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# The Effects of Timing and Application of Vibration on Muscular Contractions.

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**Abstract.**

Background:

The effect of vibration stimulation on muscular strength is an emerging field of research with very little comprehensive work conducted at this stage.

Hypothesis:

There will be no effects of timing or application of vibration stimulation on muscular strength and activation across isometric, isokinetic and concentric isotonic contractions.

Methods:

Twenty-eight recreational athletes with mean ± SD age 22.8 ± 5.6 yrs, height 174.1 ± 8.8 cm and body mass 78.0 ± 13.6 kg participated in this study. The vibration stimulation was delivered at 50.42 ± 1.16 Hz with an acceleration of 13.24 ± 0.18$ms^{-2}$.

Results:

A series of one-way ANOVA's revealed significant ($p < .05$) improvements of 14.7 ± 2.9% and 15.3 ± 3.1% above normal contraction levels for concentric isotonic strength during and post the vibration stimulation, respectively. No significant improvements in isometric and isokinetic strength were evident. Concurrent measurement of electromyography (EMG) presented significant improvements during stimulation of 30.1 ± 14.6%, 43.0 ± 13.0% and 107.1 ± 44.4% in mean activation of rectus femoris (RF) for the isometric, isokinetic and concentric isotonic contractions, respectively. Synchronous collection of vibromyography

(VMG) during stimulation displayed a significant decrease of −6.4 ± 1.5%, −5.1 ± 1.2% and −4.1 ± 1.7% in mean VMG activity of RF for the isometric, isokinetic and concentric isotonic contractions, respectively.

Conclusions:

Significant improvements in muscular strength and activation for concentric isotonic contractions performed during an applied vibration, suggest that the optimal timing of a vibratory stimulation would be whilst the participant is contracting isotonically. However, further research needs to be conducted to establish the exact mechanism behind these improvements.

Index Terms: Strength, force production, muscle activation.

**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 (9). Every material known to man vibrates at its own natural frequency (8). Biological material is no different, and muscle tissue has also been shown to vibrate at specific frequencies while at rest and contracting (2). 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 (7). From that point, extensive work has, and is still being conducted in the fields of occupational health and safety (14, 18), ergonomics (25) and rehabilitation (3). However, it has taken until the mid 1990's for study of the application of vibratory stimulation in strength development to begin (10). Just as these studies cover a broad range of topics, equally wide ranges of parameters have been submitted to various vibration applications.

Some of the parameters research into this field have examined include reaction time and effect on human reflexes (6, 7), muscle spindle activation (19), kinaesthic awareness (6, 7, 12) and strength and power development (4, 5, 10, 11, 20). Examination of these studies accentuates the fact that there appears to be a lack of replication in vibration stimulation utilised and the conditions in which it was applied. Thus making the drawing of definitive conclusions about the effects of vibration on biological tissue extremely difficult.

Present research that has been conducted on the effects of vibration stimulation on the development of strength has also been plagued by wide variability in methodology. One of the few instances where similar vibration stimulation was used occurred in work conducted by Bosco and colleagues (5) and Rittweger and associates (20). An investigation conducted by Bosco and colleagues (5) utilized a vibrating platform to deliver stimulation to participants at 26 Hz. This study revealed significant improvements in power output during a leg press exercise. Research conducted by Rittweger and associates (20) also used a vibrating platform to stimulate participants at 26 Hz. The results of this study display a reduction in force output for an isometric leg extension and EMG median frequency. Another study conducted by Issurin and Tenenbaum (11) examined explosive strength while vibration was applied during a bicep curl. This study utilised a vibration at 44 Hz and found substantial improvements in maximum power in the vicinity of 30%. 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. A further study conducted by Bosco and associates (4) also found improvements of around 13% in bicep curl performed during a vibration treatment. This study also noted an 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.

