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Influence of Resistance Load on Electromyography Response to Vibration Training with Sub-maximal Isometric Contractions

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Abstract. The purpose of this study was to assess the effect of direct vibration during two sub-maximal isometric loading conditions on electromyographic output. Sixteen participants performed isometric knee extensions, at an angle of 150°, under four conditions in random order: 1) a load of 10% one repetition maximum [1 RM] with no vibration (10%+NV); 2) a load of 30% 1RM with no vibration (30%+NV); 3) a load of 10% 1RM with vibration (10%+V); and 4) a load of 30% 1RM with vibration (30%+V). Direct vibration (amplitude = 1.2mm, frequency = 65 Hz) was applied to the distal end of the quadriceps using a purpose built portable vibrator. Electromyographic root-mean-squared (EMGrms) output of the rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM) was measured and assessed.

Vibration significantly enhanced RF, VL and VM EMGrms output in comparison to no vibration in both the 10% 1RM and 30% 1RM loading conditions, but the degree of vibration induced enhancement was not affected by the magnitude of loading (Vibration *vs* no vibration, RF: 58 μV *vs* 47 μV, VL: 59 μV *vs* 47 μV, VM: 87 μV *vs* 57 μV, $p < 0.05$).

Keywords: Vibration Exercise, Direct Vibration, Nueromuscular Output

1. Introduction

Vibration training is a novel strength training method that has gained in popularity in the last five years. It involves the application of vibration stimulation to the muscle during conventional maximal and sub-maximal strength training exercises. Understanding the effect of vibration with sub-maximal contractions is important as sub-maximal contractions are frequently employed by those recovering from muscular, soft tissue and neural (e.g. stroke) injury and by the elderly.

Although it has been reported that vibration training with a sub-maximal loading exercise can induce a significant gain in strength and power, both while the exercise is being completed [1, 2] and within a short period of continued training (12 weeks) [3], it is still unclear how the resistance load applied during vibration training influences the vibration training effect. The issue of a load dependent response in vibration training is important. If heavier loading is required to cause a vibration induced enhancement it may negate its use in individuals who use light loading (e.g. injured and elderly); while in contrast, if lighter loading causes a greater enhancement associated with vibration, it may encourage the use of vibration training as individuals are more likely to adhere to a resistance training programme that requires less effort (a lighter load) but produces a greater response.

A second issue in vibration training is the method of vibration application. Currently, the most common vibration training apparatus apply vibration indirectly to the targeted muscle; that is the vibration is transmitted from a vibrating source located away from the muscle, through part of the human body to the targeted muscle (‘indirect vibration’). For example, a vibrating platform applies vibrations through the feet to enhance the neuromuscular output of the quadriceps, or a vibrating dumbbell applies vibration through the

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hand to enhance the output of the biceps. However, this method of vibration application may impose significant limitations on the applicability of vibration training. Firstly, it has been found that the vibration training effect is greater with a smaller distance between the vibration source and target muscle [2], as the vibration signal is attenuated by soft tissue during its transmission through the body [4] potentially resulting in a vibration signal at the muscle that is not large enough to elicit a facilitating effect on neuromuscular performance. Secondly, as the orientation of the joint(s) change during the exercise, the amount of vibration that reaches the target muscle also changes. Thirdly, this method of vibration application may limit the range and type of exercises that can be completed, especially when a vibrating platform is used. The use of a portable vibration device that could be attached to the body directly over the tendon of the targeted muscle (‘direct vibration’) may be able to more effectively stimulate the target muscle by circumventing the above limitations.

The aim of the present study was to assess, using direct vibration, the neuromuscular (electromyographic [EMG]) response to vibration training when different sub-maximal loads are employed (10% and 30% one repetition maximum [1RM]). It is hypothesized that direct vibration will enhance neuromuscular output, and this enhancement by vibration is dependant on the resistance load applied.

2. Methods

2.1. Participants.

Sixteen healthy adult male volunteers took part in the present study. The average age, mass and height of the participants were 21.4 ± 2.1 (years), 77.1 ± 14.5 (kg), and 179 ± 8 (cm) respectively. Participants exhibited no evidence of neuromuscular disease or injury. The local university ethics committee approved the study and informed consent was obtained from all participants.

