The influence of vibration on maximal torque generation

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Introduction

Mechanical vibration is a stimulation that the human body must endure as part of everyday activity. 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 (5). Research into the effects of vibration on biological tissue is by no means new, with studies extending back to the mid 1960's examining the response of human reflexes to vibratory stimulation (4). From that point, extensive work has, and is still being conducted in the fields of occupational health and safety (8) and ergonomics (15). However, it has taken until the mid 1990's for study of the application of vibratory stimulation in strength development to begin'(6).

Research conducted by Bosco and colleagues (3) on vibration and strength development revealed significant improvements in power output during a leg press exercise. Conversely, an investigation conducted by Rittweger and associates (12) discovered a reduction in force output for an isometric leg extension and EMG median frequency. Further study conducted by Issurin and Tenenbaum (7) examined explosive strength while vibration was applied during a bicep curl. This study found substantial improvements in maximum power in the vicinity of 30%. Each of these investigators implied that the improvements realised were due to an increase in neuromuscular activity. However, the lack of EMG data collected, means that these inferences cannot be supported by data. Research conducted by Bosco and associates (2) also found improvements of around 13% in a bicep curl performed during vibration treatment. However, this study also noted a significant increase in electromyography-root mean square analysis (EMG_{RMS}) during the lifts. With this added information, the suggestion of improved muscular activation gains some support from experimental data.

Statement of the Problem

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 is to address this issue by examining the effects of a superimposed vibration at 50 Hz on muscular activation and torque for a concentric isotonic contraction. In examining the torque developed along with simultaneous EMG data collection, this study will provide information on the effects of vibration stimulation on muscular force production supported by 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.

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Methods

Subjects: Twenty-eight participants (9 females) were recruited with basic anthropometric and strength characteristics as follows: (mean ± SD) age 22.8 ± 5.6yrs, height 174.1 ± 8.8cm, body mass 78.0 ± 13.6kg and (mean ± SE) peak concentric isotonic leg extension 170.36 ± 9.01Nm. Participant's were advised on the procedures and requirements then completed an informed consent document, and asked to complete a pre-activity readiness questionnaire to screen for any neuromuscular disorders that may have excluded them from the study.

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, proximal and clear of the EMG electrodes and accelerometer collecting from Rectus Femoris (RF). A connecting velcro strap was anchored to the face of the piston, while the other was attached to the participant's thigh transferring vibration to the leg. A series of trials were conducted to establish the vibration transferred to the participant's leg. The output of a triaxial accelerometer, adjacent to the velcro anchor on the skin of the participant's involved leg, was recorded by an AMLAB computer (Associative Measurement, Sydney, Australia) sampling at 1000 Hz. The data was analysed via Fast Fourier Transform (FFT) collecting 1024 data points in the last second of a five second period. This data confirmed that the system was delivering 50.42 ± 1.16 Hz at 13.24 ± 0.18ms^{-2}.

Torque measurements: Peak concentric isotonic torque (Nm) was controlled by a Biodex System 3 Isokinetic Dynamometer (Shirley, New York, USA). Torque data was recorded as a single figure for each successfully completed lift. Further calculations were conducted on the data collected to express the peak values for torque as a percentage of the initial normal peak contraction.

Electromyographic (EMG) Data Collection and Analysis: EMG signals were collected from RF via silver/silver chloride (Ag/Ag Cl) surface electrodes (10mm x 30mm) (3M red dot, 3M Health Care, St.Paul, USA) with an interelectrode 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 and positioned as to perpendicularly dissect the fibres of the muscle. A reference electrode was placed on the patella of the participant's involved limb. Preparation of the skin involved removal of any hair and excess dead skin cells, and subsequent cleaning with an alcohol swab. Data collection was achieved via an AMLAB computer sampling at 1000 Hz. Synchronisation of EMG with the VMG data collection was achieved via a proximity switch (RS Components, Brisbane, Australia) aimed at the armature of the dynamometer. The raw signal was analysed using root mean square (RMS) calculations.