At present there appears to be a need for research conducted on the effects of vibration on skeletal muscle tissue examining an array of contraction types under similar conditions. The aim of the present study is to address this issue by examining the effects of a superimposed vibration at 50 Hz on muscular activation and strength

for an isometric, isokinetic and concentric isotonic contraction. In examining the three types of muscular contraction along with simultaneous EMG data collection, this study will provide information on each of the contraction types under the same set of conditions, allowing the comparison of responses to a vibration stimulation to be made. 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 (19 males and 9 females) were recruited from the Central Queensland University and local communities. Table 1 displays the basic anthropometric and strength characteristics of the participants. Each participant was advised on the procedures and requirements then completed an informed consent document and were 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.

[Table 1 Here]

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 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. A series of 10 trials were conducted to establish the level of vibration transferred to the participant's leg through the system. The output of a triaxial accelerometer, attached 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. Results of this collection confirmed that the system was delivering 50.42 ± 1.16 Hz at 13.24 ± $0.18 ms^{-2}$.

Mechanical force and torque measurements:

Peak and mean 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 analysis involved establishing the peak and mean values of the full five second contraction. Peak isokinetic torque (Nm) was recorded via the Biodex System 3 Isokinetic Dynamometer (Shirley, New York, USA). Torque data collection was sampled at 100 Hz for the time period required to complete three full leg extensions at $60 °.s^{-1}$. Analysis of the isokinetic contractions involved observation of the graphical representation of the torque data to identify the peak contraction within the set. Peak concentric isotonic torque (Nm) was also controlled by the dynamometer for the

entire contraction and recorded as a single figure for each successful lift. Further calculations were conducted on the data collected to express the peak and mean values for force and torque as percentages of the normal peak contraction.

Electromyographic (EMG) Data Collection and Analysis:

The EMG signals were collected from RF and vastus lateralis (VL) 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. The electrodes for VL were positioned 140mm proximal to the tip of the patella, and 60mm laterally from the mid-line of the thigh. Both sets of electrodes were positioned as to perpendicularly dissect the fibres of the respective muscles. A reference electrode was placed on the patella of the participant's involved limb. Refer to Figure 1 for an illustration of electrode placement. 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 and force data collection was achieved via a software trigger set at 30 N force for the isometric contractions, and a proximity switch (RS Components, Brisbane, Australia) aimed at the armature of the dynamometer for both the isokinetic and isotonic contractions. The raw signal for each contraction type was initially analysed using root mean square (RMS) calculations. Peak and mean EMG signals were identified using the same technique as used for the force data.

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. Refer to Figure 1 for an illustration of accelerometer placement with respect to EMG electrodes. Corresponding with the EMG signal examination, the raw VMG signal for each contraction type was initially analysed using RMS calculations. Peak and mean VMG signals were identified using the same technique as used for the force data. Figure 2 displays a sample signal collected for a subject performing isokinetic contractions whilst being vibrated.

[Figure 1 Here]

[Figure 2 Here]

Experimental Protocol:

Participants completed three familiarisation sessions across a period of seven days to ensure that they were comfortable with the testing procedures, establish peak levels for each contraction type 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 of the type being tested in that session 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. A

single contraction type was tested per session and individual sessions were separated by a minimum of 24 hours to reduce any effects of muscular fatigue.

Isometric contraction:

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 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 ICC = 0.61 and TEM% = 13.05% 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.

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.

Isokinetic Contraction:

Each participant initially performed a set of three normal isokinetic contractions at 60 °.s$^{-1}$ to establish peak isokinetic torque and muscle activation for the test session. Torque data for this initial set of contractions was compared with that collected in the final familiarisation session to establish the reliability of the measure. The peak of repeated trials produced ICC = 0.78 and TEM% = 6.80%, respectively. Participants were then asked to perform three further sets under the same aforementioned experimental conditions in a randomised order.

Isotonic Contraction:

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. Once again, the torque data collected during this contraction was compared with the information recorded in the final familiarisation session to establish the reliability of the measure. The peak of repeated trials produced ICC = 0.99 and TEM% = 6.44%, respectively. Participants were then randomly subjected to the same three previously mentioned conditions with their peak concentric isotonic lift established in each case.