2.2. Vibration.

Vibration was produced by a portable muscle-tendon vibrator developed in-house (detailed in Appendix 1). This was strapped onto the skin directly over the distal muscle-tendon of the quadriceps, about 5 cm proximal to the knee cap. The vibrator uses an eccentric mass rotating mechanism to produce vibration with different amplitudes and frequencies. This vibrator can produce a repeatable vibration amplitude and frequency across test days in different operational conditions, including joint angles and forces by which the vibrator is strapped to the muscle [5]. Vibration amplitude and frequency in the present study were set at 1.2 mm and 65 Hz, respectively. These vibration characteristics were found to be appropriate to stimulate the biceps during sub-maximal isometric contractions and produced greater enhancements than 0.5 mm and 30 Hz [5].

2.3. Experiment design.

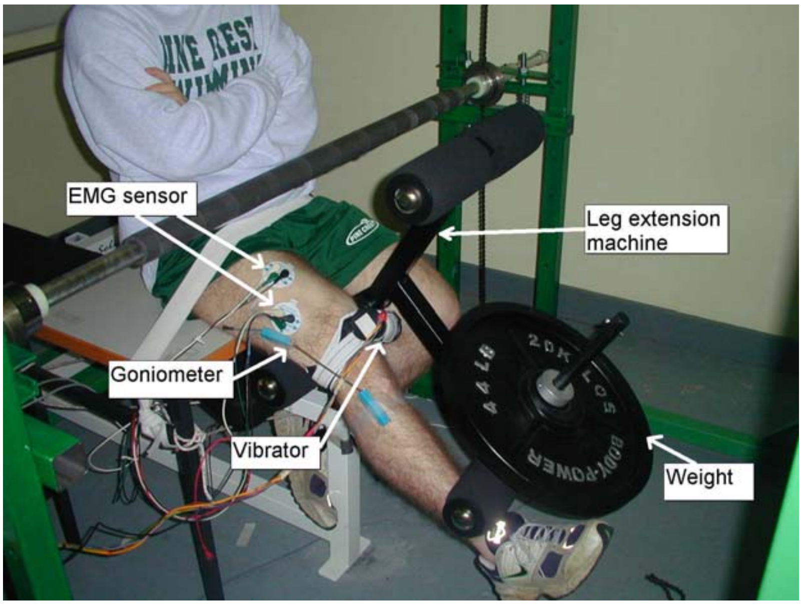

Fig. 1: Experiment Setup.

Participants performed an isometric knee extension under four conditions in random order: 1) a load of 10% 1 RM with no vibration (10%+NV); 2) a load of 30% 1RM with no vibration (30%+NV); 3) a load of 10% 1RM with vibration (10%+V); and 4) a load of 30% 1RM with vibration (30%+V). During the test, participants were firmly secured to a knee extension machine by straps wrapped over the hip and both thighs (Figure 1). The poplital fossa of the participant was aligned to the rotation axis of the weight on the machine. Participants were instructed to hold their arms across their chest and keep their back straight during exercise. Only the dominant leg was used in lifting and holding the weight. Participants were instructed to extend their knee joint to an angle of 150° and hold this joint angle for 20 seconds in each experiment condition. The duration of 20 second was used to allow the tonic vibration reflex (TVR) to be fully developed [6, 7].

1RM knee extension strength was estimated on each participant using a 10RM load protocol, carried out on a separate day, at least six days before the start of the experiment [8]. Participants were also familiarized with the test procedure on that day. For all participants, each test condition was re-tested on another day to establish the repeatability of the experiment. There was at least three days interval between test days.