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Vibromyographic (VMG) Data Collection and Analysis: The VMG signal was collected from RF via a triaxial accelerometer (Applied Measurement, Victoria, Australia), positioned medially, directly opposite the RF EMG electrodes, affixed to the skin by doubled-sided tape and held there with sports tape. Corresponding with the EMG signal examination, the raw VMG signal for each contraction type was analysed using RMS calculations.

Experimental Protocol: Participants completed three familiarisation sessions across a period of seven days to ensure that they were comfortable with testing procedures, establish maximal concentric isotonic leg extension and remove any learning effect that may have biased the results. Prior to each familiarization and test sessions, participants performed a standardised 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 then performed a set of three near peak contractions to complete the warm-up. Each individual received a standardised set of instructions and motivation both prior and throughout test sessions. The results of each contraction were not revealed to the participants until all test sessions were completed to limit any extrinsic form of motivation.

Participants were positioned in the dynamometer and firmly held by straps across the chest and waist to limit extraneous body movement. The armature of the dynamometer was positioned such that the axis of motion at the knee joint was aligned with the shaft of the dynamometer. Range of motion of knee extension was set from 90 to 180∞ knee flexion. A successful lift was achieved only if the participant was able to reach that end of range. Peak concentric isotonic torque and muscle activation for the test session was initially established by following a protocol similar to that followed to establish a 1RM lift. The torque data collected during this initial contraction was compared with that collected in the final familiarisation session to establish the reliability of the measure using intra-class correlation (ICC) and technical error of measurement percentage (TEM%) calculations. The peak of repeated trials produced an intraclass correlation (ICC) = 0.99 and TEM% = 6.44%, respectively. After the normal contraction, participants were then asked to perform three more contractions under the following conditions:

Vibration treatment applied before contraction (Pre): A 30 second vibration treatment was applied to the participant's dominant leg with a contraction performed immediately afterward.

Vibration treatment applied during contraction (During): Participants had their leg vibrated whilst they performed the contraction.

Contraction performed after a vibration treatment (Post): Participants had their leg vibrated for 30 seconds, then were given a three minute rest period prior to performing a contraction. This condition aimed to examine any residual effect of the treatment.

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Test conditions were administered in a randomised fashion separated by a three to five minute rest period to minimise any ordered effect and muscular fatigue.

Statistical Ananlysis

The raw data collected for each parameter was calculated and analysed as a percentage difference from the initial normal contraction in the individual test session. Statistical analysis involved using a one-way analysis of variance calculation (ANOVA) comparing the EMG, VMG and torque data calculated for each condition. Tukey post hoc tests were conducted to establish the location of any significant differences, with statistical significance accepted at or below .05.

Results

Torque: A one-way ANOVA conducted on the torque data revealed significant improvements between the normal contraction and the contractions with a vibration stimulation ($F(3,108) = 9.929$, $p < .05$). Tukey post hoc analysis highlighted significant improvements of $14.7 \pm 2.9\%$ for the during condition and $15.3 \pm 3.1\%$ for the post condition.

EMG: ANOVA analysis conducted on the EMG data collected presented significant differences between the normal contraction and the experimental conditions. Mean activation of RF of $107.1 \pm 44.4\%$ ($F(3,106) = 5.722$, $p < .05$) for the during condition was recorded.

VMG: An ANOVA performed on the VMG data collected revealed a significant difference between the normal contraction and the experimental conditions for mean VMG activity of $-4.1 \pm 1.7\%$ ($F(3,108) = 5.079$, $p < .05$) during vibration stimulation.

Discussion

Statistically significant ($p < .05$) improvements were recorded for peak concentric isotonic strength both during and three minutes after an applied vibration. Concurrent monitoring of muscular activation also exposed a significant improvement in mean activation of RF for concentric isotonic contractions performed during the vibration stimulation. While synchronous measurement of VMG activity of the RF revealed significant decreases in mean activity for concentric isotonic contractions performed during the applied vibration.