Statistical Analysis:

Measures of reliability for the force and torque data were achieved through the use of ICC and TEM%, comparing the results from the third familiarisation session and the initial normal test contraction for each contraction type. 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

for each of the contraction types involved using a one-way analysis of variance calculation (ANOVA) comparing the EMG, VMG, force 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. Statistical power for this investigation was calculated at 90%.

**Results.**

Strength:

Results of a one-way ANOVA conducted on the strength data for the concentric isotonic contractions revealed some significant improvements in torque between the normal contraction and the contractions with a vibration stimulation ($F(3,108) = 9.929$, $p < .05$). Tukey post hoc analysis revealed significant improvements of 14.7 ± 2.9% for the during condition and 15.3 ± 3.1% for the post condition. Similar analysis of the strength data for the isometric and isokinetic contractions revealed no significant improvements. Figure 3 graphically displays the percentage change in strength of the three conditions over the normal contraction level for each contraction type.

EMG:

Results of a one-way ANOVA analysis conducted on the EMG data collected for the isometric contraction, revealed significant differences between the normal contraction and the experimental conditions for peak ($F(3,107) = 4.399$, $p < .05$) and mean ($F(3,107) = 3.757$, $p < .05$) activation of RF. Post hoc analysis highlighted a significant increase in peak EMG of 39.0 ± 18.4% above the normal contraction level

for the during condition, with non-significant decrements of −1.8 ± 3.9% and −1.7 ± 5.0% recorded for the pre and post conditions, respectively. Likewise, an ANOVA analysis of the mean EMG activation of RF presented an improvement of 30.1 ± 14.6% above the normal contraction level for the during condition, with a smaller non-significant improvement of 0.6% ± 2.9% recorded for the pre condition.

Similarly, significant differences between the normal contraction and the experimental conditions were discovered in peak ($F(3,105) = 3.013$, $p < .05$) and mean ($F(3,106) = 5.570$, $p < .05$) activation of VL. Tukey post hoc testing for peak activation of VL revealed a significant improvement of 16.4 ± 6.1% for the during condition, with a small non-significant decrement of −0.4 ± 3.6% recorded for the pre condition. Analysis of the mean activation for VL highlighted a significant improvement of 27.7 ± 8.6% for the during condition, with smaller non-significant improvements of 5.6 ± 5.0% and 2.9 ± 4.3% recorded for the pre and post conditions, respectively.

Results of an ANOVA analysis conducted on the data collected for the isokinetic contraction revealed significant differences between the normal contraction and the experimental conditions for mean activation of RF ($F(3,103) = 3.742$, $p < .05$). Post hoc analysis highlighted a significant improvement of 43.0% ± 13.0 above the normal contraction level for the during condition.

Similar ANOVA analysis conducted on the data collected for the isotonic contraction presented significant differences between the normal contraction and the experimental conditions for peak ($F(3,106) = 4.806$, $p < .05$) and mean ($F(3,106) =$

5.722, $p < .05$) activation of RF. Post hoc testing of the peak EMG activation for RF revealed a significant improvement of 84.7 ± 37.5% for the during condition, with smaller non-significant improvements of 2.9 ± 6.0% and 7.9 ± 5.7% realised for both the pre and post conditions, respectively. Similar post hoc analysis of the mean activation data for RF showed a significant improvement of 107.1 ± 44.4% for the during condition, while smaller non-significant improvements of 4.5 ± 4.5% and 6.5 ± 4.7% were noted for the pre and post conditions, respectively.

Similarly, significant differences between the normal contraction and the experimental conditions were observed in mean ($F(3,103) = 3.935$, $p < .05$) activation of VL. Tukey post hoc analysis revealed a significant improvement of 21.7 ± 8.1% above the normal contraction level for the during condition, with smaller non-significant improvements of 1.0 ± 3.9% and 3.2 ± 5.5% realised for both the pre and post conditions, respectively. Figure 3 displays a graphical representation of the percentage change in mean muscle activation for RF for the three contraction types over the three experimental conditions.