2.4. Measurements.

Rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM) EMG signals were measured for 20 seconds in each experimental condition. The EMG electrode on the RF was placed at half of the distance along a line connecting the anterior superior spina iliaca to the superior patella [9]. The EMG electrode on the VL was placed at two-thirds of the distance along a line connecting the anterior superior spina iliaca to the lateral border of the patella [9]. The electrode on the VM was placed at four-fifths of the distance along a line connecting the anterior superior spina iliaca and the joint space in front of the anterior border of the medial ligament [9]. A semi-permanent marker and the application of a waterproof elastic plaster over the marker were used to facilitate accurate relocation of the EMG electrodes across different days. The skin was abraded and cleaned, and a bipolar electrode (AE-131, NeuroDyne Medical, USA) with a centre-to-centre distance of 2cm was attached to the muscle. The resistance between the electrodes was measured to ensure that it was less than 5 kΩ [10]**.** The EMG signals were differentially amplified (bandwidth = 10~500 Hz, input impedance = 100 MΩ, common mode rejection ratio >75 dB from DC to 100 Hz) with a Powerlab 4/20T unit (Powerlab®, ADInstruments, USA). The sampling frequency for the EMG signal was set at 1000 Hz and the EMG signal was measured for a 20-second duration for each test. The raw EMG signal was converted on-line to a root-mean-squared value of EMG (EMGrms) by Powerlab (averaging constant 50ms), and stored for later analysis. To check if motion induced artifacts were present in the EMG signal, vibration was applied to the muscle of all participants for a short period (three seconds, which is too short for TVR to develop) before the experiment, when the muscle was in a state of rest. The power spectrum of the measured EMG showed no peak at the applied vibration frequency, indicating that there was no electrical or motion artifact [11]. Knee joint angle was monitored by an electrogoniometer (XM180, Biometrics, UK) to ensure that the knee joint angle was at 150° at the start of each test.

2.5. Data analysis.

EMGrms data measured on the RF, VL and VM were used for the analysis. The first 5-second segment of EMGrms data was discarded to eliminate any transient effect [12]. The EMGrms was averaged for the remaining 15 seconds. This average EMGrms was the dependent variable in this study.

2.6. Statistical methods.

The inter-day reliability of the EMG measurement was calculated using Intraclass correlation [ICC] [13]. Paired t-tests were also employed to examine whether there was a difference in the mean value of EMG response from test day to re-test day. To determine the effect of vibration treatment (vibration, no vibration) and load (10% 1RM, 30% 1RM) on EMG variables, a two factor ANOVA [load (2) × vibration (2)] with repeated measures was employed. For all analyses a probability value of significance of $p<0.05$ was utilized. Where a significant interaction was found, a simple effects analysis with appropriate Bonferroni adjustment was employed to locate where the significant difference rests. SPSS® (version 11.5) was used for all statistical analysis.

3. Results

3.1. Reliability of measurements.

The reliability of EMGrms measurements on the RF, VL and VM across two different test days was high, with ICC values ranging from 0.63 to 0.91 (Tables 1, 2 and 3).

As there was no significant difference between all the measurements in the first and second test day, the results from the two test days were averaged and used for the later analysis.

Table 1: Reliability of EMGrms measurement on the RF

Condition	EMGrms(Day1) (μV)	EMGrms(Day2) (μV)	p value of t test	Reliability (ICC)
10%+NV	29.2±15.9	27.8±16.3	0.739	0.70
30%+NV	66.7±27.8	59.2±23.7	0.349	0.78
10%+V	47.3±21.3	43.2±18.5	0.735	0.78
30%+V	83.3±27.1	83.4±29.8	0.838	0.91

Table 2: Reliability of EMGrms measurement on the VL

Condition	EMGrms(Day1) (μV)	EMGrms(Day2) (μV)	p value of t test	Reliability (ICC)
10%+NV	33.5±8.8	37.0±14.1	0.385	0.64
30%+NV	59.7±19.7	69.5±23.9	0.281	0.76
10%+V	48.4.±20.9	44.9±18.6	0.503	0.74
30%+V	76.4±28.4	77.7±24.0	0.572	0.78

Table 3: Reliability of EMGrms measurement on the VM

Condition	EMGrms(Day1) (μV)	EMGrms(Day2) (μV)	p value of t test	Reliability (ICC)
10%+NV	36.0±11.5	39.8±13.5	0.358	0.63
30%+NV	79.8±28.6	81.3±24.0	0.859	0.63
10%+V	66.2±25.6	64.1±22.0	0.778	0.69
30%+V	112.3.2±36.5	111.0±29.9	0.623	0.73

3.2. EMGrms under different loads and vibration treatment conditions.

Both vibration and load had a significant effect on RF EMGrms ($p < 0.05$). EMGrms with vibration was significantly higher than no vibration (58 μV vs. 47 μV, $p<0.05$) and the 30% 1RM load induced a significantly higher EMGrms (70 μV vs. 35 μV, $p < 0.05$) (Figure 2). The interaction between vibration and load was not significant (p>0.05).

Both vibration and load had a significant effect on VL EMGrms (p < 0.05) (Figure 3), but with no significant interaction between them (p>0.05). EMGrms with vibration was significantly higher than no vibration (59 μV vs. 47 μV, p < 0.05), and the load of 30% 1RM induced a significantly higher EMGrms than with 10% 1RM (69 μV vs. 38 μV , p < 0.05).

