrenme süreleri. 7th International Sport Science Congress, October, 27-29, Antalya, Turkey.