VMG:

Results of a one-way ANOVA conducted on the VMG data collected for the isometric contraction revealed significant differences between the normal contraction and the experimental conditions for peak ($F(3,108) = 11.115$, $p < .05$) and mean ($F(3,108) = 10.923$, $p < .05$) activity. Further post hoc testing of the peak VMG data shows a significant improvement of 2.2 ± 0.9% above the normal contraction level during vibration. While non-significant decrements of −1.5 ± 0.3% and −1.2 ± 0.4% were recorded for both the pre and post conditions, respectively. Post hoc

comparisons of the mean data presented a significant decrease in VMG activity of −6.4 ± 1.5% recorded for the during condition. While smaller non-significant decrements of −2.3 ± 0.5% and −1.4 ± 0.4% were registered for the pre and post conditions, respectively.

An ANOVA conducted on the data collected for the isokinetic contraction showed a significant difference between the normal contraction and the experimental conditions for mean VMG activity ($F(3,108) = 15.546$, $p < .05$). Post hoc analysis of the data found a significant decrement of −5.1 ± 1.2% below the normal contraction level for the during condition, with smaller non-significant decrements of −0.5 ± 0.1% and −0.5 ± 0.2% recorded for both the pre and post conditions, respectively.

Likewise, an ANOVA performed on the data collected during the isotonic contractions revealed a significant difference between the normal contraction and the experimental conditions for mean VMG activity ($F(3,108) = 5.079$, $p < .05$). Further post hoc analysis showed a significant decrement of −4.1 ± 1.7% below the normal contraction level was recorded for the during condition, with smaller non-significant decrements of −0.2 ± 0.1% and −0.7 ± 0.3% recorded for both the pre and post conditions, respectively. Figure 3 graphically displays the percentage change in mean VMG activity for the three contraction types across the three conditions.

[Figure 3 Here]

**Discussion.**

This study found a trend towards improvements in strength across the three types of contraction while a superimposed vibration of 50 Hz was applied. Statistically significant ($p < .05$) improvements were recorded for peak concentric isotonic strength both during and three minutes after the applied vibration. Concurrent monitoring of muscular activation also exposed a significant improvement in mean activation of RF for isometric, isokinetic and concentric isotonic contractions performed during the vibration stimulation. While synchronous measurement of VMG activity of the RF revealed significant decreases in mean activity for isometric, isokinetic and concentric isotonic contractions performed during the applied vibration.

The present study found non-significant trends towards improvements in isometric and isokinetic strength. These results have support from previous work conducted by Johnston and colleagues (13) on the effects of vibration on a number of individual muscles performing isometric contractions. This study found significant differences in response to the applied vibration between muscles. These authors suggested that muscle response was linked to muscle architecture, with the muscles attached via long thin tendons displaying a better response to a stimulation, while muscles such as the quadriceps femoris were the least responsive. Furthering this argument, the investigators also implied that the elastic and viscous properties of the muscle also played a role in its response to vibration stimulation. Barry and Cole (2) support the idea that a material's properties would have an effect on its responsiveness to stimulation, and that muscle tissue is no different to any other type of material in this regard. While this may explain the lack of response seen in the present study for

the isometric and isokinetic contractions, as one of the involved muscles was the rectus femoris; it does not account for the substantial improvements seen for the concentric isotonic contraction involving the exact same musculature.

Another explanation may exist with a number of authors suggesting that a length and muscle tension relationship exists with the response of the muscle to vibration (11, 13, 23). 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 (11) suggested that the work conducted by Samuelson and associates (23) failed to find any improvements in isometric strength of the quadriceps as they positioned their participants with knee flexed at 90 degrees. Therefore not applying the stimulation to a muscle under 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 (approximately at the limb's greatest mechanical advantage)(22), and an isokinetic and isotonic contraction where the limb moved through a range of motion from 90 degrees knee flexion through to approximately 180 degrees knee flexion. The contrasting non-significant response to vibration for both the isometric and isokinetic contractions, with the significant results for the isotonic contraction recorded in the present study, cannot be explained by this suggested length/tension relationship.

