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Effect of vibration training on neuromuscular output with ballistic knee extensions

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Abstract
The aim of the study was to determine whether vibration applied directly to a muscle-tendon could enhance neuromuscular output during and 1.5 and 10 min after a bout of ballistic resistance training. Fourteen participants were exposed to two training conditions in random order: exercise with vibration and exercise with sham vibration. The exercise comprised three sets of ballistic knee extensions with a load of 60–70% of one-repetition maximum. Vibration (1.2 mm amplitude, 65 Hz frequency) was applied with a portable vibrator strapped over the distal tendon of the quadriceps. Knee joint angular velocity, moment, and power, and rectus femoris and vastus lateralis electromyography root-mean-squared were measured during knee extension. During and after training, the vibration did not induce significant changes in peak angular velocity, time to peak angular velocity, peak moment, time to peak moment, peak power, time to peak power, or average EMG of the rectus femoris and vastus lateralis. We conclude that direct vibration, at the selected amplitude and frequency, does not enhance these neuromuscular variables in ballistic knee extensions during or immediately after training.

Keywords: Vibration training, acute, acute residual

Introduction
Vibration training uses simultaneous vibration stimulation and resistance training to enhance neuromuscular output more than resistance training alone (Luo, McNamara, & Moran, 2005a). A few studies that have examined the acute and chronic effects of vibration training either found no benefit (de Ruiter, van der Linden, van der Zijden, Hollander, & de Haan, 2003a; de Ruiter, van Raak, Schilperoort, Hollander, & de Haan, 2003b; Kvorning, Bagger, Caserotti, & Madsen, 2006; Moran, McNamara, & Luo, 2007) or a significant suppression (Bongiovanni, Hagbarth, & Stjernberg, 1990) in neuromuscular mechanical output, compared with the same training without vibration. However, a greater number of studies have reported a significant enhancement in neuromuscular output (Cochrane & Stannard, 2005; Cormie, Deane, Triplett, & McBride, 2006; Delecluse, Roelants, & Verschueren, 2003; Fattorini, Ferraresi, Rodio, Azzena, & Filippi, 2006; Issurin, Liebermann, & Tenenbaum, 1994; Issurin & Tenenbaum, 1999; Rittweger, Mutschelknauss, & Felsenberg, 2003; Torvinen et al., 2002a), thus supporting the use of vibration training.

During vibration training, vibration may be applied directly or indirectly to the muscle being trained (Luo et al., 2005a). With the indirect method, vibration is transmitted from a vibrating source (e.g. a vibrating platform) distal to the target muscle(s), through part of the body to the target muscle(s) (Delecluse et al., 2003; Issurin & Tenenbaum, 1999). Unfortunately, this method limits the range of exercises that can be performed and may reduce the extent to which some dynamic exercises can be performed with high loading. A second possible limitation to indirect vibration is the attenuation of the vibration amplitude as it travels from the vibration source through the body to the target muscle (von Gierke & Goldman, 1987), with the degree of attenuation changing with changes in body posture and muscle tension. Given that enhancement from vibration training is influenced by the amplitude of the signal (Cochrane & Stannard, 2005; Cordo et al., 1996; Matthews & Watson, 1981; Torvinen et al., 2002a, 2002b) and that muscle spindle sensitivity is influenced by the amplitude of vibration (Cordo et al., 1996; Matthews & Watson, 1981), it may be more appropriate to apply the vibration directly to the target muscle.
A portable vibrator that can be strapped to the tendon of the muscle to be trained offers the potential to circumvent these problems (Luo, McNamara, & Moran, 2005b).

