©Journal of Sports Science and Medicine (2004) **3,** 16-22
http://www.jssm.org

Research article

THE INFLUENCE OF VIBRATION ON MUSCLE ACTIVATION AND RATE OF FORCE DEVELOPMENT DURING MAXIMAL ISOMETRIC CONTRACTIONS

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Received: 25 April 2003 / Accepted: 04 December 2003 / Published (online): 01 March 2004

ABSTRACT

At present there appears to be a need for research conducted on the effects of vibration on the contractile ability of skeletal muscle tissue. The aim of this study was to address this issue by examining the effects of a superimposed muscle/tendon vibration at 50.42±1.16 Hz (acceleration 13.24 ± 0.18ms^{-2}: displacement ≈5mm) on muscular activation and maximal isometric contraction. Sixteen participants with a mean age, body mass, and height of 22 ± 4.4 years, 73.2 ± 11.7 kg and 173.1 ± 9.7 cms, respectively, were recruited for this study. Electromyography and accelerometry from the rectus femoris, and maximal isometric force data characteristics were collected from the dominant limb under conditions of vibration, and no-vibration. A superimposed 50 Hz vibration was used during the contraction phase for the maximal isometric leg extension for the condition of vibration. A one-way ANOVA revealed no significant ($p > 0.05$) differences between the vibration and no-vibration conditions for peak normalized EMG_{RMS} (84.74% Vs 88.1%) values. An ANOVA revealed significant ($p > 0.05$) differences between the peak fundamental frequencies of the FFT between the conditions vibration (27.1 ± 12.2 Hz) and no-vibration (9.8 ± 3.5 Hz). 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 were not significantly different. The results of this study suggest that the application of vibration stimulation at 50 Hz during the contraction does not contribute to muscle activation, or enhance force production for maximal isometric contractions.

KEY WORDS: Strength, oscillations, isometric, peak, muscle activation

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INTRODUCTION

The study of vibration involves both linear and nonlinear oscillatory motions of bodies and the accompanying forces that result. External vibrations are classified as either whole body vibrations (WBV) or, site specific vibrations such as hand arm vibrations (HAV). The application of a vibratory stimulation to the human body or a specific limb increases the normal acceleration of the mass to the excitation frequency of the source resulting in an increase in force and a change in performance. When the frequency of excitation coincides with one of the natural frequencies of the system being vibrated then a condition of resonance is encountered and large oscillations may result causing damage to the system (Griffin, 1996).

Mechanical vibration is a source of stimulation that the human body is exposed to during everyday living activities. The source of this vibration may vary from vehicles of transportation such as trains, automobiles, planes and even spacecraft, to tools of work such as chainsaws, hammers and grinders (Griffin, 1996). Every material known to man vibrates at its own natural frequency (Giancoli, 1998). Biological material is no different, and muscle tissue has also been shown to vibrate at specific frequencies while at rest and contracting (Barry and Cole, 1990). Studies applying vibration to muscles have been shown to improve muscular strength and power development (Johnston et al., 1970; Samuelson et al., 1989; Issurin et al., 1994; Issurin and Tenenbaum, 1999; Warman et al., 2002), improve movement of neuromuscular deficient patients (Hagbarth and Eklund, 1966), improve kinaesthetic awareness (Burke et al., 1996), prevent bone loss (Flieger et al., 1998) and provide insights into the effects of fatigue (Herzog et al., 1994; Gabriel et al., 2002).