Previous research has also implied that the intensity of the vibration used by other investigators may have been the reason behind the varying results being

recorded across contraction types (11). The current study examined each contraction type under the same conditions, and applied the same vibration stimulation in each case. Therefore, this reasoning also fails to explain the difference in response between contraction types seen in this investigation.

One possible explanation for the differences in response may reside in contraction velocity. The contraction velocity of both the isometric and isokinetic contractions was limited via the testing protocol. Whereas the contraction velocity of the concentric isotonic contraction was determined by the participant. 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 strength measures (4, 5, 10, 11). 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 an unexamined reason behind these improvements may be in the selection of contraction velocity and its possible affect on the effectiveness of the vibration stimulation. Another plausible explanation for the differing responses may reside in the sample population used in the present study. An isotonic contraction is more commonly used in everyday human movement and is the most frequently used contraction in most resistance training programs (22), whereas an isometric contraction is by far less common in everyday use, apart from small range postural control, and an isokinetic contraction even less so (22). It is possible that the sample population used in this study was more familiar with an isotonic contraction. Therefore the response to an applied vibration was accentuated by this familiarisation, even though each participant underwent extensive familiarisation in each contraction type prior to testing.

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 (4, 5, 11). To explain this improvement in force output, one must also consider the simultaneous neuromuscular activity occurring. The application of a vibration to the quadriceps muscle has been shown to elicit excitability of the spinal reflex (6). While vibration has also been suggested to elicit an excitatory inflow of motorneuron activity via muscle spindle-α-motorneurone interaction and a Ia afferent loop (25). Further, it has been shown that vibration stimulation drives α-motorneurones via a Ia neuron loop producing force without input from the central nervous system (21). Martin and Park (15) imply that this vibration reflex (TVR) operates predominately via α-motorneurones and does not use the same cortically originating efferent neural pathways as does voluntary contractions. However, enhancement of these voluntary pathways via vibration stimulation can not be dismissed (4), 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 across each contraction type. 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. This was certainly the case for the concentric isotonic contraction, with significant improvements in strength realised during the applied vibration. However, similar improvements in strength for the isometric and isokinetic contractions were not recorded, even though significant enhancement of neural activation was achieved. Siggelkow and associates (24) 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 was 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 (5) 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 was 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 (20), 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 temperature of the involved musculature. This provides another area for future research in the field of vibration and strength development.

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 attachment and re-attachment during contraction (1), while others imply that is due to the gross lateral expansion of the muscle tissue as it contracts and shortens (17). 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. The resultant information, being a more reliable indicator of absolute force production (16, 17). Research conducted by Matheson and associates (16) 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 concentric isotonic force production 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 for the concentric isotonic contraction, 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. It also appears that there may be a trend for similar vibration induced improvements in both isometric and isokinetic contractions via similar neuromuscular enhancement. However this requires further research to be conducted on a group of participants more familiar with the contraction type to substantiate any claims. 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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Table 1

Participant's basic anthropometric and strength characteristics.

| **Characteristic** | **Mean ± SD** |
|---|---|
| Age (yrs) | 22.8 ± 5.6 |
| Height (cm) | 174.1 ± 8.8 |
| Body Mass (kg) | 78.0 ± 13.6 |
| **Characteristic** | **Mean ± SE** |
| Peak Isometric Force (N) | 665.28 ± 26.50 |
| Peak Isokinetic Torque (Nm) | 1991.82 ± 86.58 |
| Peak Concentric Isotonic Torque (Nm) | 170.36 ± 9.01 |