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The significant improvements witnessed in the present study for the concentric isotonic contractions both during and post the applied vibration has support in the recent literature examining the effects of stimulation on strength (2, 3, 7). To explain this improvement in force output, one must also consider the simultaneous neuromuscular activity occurring. The application of a vibration to skeletal muscle has been suggested to elicit an excitatory inflow of motorneuron activity via muscle spindle-a-motorneurone interaction (15). Further, it has been shown that vibration stimulation drives a-motorneurones via a Ia neuron loop producing force without input from the central nervous system (13). Martin and Park (9) imply that this tonic vibration reflex (TVR) operates predominately via a-motorneurones and does not use the same cortically originating efferent neural pathways as does voluntary contractions. However, enhancement of voluntary pathways via vibration stimulation cannot be dismissed (2), especially when concurrent collection of EMG data has been achieved. This suggestion has support from the present study. An examination of the EMG data collected during contractions while the vibration treatment was applied reveals significant improvements in mean activation of the RF. These results indicate that the applied vibration induced significantly more neural activation of the muscles, suggesting that more motor units were activated, therefore more muscle fibres were recruited and a greater force produced. Siggelkow and associates (14) also suggest that additional mechanisms mediated by dynamic mechanoreceptors may also be involved along with other skin receptors possibly activated by the applied vibration. Establishing the possible additional effects of these mechanisms were outside the scope of the present study, and would definitely warrant further investigation.

The improvements in concentric isotonic contraction realised post the vibration treatment is not as easily explained. With the EMG data suggesting that neural activity had almost returned to the levels recorded in the initial contraction. Bosco and colleagues (2) also found improvements in isotonic contraction post a vibration treatment with a concurrent decrease in EMG activity. The investigators suggest that a possible cause for this was an increase in neuromuscular efficiency. A further suggestion for this response is localised vasodilation increasing muscle operating temperature. This suggestion has support from more recent work conducted on the use of vibration treatment during exercise by Rittweger and associates (12), who reported similar vasodilatory effects after exposure to vibration. These factors imply that an applied vibration may act as a facilitator to muscle warm-up prior to exercise, or recovery from fatiguing exercise, by encouraging blood flow with the possible enhancement of metabolite delivery and waste product removal. Whilst outside of the scope of the present study, anecdotal evidence collected from participants suggested that the vibration treatment enhanced localised blood flow, and raised the temperature of the involved musculature. This provides another area for future research in the field of vibration and strength development.

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A factor that separates the present study from those conducted recently on strength development, is the inclusion of synchronous collection of VMG data from the contracting muscle. The exact mechanism for the production of vibrations by the muscles while contracting is not yet fully understood. Some authors suggest that muscular vibrations are the result of cross-bridge cycling during contraction (1), while others imply that is due to the gross lateral expansion of the muscle tissue as it contracts and shortens (11). Previous research into VMG has implied that it is a technique examining the mechanical response of a muscle fibre to contraction as opposed to the electrical properties of contraction determined by EMG, with the resultant information, being a more reliable indicator of absolute force production (10, 11). Research conducted by Matheson and associates (10) examined the EMG and VMG relationship to force production. The investigators examined the EMG_{RMS} and vibromyography (root mean square analysis) (VMG_{RMS}) response over increments of 20 to 100% maximal voluntary contraction (MVC), and found that the VMG_{RMS} response increased in a linear fashion up to approximately 80% MVC. Beyond that point the relationship curve fell significantly to where at 100% MVC the VMG_{RMS} signal resembled that recorded at approximately 50% MVC. The investigators suggested a possible explanation for this response was due to wave summation occurring around that point. At approximately 80% MVC and beyond, single motor unit twitches fuse into subsequent tetany, possibly producing a lower vibration signal. The present study recorded similar results with significant decreases in VMG_{RMS} signal during the applied vibration where significant increases in torque and EMG signal were recorded. It is suggested that the initial normal contraction level established, provided a baseline similar to that around 80 to 100% MVC and the improvements in strength realised pushed that level higher with subsequent decreases in VMG_{RMS} output. However, the VMG_{RMS} signal recorded post the vibration application returned back to what might be considered normal contraction levels while force production remained enhanced. As with the EMG response in this case, the VMG response cannot be easily explained. Perhaps this provides further support to the suggestion that any post vibration effect may be due to a vasodilatory effect and its associated advantages instead of any neuromuscular effect.