The research examining isometric strength development is even less understood with contrasting results appearing in the literature. The mixed results reported may result from the transmissibility of a vibration signal applied at the skin surface directly to the muscle/tendon unit or through WBV. The transmissibility of the vibration signal is dependent on muscle length and joint torque, likewise the signal application in relation to joint position can also affect the end frequency of vibration (Griffin, 1996; Wakeling and Nigg, 2001). The research utilising the direct application of a vibration signal at the surface of the muscle/tendon unit without concern of the joint position has demonstrated more comparable results. Studies conducted by Bosco and colleagues (1999a) on vibration and isometric strength development revealed significant improvements in power output during an arm extension exercise at near full extension with a 30 Hz vibration frequency. Bosco and colleagues (1999b), and Gabriel and colleagues (2002) have also reported a 10% isometric strength gain at joint angles of 170 degrees and 90 degrees, respectively. These data sets were also accompanied by mean changes in peak to peak electromyography (EMG) activity as a result of vibration at frequencies of 30 and 60 Hz, respectively. Changes accompanying vibration treatments have been suggested to be due to an increase in neuromuscular activity. However, not all studies have collected EMG and so these inferences may not be supported by the current data.

Investigations conducted by Rittweger and associates (2000) discovered a reduction in force output for an isometric leg extension at 90 degree knee angle and EMG median frequency after the effects of a 26 Hz WBV treatment. Likewise, Torvinen and associates (2001) also found no change in isometric leg strength at 90 degree knee angle, vertical jump height and grip strength after four minutes of incrementing 25 to 40 Hz WBV treatments. They further found no change in the mean power frequency and root mean square EMG activity for the soleus and decreases in the mean power frequency EMG for the vastus lateralis and gluteus medius muscles. Research by De Ruiter and colleagues (2003) also report no change in isometric leg strength at 110 degree knee angle or rate of force development as a result of a 30 Hz WBV frequency.

At present there appears to be a need for research on the effects of vibration on the contractile ability of skeletal muscle tissue. The aim of this study was to address this issue by examining the effects of a direct superimposed muscle/tendon vibration at 50 Hz on isometric strength characteristics and muscular activation during an isometric leg extension task. In examining the peak force, and rate of force development, along with simultaneous EMG data collection, this study provides information on the effects of vibration stimulation on isometric strength and the underlying neural activation of the musculature. The significance of this study is that it may provide substantial information on enhancing muscular strength and therefore further development of strength and power adaptations during athletic training. This knowledge also has applications in the treatment of neuromuscular disorders, muscular atrophy and rehabilitation.

METHODS

Subjects

Sixteen participants were recruited from the Central Queensland University and local communities. Prior to participation in the study each individual was advised on the procedures and requirements for the study and then completed and signed an informed consent document. Each participant was also asked to complete a pre-activity readiness questionnaire to screen for any neuromuscular disorders that may have excluded them from the study. Central Queensland University Human Ethics Committee gave approval for the experimentation.

Vibratory stimulation

A four kilowatt, three phase electrical induction motor (TECO Co. Ltd., Taiwan) running at 2870rpm (50 Hz) was directly coupled to a two cylinder air conditioning compressor with exposed piston faces driven by an offset cam (Motorcraft, Australia). A velcro strap was wrapped firmly around the participant's upper thigh and clear of the EMG electrodes and accelerometer collecting from rectus femoris (RF). A connecting velcro strap was anchored at one end to the face of the piston, while the other was attached to the participant's thigh to transfer vibration to the leg, see Figure 1. The output of a triaxial accelerometer was recorded by an AMLAB computer (Associative Measurement, Sydney, Australia) sampling at 1000 Hz. The data was analysed via FFT collecting 1024 data points in the last second of a five second period. Results of this collection confirmed that the system was delivering 50.42 ± 1.16 Hz at an acceleration of $13.24 \pm 0.18 \text{ms}^{-2}$ with an approximate displacement of 5.0 mm.