With traditional (non-vibration) resistance training, it has been suggested that the increase in functional strength and power may be greater when maximal-effort dynamic contractions are used compared with maximal-effort isometric contractions (Duchateau & Hainaut, 2003). Only four studies with appropriate controls (Luo et al., 2005a) have investigated the use of vibration training with maximal-effort dynamic exercises (Issurin & Tenenbaum, 1999; Issurin et al., 1994; Liebermann & Issurin, 1997; Moran et al., 2007). Of these studies, three (Issurin & Tenenbaum, 1999; Issurin et al., 1994; Liebermann & Issurin, 1997) found a significant enhancement of strength and power with vibration, but all of them employed the indirect vibration method. In contrast, Moran et al. (2007) examined direct vibration during a three-set maximal-effort dynamic bicep curl exercise, but found no enhancement in neuromuscular output. However, this lack of vibration effect may have been due to the type of contraction employed, as the participants had to decelerate the free weight (70% 1-RM) towards the end of the concentric phase. Such decelerations result in a decrease in muscle activity and force output when compared with performing the same exercise but with the resistance load being projected into the air (ballistic contraction) (Newton, Kraemer, Hakkinen, Humphries, & Murphy, 1996). It is possible that the reduced force output interfered with any vibration-induced enhancement and a ballistic exercise may be able to demonstrate a positive vibration effect if one is evident.

Finally, vibration may also have a positive effect on the strength and power produced immediately after vibration training (acute residual effect) (Cochrane & Stannard, 2005; Cormie et al., 2006; Torvinen et al., 2002a; Warman, Humphries, & Purton, 2002), which suggests that vibration training could be an effective warm-up for the subsequent strength or power training exercise. However, this acute residual effect has only been found after vibration training with a very light exercise (Cochrane & Stannard, 2005; Torvinen et al., 2002a) or no exercise (Warman et al., 2002). Only Issurin and Tenenbaum (1999) have investigated the acute residual effect of vibration training with maximal-effort dynamic exercises. Although no residual enhancement was found, the authors suggested that the short duration of vibration employed in their study (only one set lasting 6–7 s) may not have been sufficient to induce a residual effect. It is possible that with multiple sets of vibration training, which would reflect a more traditional training session, a greater residual effect may be achieved.

Therefore, the aims of the present study were (1) to examine the acute and acute residual effects of direct vibration on neuromuscular performance while undertaking a ballistic knee extension resistance exercise, and (2) to determine whether the effects of vibration, if any, were due to a placebo effect. It was hypothesized that neuromuscular performance would be enhanced by direct vibration, and that this enhancement would not be due to a placebo effect.

Methods

Participants

Fourteen young adult male volunteers, with at least two years’ experience of resistance training, took part in the study. Dublin City University’s Ethics Committee approved the study and written informed consent was obtained from all participants. The mean (± s) age, mass, and height of the participants were 21.6 ± 2.2 years, 77.1 ± 15.1 kg, and 1.80 ± 0.10 m, respectively. Participants were in general good health and free from neuromuscular disease and injury, and were not allowed to undertake any resistance training on their legs during the experimental period.

Training conditions

Participants were exposed to two training conditions in random order: (1) exercise with superimposed vibration and (2) exercise with sham vibration. The exercise condition comprised three sets of ballistic knee extensions with a load of 60–70% of the participant’s one-repetition maximum (1-RM) performed on a leg extension machine (Figure 1).
Each set consisted of five repetitions. This combination of three sets of five repetitions was selected because it represents a common training programme design for developing mechanical power (Baechle, Earle, & Wathen, 2000).

Test equipment

Participants were assessed on a leg extension machine and were firmly strapped to the seat. Their popliteal fossa was aligned to the rotation axis of the load on the machine. The participants were instructed to hold their arms across their chest and keep their back straight during the exercise. Only the participant’s dominant leg, determined via a maximum-effort kicking task, was used in lifting the weight. In the concentric phase, participants were instructed to “lift the weight as hard and as fast as possible, so as to attempt to project it”. In the eccentric phase, participants were instructed to “lower the weight to the start position before the next contraction begins”. Subsequent analysis indicated significant knee joint power in both the eccentric and concentric phase, which confirmed that a stretch–shortening cycle of the knee extensors was employed. A safety bar was firmly fixed to an exterior frame support to stop the weight from hitting the participant in the lifting phase (Figure 1).