Both vibration and load had a significant effect on VM EMGrms (p<0.05) (Figure 4), but with no significant interaction between them (p>0.05). The EMGrms with vibration was significantly higher than no vibration (87 μV vs. 57 μV, p < 0.05), and the load of 30% 1RM induced a significantly higher EMGrms (95 μV vs. 50 μV , p < 0.05).

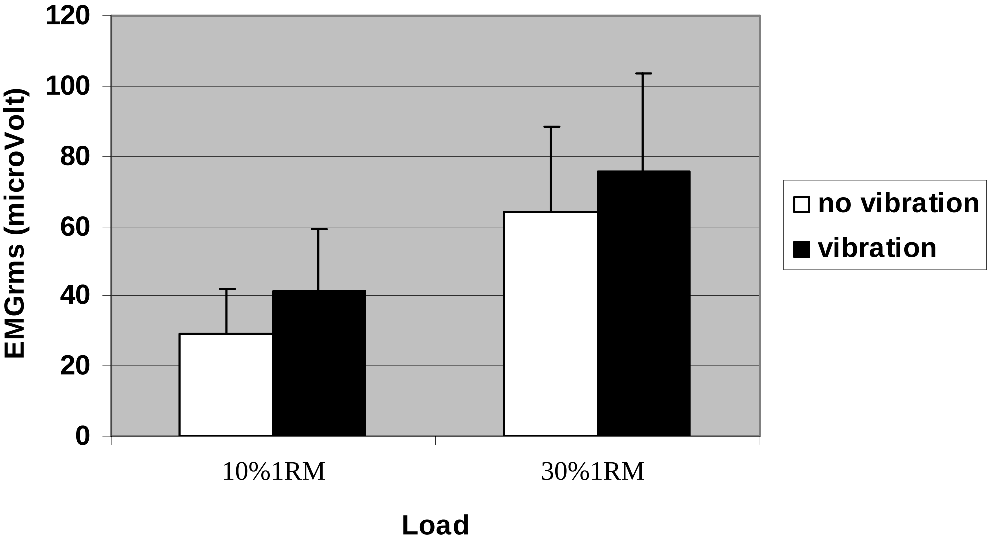

Fig. 2: RF EMGrms under different loads.

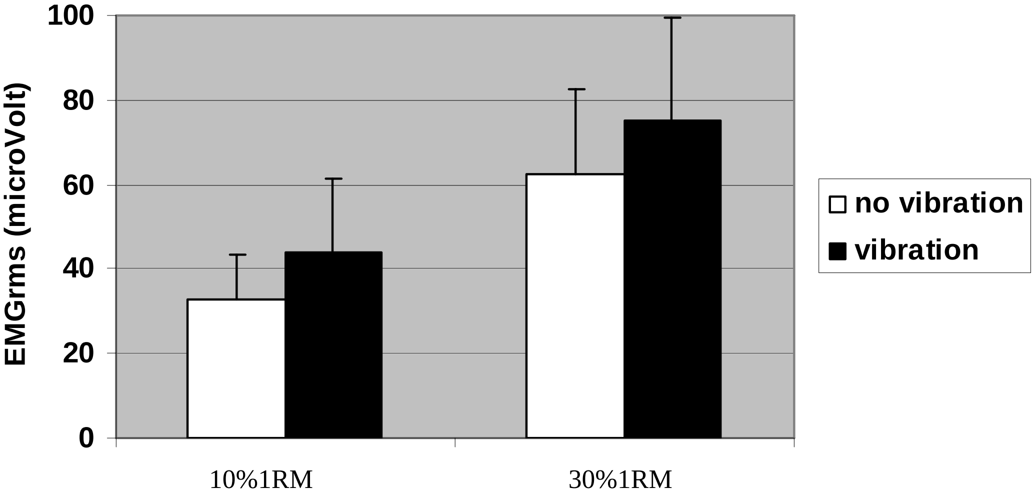

Fig. 3: VL EMGrms under different loads.