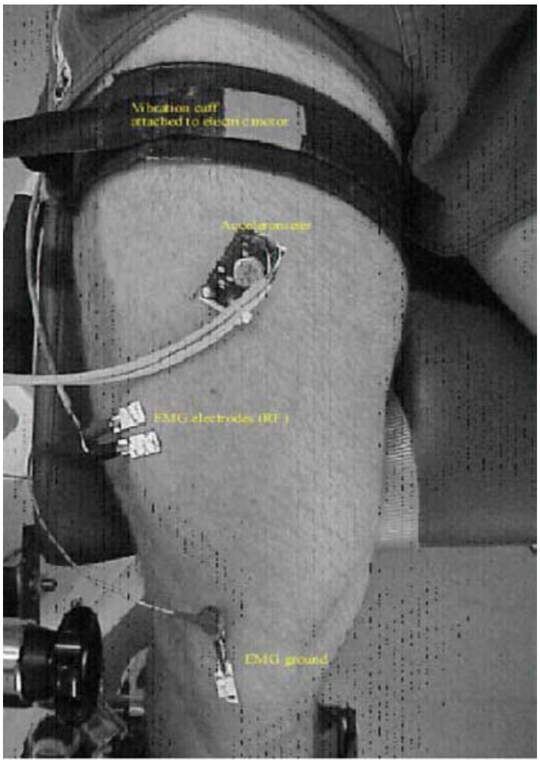

Figure 1. Experimental setup of the EMG placement, accelerometer, and vibration cuff.

Mechanical force measurements and analysis

Peak isometric force (N) was recorded via a load cell (Scale Components, Brisbane, Australia) anchored to the laboratory wall and attached to a cuff designed to slide onto the lower leg of the participant. Data collection was achieved via an AMLAB computer sampling at 1000 Hz for a period of five seconds. Subsequent post analysis processing was performed using custom written software developed within the Visual Basic (version 6, Microsoft Corporation, Redmond WA) programming environment. To determine all isometric force characteristics peak values of the full five second isometric contraction were established, and RFD times at 0.05, 0.01, 0.1, and 0.5 s, and RFD at 50, 75, and 90% of peak force were calculated following the methods of Hakkinen et al., (1998). The calculation of the force data characteristics follow a standard technique used to calculate RFD values based on the first derivative of the force-time curve. The times selected also provide a continuum of values between the early (0-200 ms) and late phase (200-500 ms) of muscle contraction to highlight the accelerative and functional qualities of the muscle.

Electromyographic (EMG) data collection and analysis

The EMG signals were collected from RF muscle via silver/silver chloride (Ag/Ag Cl) surface electrodes (10mm x 30mm) (3M red dot, 3M Health Care, St.Paul, USA) with an interelectrode edge to edge distance of 5mm. Electrodes for RF were positioned on the lateral side of the pennation, 190mm proximal to the tip of the patella along the mid-line of the thigh. Electrodes were positioned as to perpendicularly dissect the fibers. A reference electrode was placed on the patella of the participant's involved limb. Prior to application the electrical impedance of the skin at the site of electrode placement was minimized using standard skin preparation techniques. All EMG cables were fastened and supported to reduce any movement artifact. Data collection was achieved via an AMLAB computer sampling at 1000 Hz for a period of five seconds. Synchronisation of EMG and force data collection was achieved via a software trigger set at 30 N of force for the isometric contractions. The EMG signals were digitally filtered with a bi-directional, band-pass, fourth-order, Butterworth filter, with a frequency between 50-350 Hz. This range was determined, using a power spectrum density analysis of the signals, so that this filter cut-off preserved the integrity of the signal while eliminating much of the electrical noise generated by the electronics of the motor (≈ 50 Hz). Custom written software developed within the Visual Basic (version 6.0, Microsoft Corporation, Redmond WA) programming environment converted the amplified raw EMG signal to a root mean square signal after transformation. Peak EMG_{RMS} signals were normalized and expressed as a ratio of a resting value so the average (mV) at rest (no contraction) value was divided by the peak (mV) values for the maximal trials of the vibration or no-vibration trials. The resting value recorded in the testing position was chosen as a precaution due to the 2 hour time frame between vibration and no-vibration testing conditions. Also the resting value does not change drastically, as a maximal contraction can change due to learning, motivation, and novelty in the case of an added vibration treatment to a contraction.