Study design

Knee extension 1-RM strength was estimated for each participant using a 10-RM load protocol (Baechle et al., 2000), which was undertaken at least 3 days before the start of the experiment. This 1-RM strength was used for the duration of all test days. During this visit, participants also familiarized themselves with the test procedure and the ballistic knee extension exercise. They were also trained to perform maximal-effort isometric contractions of the knee extensors. During the test day, participants performed a warm-up exercise (one set of 10 repetitions at 25% of 1-RM), followed by a maximal-effort isometric contraction of the knee extensors for 5 s from a knee joint angle of 120°. After 5 min rest, a set of five repetitions of ballistic knee extensions with a 60–70% 1-RM load was performed as the pre-training test. After a further 5 min, the participants performed three sets of the same training exercise with either the sham vibration or with the vibration proper, with 5 min rest between sets (Figure 2). Post-training tests consisted of two sets of five repetitions of ballistic knee extension actions performed at 1.5 min and 10 min after the end of vibration training. This procedure was undertaken on two occasions separated by at least 3 days, once for each experimental condition (vibration and sham vibration).

Vibration

Direct vibration was produced by a portable muscle-tendon vibrator that was developed in-house (Luo et al., 2005b). The vibrator was strapped to the skin over the muscle-tendon of the quadriceps 5–10 cm from the superior surface of the patella, depending on the size of the participant’s leg. The distance (to the nearest millimetre) was recorded to aid accurate repositioning on different test days. In a previous study, we found that the vibrator could produce repeatable vibration amplitude and frequency across different operational conditions, including different test days, joint angles, and forces by which the vibrator was strapped to the muscle (Luo et al., 2005b). Vibration amplitude and frequency were set at 1.2 mm and 65 Hz, respectively. These vibration characteristics were selected because we have previously shown them to be effective in stimulating sub-maximal isometric contractions (Luo et al., 2005b). In addition, our previous study found that the vibration characteristics employed in the current study (vibration amplitude and frequency, and the location of vibrator) could induce tonic vibration reflex and significantly enhance EMG output of the quadriceps during sub-maximal isometric contractions (Luo, McNamara, & Moran, 2007). In the sham vibration conditions, the eccentric mass was taken off the motor, but the participants could still hear the noise of the motor. They were informed before the experiment that this was another kind of vibration training with a very small vibration amplitude that they may not be able to feel. In the sham vibration condition, the vibration acceleration measured on the housing of the vibrator was $0.02 \text{ m} \cdot \text{s}^{-2}$ with a negligible amplitude (0.1 μm).

Measurements

The knee joint angle and EMG of the rectus femoris and vastus lateralis were measured during training.
and in pre- and post-training tests. Electromyograms were also recorded during the maximal isometric contraction of the knee extensors. Knee joint angle was measured by an electrogoniometer (XM110, Biometrics, Gwent, UK), amplified (DataLink, Biometrics, Gwent, UK) and sampled at a frequency of 50 Hz. The EMG electrode on the rectus femoris was placed at half of the distance along a line connecting the anterior superior spina iliaca to the superior patella according to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles, http://www.seniam.org/, accessed in 2004). The EMG electrode on the vastus lateralis was placed at two-thirds of the distance along a line connecting the anterior superior spina iliaca to the lateral border of the patella (SENIAM). The skin was abraded and cleaned and a bipolar electrode (AE-131, NeuroDyne Medical, Cambridge, MA) with a centre-to-centre distance of 2 cm was attached to the muscle. The resistance between the electrodes was measured to ensure that it was less than 5 kΩ.

The EMG signals were connected to the differential amplifier (input impedance = 100 MΩ, bandwidth = 10–500 Hz, common mode rejection ratio > 75 dB from DC to 100 Hz) of a Powerlab 4/20T unit (Powerlab, AD Instruments, Colorado Springs, CO). The EMG signal was sampled at 1000 Hz, and was converted on-line to a root-mean-squared value of EMG (EMGrms) by Powerlab (averaging constant 50 ms). Synchronization of the goniometer and EMG measurements was achieved by connecting an output stimulation signal from the Powerlab to the DataLink. The absence of vibration-induced electrical and/or movement artifacts in the EMG signal was checked for before each experiment. This was performed by analysing the power spectrum of the EMG signal collected while each participant’s leg was in a state of rest (Luo et al., 2005b), with vibration applied for 3 s as detailed above. The power spectrum indicated no peaks at the vibration frequency, confirming that no artifacts were present.