The results of this study suggest that the application of vibration stimulation at 50 Hz during the contraction does enhance force production for concentric isotonic contractions. This appears to be achieved via the enhancement of neuromuscular activity as seen through the improvements in EMG activity of the involved musculature. Further enhanced knowledge of the effects of vibration on skeletal muscle tissue may have significant implications for rehabilitation, treatment of neuromuscular disorders and conditions where muscular atrophy is a major factor. Possible extensions of this knowledge to other biological tissues such as bone may provide valuable information in the furthering of treatment for bone disorders.

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STATEMENT OF THE PROBLEM: 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 is to address this issue by examining the effects of a superimposed vibration at 50 Hz on muscular activation and torque for a concentric isotonic contraction. In examining the torque developed along with simultaneous EMG data collection, this study will provide information on the effects of vibration stimulation on muscular force production supported by 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: Twenty-eight participants (9 females) were recruited with basic anthropometric and strength characteristics as follows: (mean $\pm$ SD) age 22.8 $\pm$ 5.6yrs, height 174.1 $\pm$ 8.8cm, body mass 78.0 $\pm$ 13.6kg and (mean $\pm$ SE) peak concentric isotonic leg extension 170.36 $\pm$ 9.01Nm. Participant's were advised on the procedures and requirements then completed an informed consent document, and asked to complete a pre-activity readiness questionnaire to screen for any neuromuscular disorders that may have excluded them from the study.

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EMG with the VMG data collection was achieved via a proximity switch (RS Components, Brisbane, Australia) aimed at the armature of the dynamometer. The raw signal was analysed using root mean square (RMS) calculations.

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STATISTICAL ANALYSIS: The raw data collected for each parameter was calculated and analysed as a percentage difference from the initial normal contraction in the individual test session. Statistical analysis involved using a one-way analysis of variance calculation (ANOVA) comparing the EMG, VMG and torque data calculated for each condition. Tukey post hoc tests were conducted to establish the location of any significant differences, with statistical significance accepted at or below .05.

RESULTS: Torque: A one-way ANOVA conducted on the torque data revealed significant improvements between the normal contraction and the contractions with a vibration stimulation ($F(3,108) = 9.929$, $p < .05$). Tukey post hoc analysis highlighted significant improvements of $14.7 \pm 2.9\%$ for the during condition and $15.3 \pm 3.1\%$ for the post condition.

EMG: ANOVA analysis conducted on the EMG data collected presented significant differences between the normal contraction and the experimental conditions. Mean activation of RF of $107.1 \pm 44.4\%$ ($F(3,106) = 5.722$, $p < .05$) for the during condition was recorded.

VMG: An ANOVA performed on the VMG data collected revealed a significant difference between the normal contraction and the experimental conditions for mean VMG activity of $-4.1 \pm 1.7\%$ ($F(3,108) = 5.079$, $p < .05$) during vibration stimulation.

DISCUSSION: Statistically significant ($p < .05$) improvements were recorded for peak concentric isotonic strength both during and three minutes after an applied vibration. Concurrent monitoring of muscular activation also exposed a significant improvement in mean activation of RF for concentric isotonic contractions performed during the vibration stimulation. While synchronous measurement of VMG activity of the RF revealed significant decreases in mean activity for concentric isotonic contractions performed during the applied vibration.

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