Experimental protocol

Participants completed two full familiarization sessions fourteen and seven days prior to the collection of all data to ensure that they were comfortable with the testing procedures. All participants performed a standardized warm-up incorporating five minutes on a cycle ergometer (Monark, Varberg, Sweden) at 60 W, followed by two minutes of static stretching of the quadriceps and hamstring muscle groups of the dominant leg (as determined by kicking preference). Participants were then asked to perform a series of graduated sub-maximal and near maximal contractions as part of the warm-up procedure. All participants performed two testing protocols separated by a two-hour rest period. Participants randomly performed either: a maximal isometric contraction under vibration or under no-vibration, see Figure 2 for a representative trial of this data. Participants were positioned in a dynamometer chair with straps anchored across the chest and waist. A cuff anchored to the laboratory wall was placed on the lower leg of the participant and adjusted such that the knee, whist performing knee extension, was held in a position of 120° flexion (Marcora and Miller, 2000).

Each participant initially performed a normal isometric contraction to establish peak isometric force and muscle activation for the test session. Force data from this initial contraction was compared with that collected in the final familiarization session to establish the reliability of the measure using intra-class correlation (ICC) and technical error of measurement percentage (TEM%) calculations. The peak MVC of the familiarization trial on day seven and the peak MVC trial on the day of the testing produced an ICC = 0.88 and TEM% = 7.74%, respectively.

Statistical analysis

Mean ± standard deviation data was presented for all subject characteristics. Statistical analysis involved a one-way analysis of variance (ANOVA) comparing vibration and no-vibration conditions for peak isometric force, peak normalized EMG_{RMS}, and peak rate of force development, rate of force development at times 0.05, 0.01, 0.1, and 0.5 s, and rate of force development at 50, 75, or 90% of peak force. Statistical significance was accepted at or below 0.05.

RESULTS

The mean age, body mass and height of participants was 22 ± 4.4 years, 73.2 ± 11.7 kg and 173.1 ± 9.7 cms, respectively. A one-way ANOVA revealed no significant differences between the values for peak isometric force for the condition of vibration (580.8 ± 163.5 N) or the condition of no vibration (493.1 ± 163.9 N). Similarly, no differences were found between the rate of force development times and the percentages of peak force, see Table 1.

A one-way ANOVA revealed no significant differences between the values for peak normalized EMG_{RMS} (84.74% Vs 88.1%) between the conditions of vibration and no-vibration for the isometric leg extension, respectively.