Data analysis

The sampled joint angle data were filtered by a windowed-sinc filter (Smith, 1997). The residual method (Winter, 1990) was used to determine the optimal cut-off frequency for filtering of joint angle data, and the optimal cut-off frequency was found to be 2 Hz. The angular velocity and acceleration data were calculated from the filtered joint angle data by differentiation (Winter, 1990). The concentric phase was determined as the time from when the knee joint angular velocity changed from negative to positive to when the knee joint angular velocity changed to negative again. The moment and power data were calculated using standard inverse dynamics (Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1994; Winter, 1990). For knee joint angular velocity (ω), extension moment (Mknee), and power (Pknee), the peak value and the time to peak value were determined as the dependant mechanical variables. EMGrms data on the rectus femoris and vastus lateralis during the concentric phase were averaged (aEMGrms) and then normalized to the average EMGrms (aEMGrms) measured during the 5-s maximal isometric contraction of the knee extensors.

To maximize Cronbach’s alpha coefficient for the dependent variables, dependent mechanical and EMG variables for the second, third, and fourth repetitions of each set were selected and averaged to represent the variables for each set.

Statistical analysis

Since identical pre-training tests were undertaken in both experimental conditions (vibration and sham vibration) performed on two different days, the inter-day reliability of all dependent variables was assessed using intra-class correlation (ICC) and the 95% limits of agreement (Atkinson & Nevill, 1998; Nevill & Atkinson, 1997). To assess the 95% limits of agreement, the heteroscedasticity of the data was first investigated by examining whether there was a positive and significant relationship between the differences in the day-to-day measurements and the size of the measurements. If heteroscedasticity was present, the data were logarithmic (natural) transformed and the ratio limits of agreement were calculated (Atkinson & Nevill, 1998; Nevill & Atkinson, 1997).

To determine the acute effect of the vibration treatment (vibration, sham vibration) and set (pre-training test, set 1, set 2, set 3) on the mechanical and EMG variables during training, a two-factor [vibration treatment (2) × set (4)] analysis of variance (ANOVA) with repeated measures on the participants was employed. To examine the acute residual effect of the vibration treatment (vibration, sham vibration) and test time (pre-training test, post-training test at 1.5 min, post-training test at 10 min) on the mechanical and EMG variables after training, a second two-factor [vibration treatment (2) × test time (3)] ANOVA was employed. For all analyses, statistical significance was set at P < 0.05. Where a significant main effect or interaction involving the independent variable of vibration treatment was found, a main or simple effects analysis was undertaken with appropriate Bonferroni adjustment to identify where the significant difference lay. SPSS (version 11.5) was used for all statistical analysis.
Results

Reliability of measurement

The ICC of pre-training test measurements ranged from 0.61 to 0.92 (Table I). As heteroscedasticity was found in the pre-training test measurement of three variables ($M_{\text{peak}}$, $P_{\text{peak}}$, and $aEMG_{\text{rms}}$ on vastus lateralis), ratio limits of agreement were calculated for all variables (Table I). The ratio ranged from 1.16 to 1.33.

Mechanical and EMG variables during training (acute effect)

Vibration treatment, set, and their interactions did not have a significant acute effect on peak angular velocity ($\omega_{\text{peak}}$), time to peak angular velocity ($T_{\omega}$), peak moment ($M_{\text{peak}}$), time to peak moment ($T_M$), peak power ($P_{\text{peak}}$) or time to peak power ($T_p$) ($P > 0.05$) (Table II).

Vibration had a significant acute effect on the $aEMG_{\text{rms}}$ of the rectus femoris ($P=0.03$). Main effects analysis showed that the $aEMG_{\text{rms}}$ was significantly lower with vibration than with sham vibration ($P=0.03$). Although the decrease in $aEMG_{\text{rms}}$ in the vibration group was approximately 10%, 14%, and 15% in sets 1, 2, and 3, respectively (Table II), this decrease was unlikely to be induced by vibration, as $aEMG_{\text{rms}}$ in the vibration group was already significantly lower than that in sham vibration group in the pre-training test (by 7%, $P=0.03$), and neither training set ($P=0.37$) nor its interaction ($P=0.41$) had a significant effect. Vibration treatment ($P=0.61$), set ($P=0.22$), and their interactions ($P=0.28$) did not have any significant acute effect on the $aEMG_{\text{rms}}$ of the vastus lateralis.