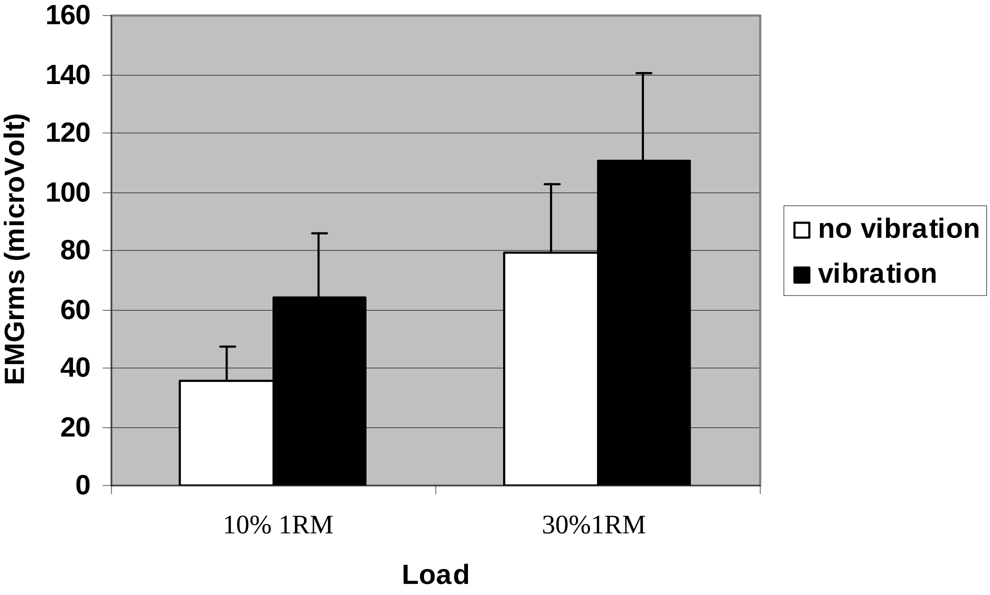

Fig. 4: VM EMGrms under different loads.

4. Discussion

The results of this study showed that direct vibration could induce significantly higher muscle activity on the RF, VL and VM in both 10% 1RM and 30% 1RM load conditions ($p<0.05$). However, the positive effect of vibration was not significantly influenced by the load imposed [10% and 30% 1RM] ($p>0.05$).

It has been found that muscle spindle primary endings are very sensitive to vibration [14]. Muscle vibration could induce a sustained discharge of Ia afferents and cause a reflex contraction of the muscle being vibrated, i.e. tonic vibration reflex (TVR) [7]. The initial voluntary contraction of the muscle may be accompanied by an increase of gamma motor activity which could keep the intrafusal fibers tense [7]. This increased tension of intrafusal fibers could therefore increase the sensitivity (gain) of muscle spindle endings, and in consequence would increase the TVR from the vibration stimulation [7, 15]. However, it was also found that although TVR could be enhanced by initial voluntary contraction at 10% of maximal voluntary contraction (MVC), a higher level of voluntary contraction (20% MVC) could not enhance TVR further [12]. This latter inability may be due to the activation of α motor units by vibration induced Ia afferent reaching its maximum at moderate levels of voluntary contraction [12]. Thus it may be suggested that the enhancement from vibration training is achieved even if the exercise intensity was kept at a moderate level.

The results of the present study are in line with some other vibration training studies which have investigated the influence of resistance load in vibration training. Roelants et al. [2] measured the EMG on RF, VL, VM when different exercises were performed during whole-body vibration training. The authors [2] found that the increase in muscle activity caused by whole body vibration was not significantly different between high squat exercise (knee angle 125°, hip angle 140°) and low squat exercise (knee and hip angles 90°) even though the loading on the muscles would have been greater in the latter posture. Rittweger et al. [16, 17] examined the influence of exercise load on acute vibration training effect by measuring the oxygen uptake during a bout of whole-body vibration exercise. The authors [16] found that the specific oxygen uptake (the instantaneous oxygen uptake divided by the body mass which is a measure of metabolic power) during a sub-maximal isometric contraction exercise (standing with knee flexed at 170°) could be enhanced by whole body vibration. However, the amount of increase in the specific oxygen uptake by vibration was not changed when extra-load (35% to 40% of body weight) was applied to the exercise.

It should be noted that the results of the current study were obtained when direct vibration method was used. There are limitations if these results are to be applied to indirect vibration (e.g. whole body vibration training) because of the difference between direct vibration and indirect vibration. In ‘indirect vibration’ training, vibration needs to be transmitted from the source through part of the body to the targeted muscle.