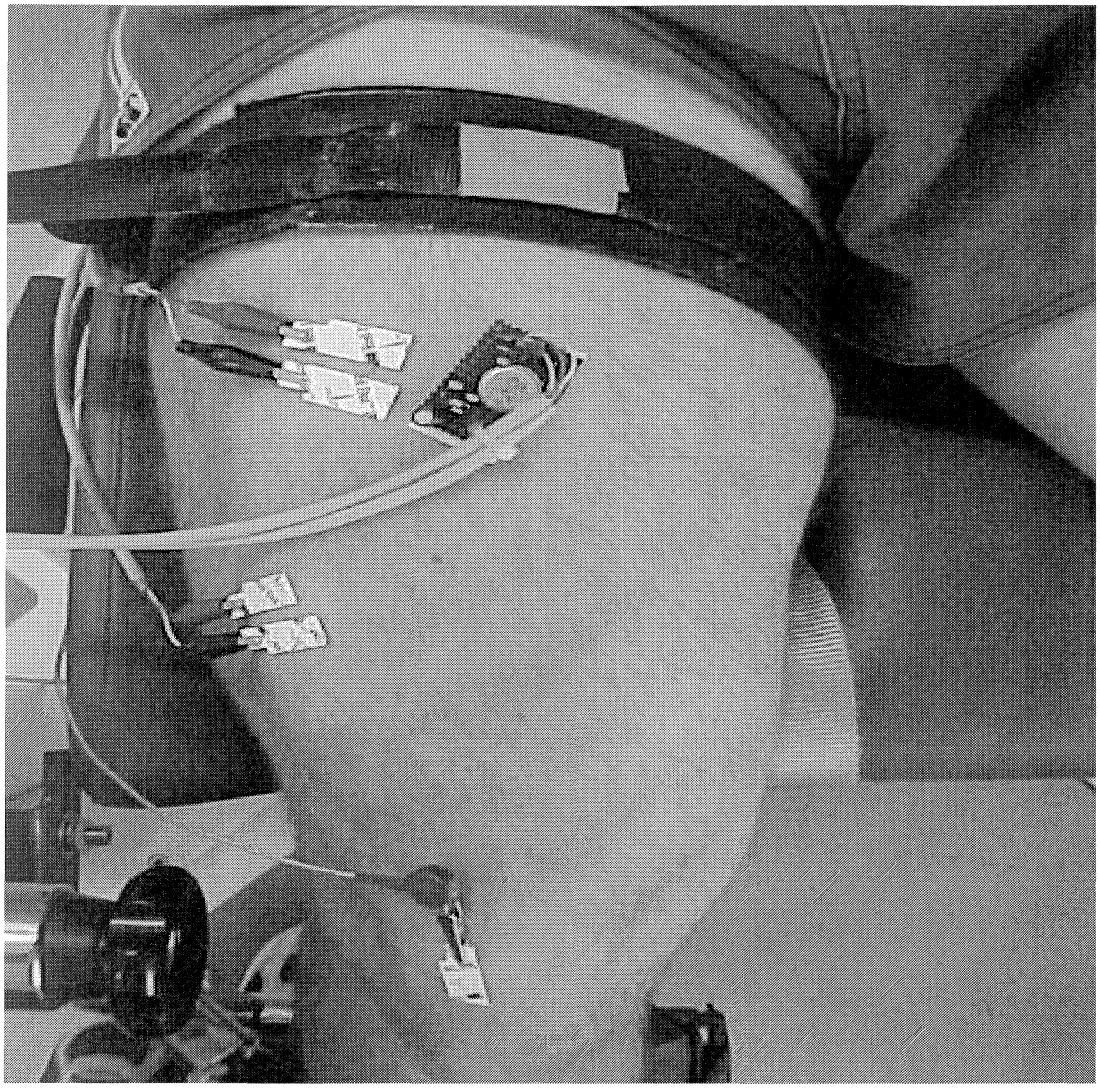

Figure 1 Placement of EMG electrodes and accelerometer with respect to attachment of vibration cuff.

Note: Taping of the electrodes or leads has been omitted to illustrate electrode placement.