Table I. Reliability (ICC and ratio limits of agreement) of pre-training test measurements.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sham vibration</th>
<th>Vibration</th>
<th>ICC</th>
<th>Ratio limits of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_{\text{peak}}$ (rad·s$^{-1}$)</td>
<td>3.15±0.55</td>
<td>3.09±0.55</td>
<td>0.82</td>
<td>1.03 (×/× 1.19)</td>
</tr>
<tr>
<td>$T_{\omega}$ (ms)</td>
<td>414±89</td>
<td>398±105</td>
<td>0.87</td>
<td>1.02 (×/× 1.16)</td>
</tr>
<tr>
<td>$M_{\text{peak}}$ (N·m)</td>
<td>69±27</td>
<td>67±22</td>
<td>0.92</td>
<td>1.02 (×/× 1.22)</td>
</tr>
<tr>
<td>$T_M$ (ms)</td>
<td>311±115</td>
<td>286±133</td>
<td>0.90</td>
<td>1.04 (×/× 1.27)</td>
</tr>
<tr>
<td>$P_{\text{peak}}$ (W)</td>
<td>195±65</td>
<td>179±49</td>
<td>0.68</td>
<td>0.99 (×/× 1.33)</td>
</tr>
<tr>
<td>$T_p$ (ms)</td>
<td>369±97</td>
<td>350±113</td>
<td>0.89</td>
<td>1.00 (×/× 1.16)</td>
</tr>
<tr>
<td>$aEMG_{\text{rms}}$ (RF)</td>
<td>166±35</td>
<td>154±42*</td>
<td>0.73</td>
<td>1.05 (×/× 1.22)</td>
</tr>
<tr>
<td>$aEMG_{\text{rms}}$ (VL)</td>
<td>199±41</td>
<td>199±41</td>
<td>0.61</td>
<td>1.00 (×/× 1.24)</td>
</tr>
</tbody>
</table>

Note. $\omega_{\text{peak}}$ = peak angular velocity; $M_{\text{peak}}$ = peak moment; $P_{\text{peak}}$ = peak power; $T_{\omega}$ = time to peak angular velocity; $T_M$ = time to peak moment; $T_p$ = time to peak power; $aEMG_{\text{rms}}$ = average root-mean-squared value of EMG; ICC = intra-class correlation coefficient; RF = rectus femoris; VL = vastus lateralis.

*Significantly different from sham vibration condition.

Table II. Acute effect of training on mechanical and EMG variables (mean±s).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Condition</th>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_{\text{peak}}$ (rad·s$^{-1}$)</td>
<td>Vibration</td>
<td>2.99±0.58</td>
<td>2.94±0.66</td>
<td>3.02±0.69</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>3.18±0.57</td>
<td>3.23±0.54</td>
<td>3.13±0.63</td>
</tr>
<tr>
<td>$T_{\omega}$ (ms)</td>
<td>Vibration</td>
<td>405±107</td>
<td>402±99</td>
<td>425±109</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>389±92</td>
<td>382±86</td>
<td>380±95</td>
</tr>
<tr>
<td>$M_{\text{peak}}$ (N·m)</td>
<td>Vibration</td>
<td>65±20</td>
<td>64±19</td>
<td>66±19</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>69±24</td>
<td>69±24</td>
<td>72±27</td>
</tr>
<tr>
<td>$T_M$ (ms)</td>
<td>Vibration</td>
<td>304±135</td>
<td>301±123</td>
<td>327±141</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>280±122</td>
<td>276±106</td>
<td>265±117</td>
</tr>
<tr>
<td>$P_{\text{peak}}$ (W)</td>
<td>Vibration</td>
<td>179±49</td>
<td>173±52</td>
<td>186±155</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>205±66</td>
<td>209±162</td>
<td>212±68</td>
</tr>
<tr>
<td>$T_p$ (ms)</td>
<td>Vibration</td>
<td>361±118</td>
<td>369±107</td>
<td>383±116</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>347±99</td>
<td>335±93</td>
<td>331±98</td>
</tr>
<tr>
<td>$aEMG_{\text{rms}}$ (RF)</td>
<td>Vibration</td>
<td>153±45*</td>
<td>147±40*</td>
<td>143±38*</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>170±35</td>
<td>170±39</td>
<td>168±43</td>
</tr>
<tr>
<td>$aEMG_{\text{rms}}$ (VL)</td>
<td>Vibration</td>
<td>185±38</td>
<td>197±44</td>
<td>181±41</td>
</tr>
<tr>
<td></td>
<td>Sham vibration</td>
<td>191±65</td>
<td>198±74</td>
<td>197±72</td>
</tr>
</tbody>
</table>