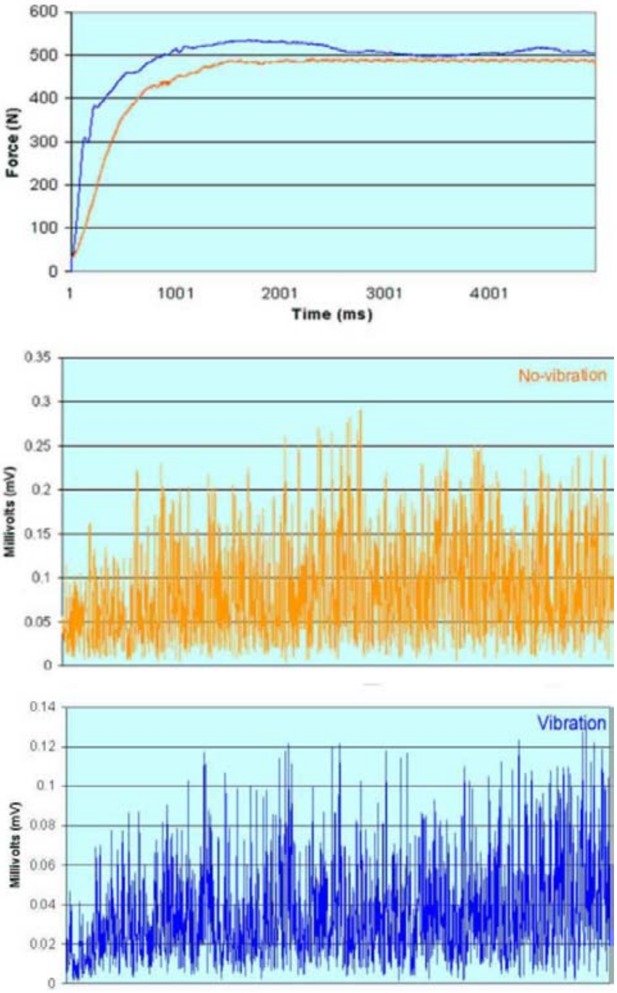

Figure 2. Representative data for isometric force trace and raw EMG for the conditions of vibration and no-vibration.

DISCUSSION

The present research agrees with previous research that has shown no improvement in isometric force or rate of force development characteristics as a result of a vibration treatment. This study found no significant changes to peak isometric force, peak rate of force development, rate of force development at times 0.05, 0.01, 0.1, 0.5 s, and rate of force development at 50, 75, and 90% of peak force, or peak normalized EMG_{RMS} values as a result of a superimposed 50 Hz vibration treatment.

Table 1. Mean (SD) values for isometric force data for subjects exposed to conditions of vibration and no vibration.

	Peak Force (N)	Time Peak (s)	Time 50% (s)	Time 75% (s)	Time 90% (s)	RFD 0.01 s ($N\cdot s^{-1}$)	RFD 0.05 s ($N.s^{-1}$)	RFD 0.1 s ($N\cdot s^{-1}$)	RFD 0.5 s ($N\cdot s^{-1}$)
Vibration	581	2.5	.22	.46	.95	983	1349	1525	913
	(164)	(1.2)	(.08)	(.21)	(.43)	(948)	(301)	(1007)	(269)
No-vibration	493	2.3	.18	.49	1.1	658	1240	1620	786
	(164)	(1.2)	(.13)	(.48)	(.90)	(383)	(301)	(970)	(258)

The present study found no significant trends towards improvements in peak isometric strength and rate of force development characteristics. The results of the present study are in agreement with research performed twenty plus years prior (Johnston et al., 1970; Samuleson et al., 1989) as well as with more recent research (Gabriel et al., 2002; Torvinen et al., 2002; Warman et al., 2002; De Ruiter et al., 2003), who have all demonstrated no change in isometric force or force characteristics as a result of vibration.

Johnston and colleagues (1970) reported on the response of isometric force output from an array of various muscles after vibration treatments. These authors reported that the muscle response was linked to muscle architecture, with the muscles attached via long thin tendons displaying a better response to stimulation, while muscles such as the rectus femoris were the least responsive. These investigators also implied that the elastic and viscous properties of the muscle also played a role in force response to vibration stimulation. Barry and Cole (1990) support the idea that a material's properties would have an effect on its responsiveness to vibration stimulation. This may explain in part the lack of response seen in the present study for the isometric contraction. However, it does not account for the substantial improvements seen for the concentric isotonic contractions involving the exact same musculature as seen in other studies.