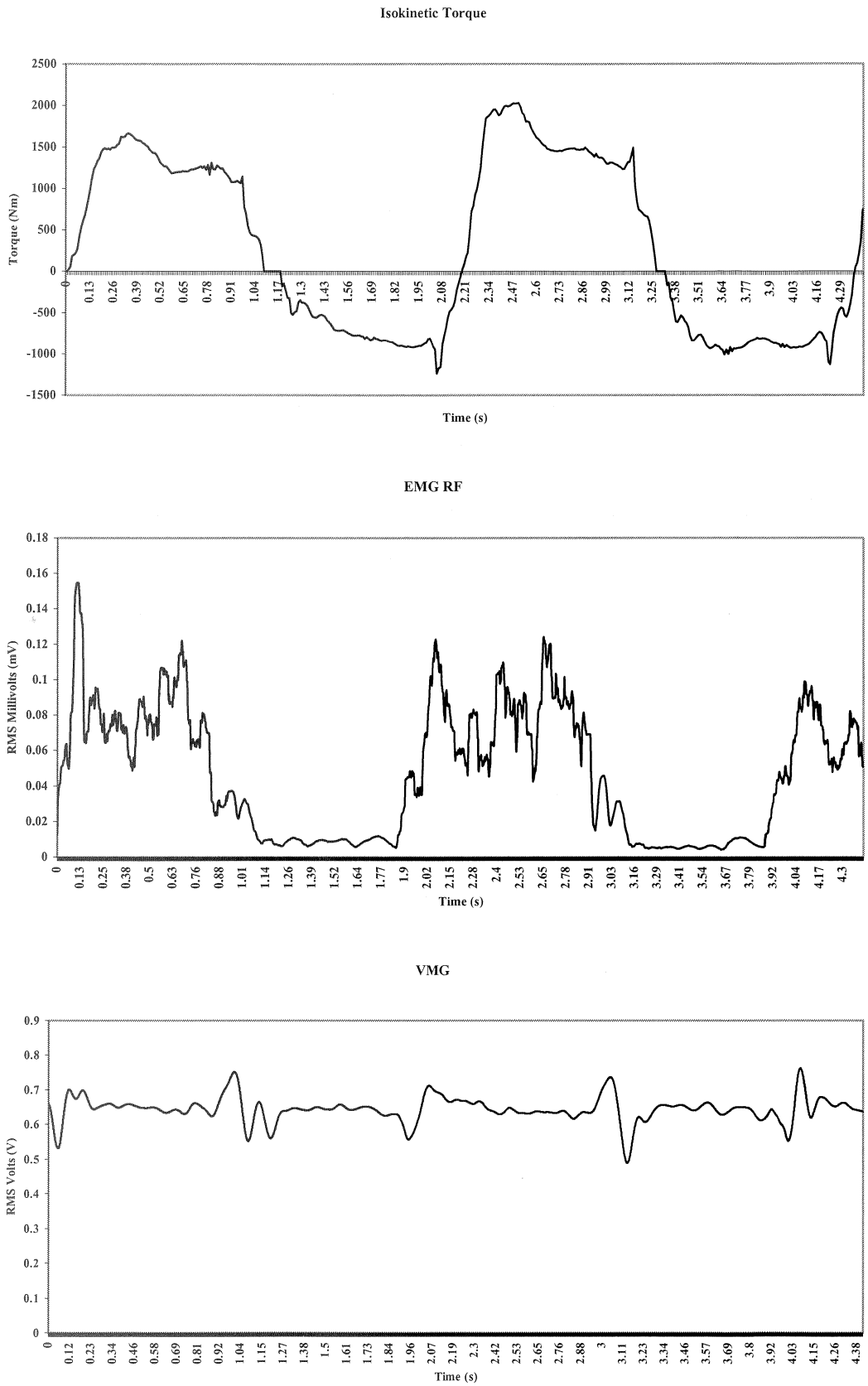


Figure 2 Sample data collection for participant performing an isokinetic contraction.