Note. $\omega_{\text{peak}}$ = peak angular velocity; $M_{\text{peak}}$ = peak moment; $P_{\text{peak}}$ = peak power; $T_{\omega}$ = time to peak angular velocity; $T_M$ = time to peak moment; $T_p$ = time to peak power; $aEMG_{\text{rms}}$ = average root-mean-squared value of EMG; RF = rectus femoris; VL = vastus lateralis.

*Significantly different from sham vibration condition.
Mechanical and EMG variables after training (acute residual effect)

Vibration treatment, test time, and their interactions did not have any significant acute residual effect on any of the mechanical variables examined ($P > 0.05$) (Table III). Compared with the sham vibration group, the aEMG$_{rms}$ of the rectus femoris in the vibration group was significantly lower ($P = 0.03$), by 16% and 15% in the post-training tests at 1.5 min and 10 min, respectively; but again these differences were unlikely to be due to vibration because aEMG$_{rms}$ in the vibration group was already significantly lower than that in the sham vibration group in the pre-training test (by 7%, $P = 0.03$), and neither test time ($P = 0.07$) nor its interaction ($P = 0.14$) had any significant effect. Finally, vibration treatment ($P = 0.67$) and its interaction ($P = 0.59$) had no significant acute residual effect on the aEMG$_{rms}$ of the vastus lateralis, but test time had a significant effect ($P = 0.004$). The aEMG$_{rms}$ of the vastus lateralis in the post-training test at 1.5 min was 10% lower than in the pre-training test ($P = 0.004$).

Discussion

The results of the current study show that the acute (within training) mechanical output and muscle activity were not enhanced by superimposed direct vibration (1.2 mm, 65 Hz) during maximal-effort ballistic knee extensions (60–70% 1-RM). These results are similar to those previously reported for the effect of direct vibration during a bicep curl exercise (70% 1-RM) (Moran et al., 2007), and confirm that the type of contraction alone (ballistic or non-ballistic) was not the reason for this lack of enhancement. This would suggest that either direct vibration is not capable of enhancing neuromuscular output or that the vibration characteristics were not appropriate. Here, we argue for the latter and suggest that a different physiological mechanism for neuromuscular enhancement may be employed during maximal-effort dynamic exercises that uses a significant stretch–shortening cycle than during submaximal isometric exercises, and that the vibration characteristics employed in the present study were not able to activate these mechanisms effectively.

The most pervading view at present is that vibration training enhances neuromuscular output via vibration-induced augmentation of Ia afferent input, which facilitates the recruitment of more motor units during strength training (Bongiovanni & Hagbarth, 1990; Bosco, Cardinale, & Tsarpela, 1999; Cardinale & Bosco, 2003; Issurin, 2005; Issurin & Tenenbaum, 1999; Issurin et al., 1994). The vibration amplitude and frequency employed in the present study (1.2 mm and 65 Hz) were within the optimal ranges of vibration parameters necessary to activate human muscle spindle primary endings. Studies employing microneurographic techniques have shown that the primary endings of human muscle spindles could be readily activated by vibration with an amplitude ranging from 0.2 to 1.5 mm applied to the muscle-tendon (Burke, Hagbarth, Lofstedt, & Wallin, 1976a; Roll, Vedel, & Ribot, 1989). In addition, the response of primary
endings could be locked in a 1:1 mode up to a vibration frequency of 100 Hz (Roll et al., 1989). Although muscles in these studies were not contracting prior to vibration, the response of muscle spindle primary endings to vibration should be greater in sub-maximal or maximal contractions because voluntary contractions can induce co-activation of the fusimotor system (Burke, Hagbarth, Lofstedt, & Wallin, 1976b) and enhance the sensitivity of muscle spindle primary endings (Brown, Crowe, & Matthews, 1965; Fattorini et al., 2006). In a previous study, we showed that applying direct vibration with the same vibration characteristics as used in the present study results in an enhancement in EMG of the rectus femoris and vastus lateralis in sub-maximal isometric contraction of the knee extensors (Luo et al., 2007). Clearly, direct vibration with the characteristics employed in the present study has the capacity to positively stimulate the neuromuscular system under certain conditions, yet in contrast to previous studies that used indirect vibration (Issurin & Tenenbaum, 1999; Issurin et al., 1994; Liebermann & Issurin, 1997) it was unable to induce an enhancement in maximal-effort dynamic exercises which use a significant stretch-shortening cycle.