Another explanation for the lack of change in isometric force in the present study may reside in the muscle length tension relationship that is developed in the muscle during vibration (Samuelson et al., 1989; Issurin and Tenenbaum, 1999). The basis of this implied relationship is that the longer the muscle and the greater the tension it is under, the greater the response will be to vibration stimulation. Issurin and Tenenbaum (1999) contend that the work by Samuelson and associates (1989) was not unsuccessful in finding isometric force improvements due to the positioning of the participant's knee at an angle of 90 degrees of flexion. Similarly, work by Torvinen and colleagues (2002), and Rittweiger and colleagues (2000) also reported no improvements in isometric force after vibration treatments using the same knee angle. In considering the length tension relationship these authors suggest that vibration stimulation applied to the muscle occurred when the muscle was not undergoing stretch. In conflict with this suggestion, with the knee flexed at 90 degrees, the rectus femoris muscle is at considerable stretch as it inserts through the patella tendon onto the shaft of the tibia. The present study examined an isometric contraction with applied vibration at 120 degrees knee flexion to maximise the limb's greatest mechanical advantage. Research by Warman and associates (2002) also used a similar knee angle and found no change in isometric force after vibration treatments. The lack of significant results evident in studies using knee angles at 90 and 120 degrees of flexion, and other studiesusing isotonic contractions cannot be explained by this suggested length/tension relationship. Future research needs to be completed across an array of vibration intensities involving a range of knee joint angles with the inclusion of a musculo-tendinous stiffness measure to determine the effect of position and vibration frequency on isometric muscle contraction.

Previous research has also implied that the frequency of the vibration used by other investigators may have been the reason behind the varying results being recorded across studies (Issurin and Tenenbaum, 1999). However, both significant and non significant results abound in the literature across a wide range of vibration frequencies (Griffin, 1996; Issurin and Tenenbaum, 1999; Torniven et al., 2002). In addition, research by Warman and associates (2002) found significant improvements in isotonic force but no improvements in isokinetic torque or isometric force after subjects received the same 50 Hz vibration frequency. The reasoning that vibration frequency was responsible for the results reported in the current research does not adequately explain the lack of significant results.

One possible explanation for the lack of significant results reported in the present study and those from other researchers may reside in the contraction velocity. The contraction velocity of an isometric contraction is limited via the testing protocol. Studies using multiple contraction modes and contractions that are not velocity constrained have shown improvements in force (Issurin and

Tenenbaum, 1999; Warman et al., 2002). The underlying mechanism/s behind the improvements witnessed in strength performances may rely on an individual optimal contraction velocity. Support for this explanation may be found in the recent studies reporting significant improvements in isotonic strength measures (Samuelson et al., 1989; Bosco et al., 1999a; Bosco et al., 1999b; Issurin and Tenenbaum, 1999). Each of these studies has examined isotonic contractions, with the participant contracting as hard and fast as possible, thereby having complete control over the contraction velocity. It is therefore possible that a mechanism other than the length tension relationship or the vibration frequency play a role in the improvements of muscle force. The selection of contraction velocity may provide answers as to the possible variation that is emerging in this developing field of research. Another plausible explanation for the differing responses between these studies may reside in the sample populations selected.

Caution is warranted in the interpretation of the above results due to the large variability in the performance of the MVC of the leg extension exercise. A retrospective analysis of the statistical power based on the results of this study would indicate that the effect size (ES) for the RFD times ranged between 0.1- 0.6 (Cohen, 1988). Since the magnitude of change under the vibration condition appears to be of practical significance, there are not enough subjects to compensate for the variability observed in this study.

CONCLUSIONS

The results of this study suggest that the application of vibration stimulation at 50 Hz during the contraction does not contribute to muscle activation, or enhance force production for maximal isometric contractions. Further enhanced knowledge of the effects of vibration on skeletal muscle tissue may have significant implications for force development, strength assessment and rehabilitation programs.

REFERENCES

Barry, D.T. and Cole, N.M. (1990) Muscle sounds are emitted at the resonant frequencies of skeletal muscle. *IEEE Transactions on Biomedical Engineering* **37**, 525-31.

Bosco, C., Cardinale, M. and Tsarpela, O. (1999a) Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *European Journal of Applied Physiology* **79**, 306-11.

Bosco, C., Colli, R., Cardinale, M., Tsarpela, O., Madella, A., Tihanyi, J. and Viru, A. (1999b) Adaptive responses of human skeletal muscle to vibration exposure. *Clinical Physiology* **19**, 183-7.