The transmission of vibration is influenced by several factors, e.g. vibration frequency, joint angle, the status of muscle contraction [18]. It has been found that with an increase of contraction force more vibration energy is dissipated during its transmission from the source to the remote muscle group [18-20]. These findings suggest that in whole-body vibration training a higher muscle contraction level associated with an increased resistance load may lead to a reduction in the vibration amplitude that reaches the target muscle group (e.g. quadriceps) and consequently a decrease in any vibration training effect [1, 21, 22]. On the other hand, with the 'direct vibration' the influence of muscle contraction status should have much less effect on the transmission of vibration because the vibration is applied directly to the targeted muscle.

5. Conclusion

Direct vibration can enhance the muscle activity in sub-maximal isometric contractions. The increase of muscle activation by direct vibration training is not affected by different resistance loads (10% or 30% 1RM).

6. Implications

Individuals who tend to use sub-maximal isometric contractions, such as those recovering from muscular, soft tissue and neural (e.g. stroke) injury and by the elderly, will gain additional training benefits if they simultaneously apply vibration directly to the target muscle.

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Appendix 1

The vibrator uses an eccentric rotating mechanism to produce vibrations with an amplitude range of 0.2–2 mm, and a frequency range of 30–200 Hz. A Brushless dc-servomotor (3564-024B, Minimotor, Switzerland) with a rotating speed capacity up to 25,000 rpm and a power rating of 109W is controlled by a motion controller (MCBL2805, Faulhaber, Germany) operating through a dc power supply unit (3gen, 400W, Excelsys, Ireland). The motion controller is controlled via software (Faulhaber Motion Manager, Faulhaber, Germany).

To protect the user from direct contact with the rotating eccentric mass, a hollow plastic cylinder housing (outer diameter = 50mm, wall thickness 2.5mm) surrounds the unit. The total length of the housing is 118 mm (Figures 1 and 5).