The reason for this may be that a mechanism other than tonic vibration reflex is responsible for the enhancement in maximal-effort dynamic exercises. This mechanism may be related to an increase of muscle spindle receptor sensitivity (gain), which requires a smaller vibration amplitude to function effectively (Cordo et al., 1996; Matthews & Watson, 1981). In an examination of cats, Matthews and Watson (1981) found that only small amplitudes of vibration (2.5–10 μm at 150 Hz) are able to enhance muscle spindle afferents during sinusoidal stretch by increasing the sensitivity (gain) of the spindles, and at low amplitudes this was localized to the stretch phase of the muscle. The discharge rate of afferents during the rising phase of the stretch was at the vibration frequency or its sub-harmonics. At higher amplitudes of vibration, however, the afferent signals were enhanced both during the rising and releasing phase of the stretch, and fired at the same frequency, resulting in a suppression of the afferent response to the sinusoidal stretch (Matthews & Watson, 1981). Cordo et al. (1996) found that the sensitivity (gain) of human muscle spindle receptors could be enhanced by noisy vibration applied directly to the muscle tendon. This enhancement was highest when the amplitude of the noisy vibration was in a particular range, decreasing with an increase of the vibration amplitude (Cordo et al., 1996). Although the above studies did not investigate the motor output directly, they indicated that small-amplitude vibration may be able to enhance the stretch reflex by enhancing the sensitivity (gain) of muscle spindle receptors, which is important in effective use of the stretch–shortening cycle (Komi, 2000). In contrast to the present study, which applied vibration with an amplitude of 1.2 mm directly to the muscle-tendon, vibration in those studies that found vibration-induced enhancement in maximal dynamic exercises (Issurin & Tenenbaum, 1999; Issurin et al., 1994; Liebermann & Issurin, 1997) was applied indirectly (0.3–0.4 mm) to the biceps by grasping a vibrating handle and, therefore, due to attenuation of the vibration signal as it travels through the body (Pyyko, Farkkila, & Toivanen, 1976; von Gierke & Goldman, 1987), an even smaller amplitude would have reached the target muscle. Therefore, it is possible that the smaller vibration amplitudes employed in these studies (Issurin & Tenenbaum, 1999; Issurin et al., 1994; Liebermann & Issurin, 1997) are more appropriate to increase the muscle spindle receptor sensitivity and the motor output in maximal-effort dynamic contractions.

Finally, while several studies (Cormie et al., 2006; Torvinen et al., 2002a; Warman et al., 2002) have found that vibration training facilitates strength and power output of subsequent contractions completed immediately after the vibration training (acute residual effect), no enhancement was found in the present study. However, since in contrast to the above studies no enhancement was found in the acute effect, no conclusion can be drawn on the lack of enhancement in the acute residual effect. Although the aEMGrms of the rectus femoris in the post-training contraction was significantly decreased by vibration training in the present study (Table III), this decrease could be explained by the significant difference between the vibration and sham vibration groups in the pre-training test. The aEMGrms of the vastus lateralis at 1.5 min after training decreased significantly (P < 0.004) from the pre-training test in both the vibration and sham vibration groups, which may be due to the increase of muscle temperature after exercise (Moran et al., 2007; Stewart, Macaluso, & De Vito, 2003).

In conclusion, for maximal-effort ballistic knee extensions (60–70% 1-RM), direct vibration stimulation had no beneficial acute or acute residual effect on neuromuscular performance when an amplitude of 1.2 mm and a frequency of 65 Hz were used.

References