Burke, J.R., Schutten, M.C., Koceja, D.M. and Kamen, G. (1966) Age-dependant effects of muscle vibration and the Jendrassik maneuver on the patellar tendon reflex response. *Archives of Physical Medicine and Rehabilitation* **77**, 600-4.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). New Jersey: Lawrence Erlbaum

De Ruiter, C.J., Van Der Linden, R.M., Van Der Zijden, M.J., Hollander, A.P. and De Hann, A. (2003) Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. *European Joural of Apllied Physiology* **88(4-5)**, 472-475.

Flieger, J., Karachalios, T., Khaldi, L., Raptou, P. and Lyritis, G. (1998) Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcified Tissue International* **63(6)**, 510-514.

Gabriel, D.A., Basford, J.R., and An, Kai-Nan. (2002) vibratory facilitation of strength in fatigued muscle. *Archives of physical Medicine and Rehabilitation* **83**, 1202-1205.

Giancoli, D. C. (1998) *Physics: Principles with Applications*. (5 ed.). New Jersey: Prentice-Hall International.

Griffin, M.J. (1996) *Handbook of Human Vibration*. San Diego: Academic Press.

Hagbarth, K.E. and Eklund, G. (1966) Tonic vibration reflexes in spasticity. *Brain Research* **2**, 201-203.

Hakkinen, K., Newton, R.U., Gordon, S.E., McCormick, M., Volek, J.S., Nindl, B.C., Gotshalk, L.A., Campbell, W.W., Evans, W.J., Hakkinen, A., Humphries, B.J. and Kraemer, W.J. (1998) Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *The Journal of Gerontology: Biological Sciences* **53(6)**, B415-23.

Herzog, W. Zhang, Y.T., Vaz, M., Guimaraes, A.C.S. and Janssen, C. (1999) Assessment of muscular fatigue using vibromyography. *Muscle and Nerve* **17**, 1156-1161.

Issurin, V.B. and Tenenbaum, G. (1999) Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *Journal of Sports Sciences* **17**, 177-82.

Issurin, V.B., Liebermann, D.G. and Tenenbaum, G. (1994) Effect of vibratory stimulation training on maximal force and flexibility. *Journal of Sports Sciences* **12**, 561-6.

Johnston, R. M., Bishop, B. and Coffey, G. H. (1970) Mechanical vibration of skeletal muscles. Physical Therapy **50(4)**, 499-505.

Marcora, S. and Miller, M.K. (2000) The effect of knee angle on the external validity of isometric measures of lower body neuromuscular function. *Journal of Sports Sciences* **18(5)**, 313-319.

Rittweger, J., Beller, G. and Felsenberg, D. (2000) Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clinical Physiology* **20**, 134-42.

Samuelson, B., Jorfeldt, L. and Ahlborg, B. (1989) Influence of vibration on endurance of maximal isometric contraction. *Clinical Physiology* **9**, 21-25.

Torvinen, S., Sievänen, H., Järvinen, T.A.H., Pasanen, M., Kontulainen, S. and Kannus, P. (2002) Effect of 4-min vertical whole body vibration on muscle performance and body balance: A randomized cross-over study. *International Journal of Sports Medicine* **23**, 374-379.

Wakeling, J.M. and Nigg, B.M. (2001) Soft-tissue vibrations in the quadriceps measured with skin mounted transducers. *Journal of Biomechanics* **34**, 539-543.

Warman, G., Humphries, B. and Purton, J (2002) The effects of timing and application of vibration on muscular contractions. *Aviation Space and Environmental Medicine* **73(2)**, 119-27, 2002.

KEY POINTS

- The application of a vibratory stimulation to the human body increases the normal acceleration resulting in an increase in force and a change in performance
- This study was to address this issue by examining the effects of a direct superimposed muscle/tendon vibration at 50 Hz on isometric strength characteristics
- No improvement or change in isometric force or rate of force development
- No changes to peak normalized EMG_{RMS} values

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