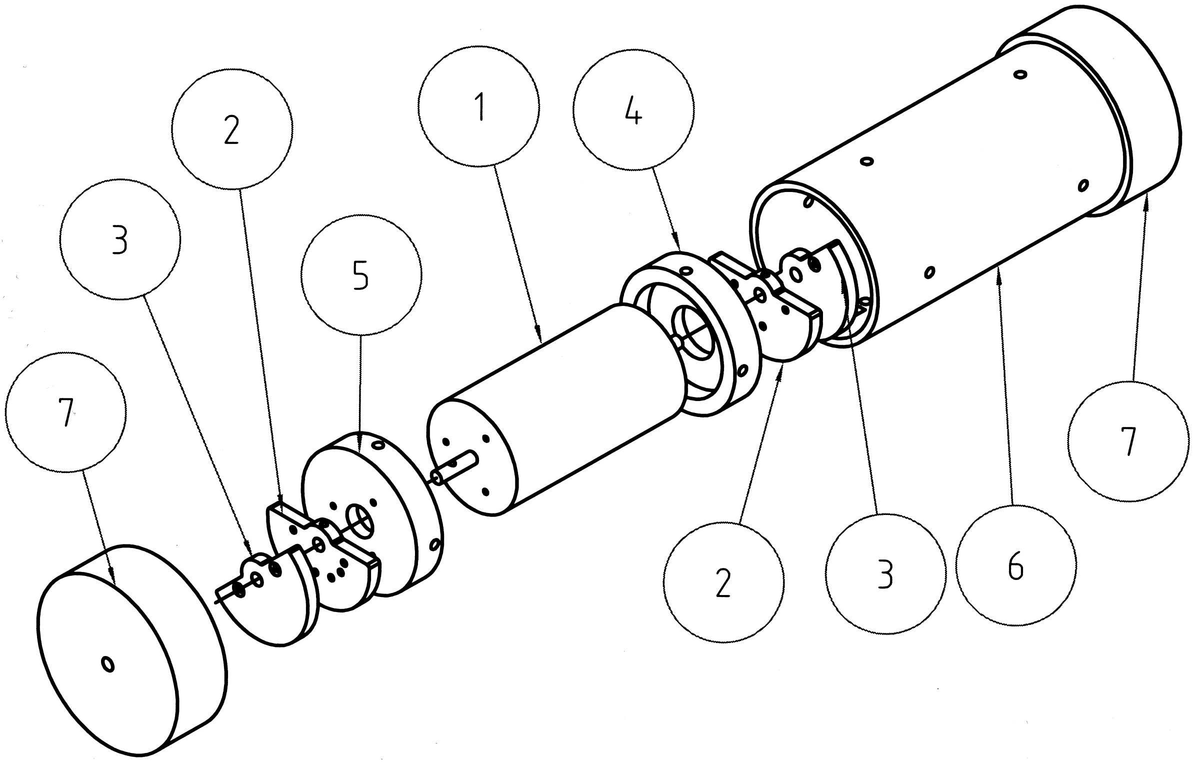

Fig. 5 Components of the vibrator (1=motor; 2 and 3=eccentric mass; 4 and 5=ring for fixation of housing to motor; 6=housing for motor; 7=cap for housing)

By setting the rotating speed of motor at 3900rpm, the vibrator can produce 65 Hz vibration. The following method was used to produce vibration amplitude of 1.2 mm.

Various vibration amplitudes can be produced by different eccentric mass weights being attached to the axes of motor. The eccentric mass used to produce an amplitude of 1.2mm was determined using a single degree of freedom system model (Figure 6). Eccentric mass, Mu, was mounted on to the mass M (mass of the motor and housing, i.e., 430 g). The eccentric radius (e) was 8.4mm and ω was the angular velocity of the eccentric mass [$\omega = 2\pi \times 65$ (frequency of vibrator = 65 Hz)]. K and B represent the stiffness and damping coefficient of the muscle tendon under the vibrator. A was the displacement amplitude of the mass M in the X-direction (A = 1.2 mm).

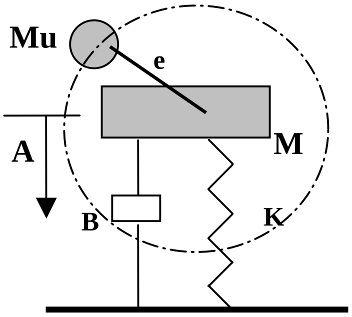

Fig. 6 Single degree of freedom system model

The displacement amplitude of the vibrator was calculated as follows [23]:

$$A = \frac{Mu}{M} \times e \times Ra \tag{1}$$

where

$$Ra = \frac{(\omega^2 / \omega_n^2)}{\sqrt{(1 - (\omega^2 / \omega_n^2))^2 + (2 \times \xi \times \omega / \omega_n)^2}} \tag{2}$$

where ω_n is the natural frequency of muscle tendon under the vibrator and ξ is the fraction of the critical damping (critical damping is the minimum viscous damping that will allow a displaced system to return to its initial position without oscillation [23]). ωn and ξ, were derived from data of Wakeling and Nigg [24] on the free vibration behaviour of the quadriceps muscle. Given a damped natural frequency range of 8.85 to 30.39 Hz and a critical damping ranged of 0.14 to 0.73 [24], average values of 19.8 Hz and 0.44 were used in the present study. By calculation from formula (1) and (2) an eccentric mass of 59 g was needed to produce 1.2 mm vibration amplitude at 65 Hz.

Three different materials (plastic, aluminum and copper) were used to make eccentric masses. For each material, there were four pieces, which functioned as eccentric masses, i.e., two eccentric masses on each side of the shaft (Figure 5). The eccentric masses were fixed to the shaft by set screws. The thickness of each eccentric mass was 4 mm. The weight of each eccentric mass was 3.5 g (plastic), 8 g (aluminium) and 26 g (copper). In order to fine-tune the weight contribution of the eccentric mass, the angle between the two pieces constituting the eccentric mass on each side of the shaft could be adjusted to six different angles: 0°, 30°, 60°, 120°, 150°, and 180°. This produces 100%, 96.6%, 86.6%, 50%, 25.8% and 0% of full eccentric force, respectively. In the current study, one aluminium and one copper eccentric mass were mounted on each side of the motor shaft. The relative angle between the aluminium and the copper eccentric mass was set at 60° to give a total effective mass weight of 59 g. Testing confirmed that with the above setting the vibrator delivered vibration with an amplitude of 1.2 mm and a frequency of 65 Hz. The vibrator has also been shown to deliver repeatable vibration amplitudes and frequencies in different operational conditions, including joint angles and forces by which the vibrator is strapped to the muscle-tendon [5].