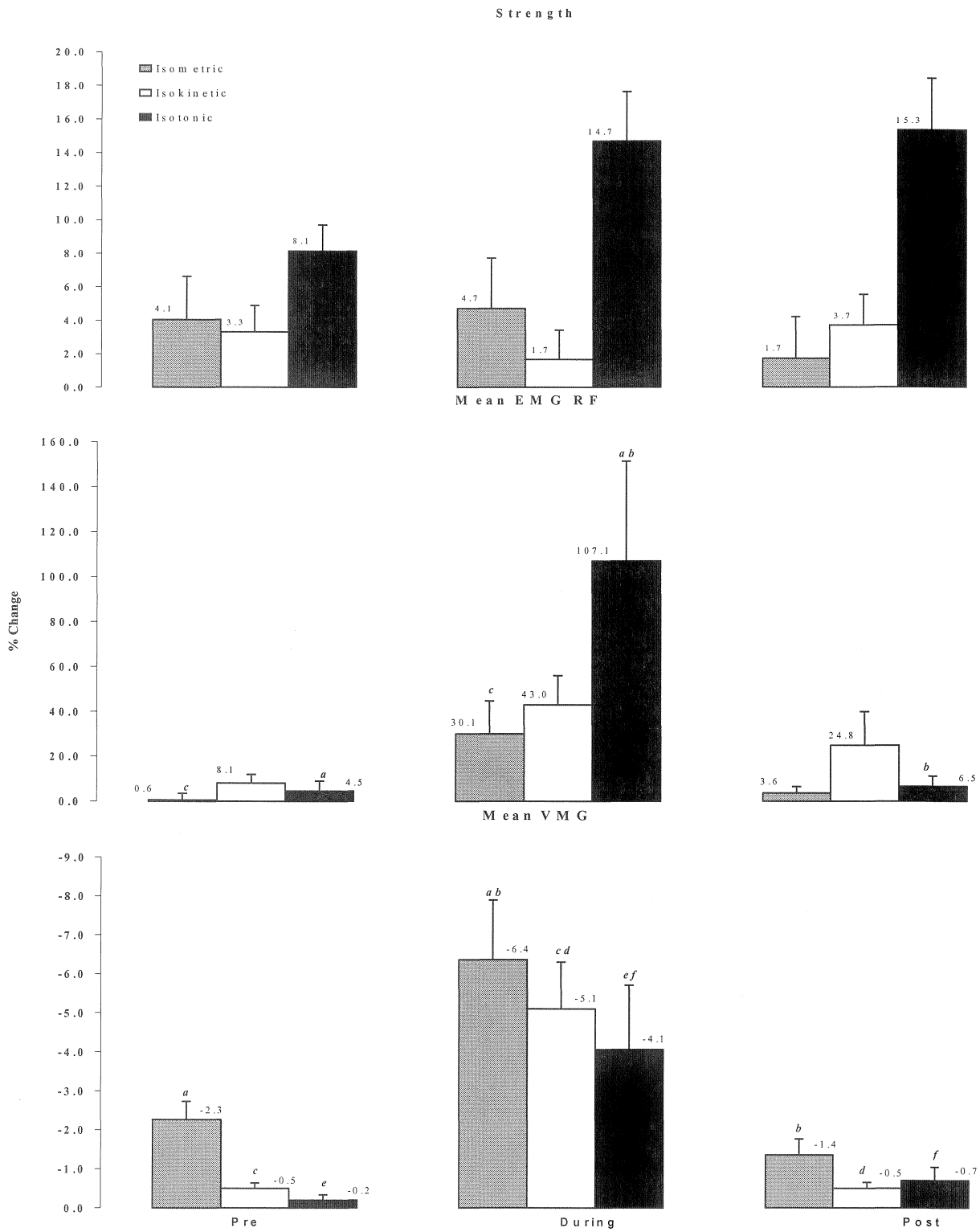


Figure 3 Graphical representation of percentage change for each contraction type across the three experimental conditions.

Note: a,b,c,d,e and f indicate significance between conditions at $p < .05$ for EMG and VMG.