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Original research

The effect of four different vibratory stimuli on dynamic range of motion of the hamstrings

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Abstract

Objective: The purpose of this study was to investigate the influence of four different segmental vibratory stimulation (VS) loads on dynamic range of motion (ROM) of the hamstrings.
Design: This study used a randomised cross-over design.
Participants: Ten male club level athletes (age 22.7 ± 3.6 yr, height 181.2 ± 6.51 cm, mass 84.9 ± 12.3 kg) volunteered to participate.
Outcome measures: A two factor repeated measures ANOVA (intervention $\times$ time) with post hoc comparisons was used to determine whether any vibration setting produced a significantly greater ROM change ($p \leqslant 0.05$).
Results: A significant increase in dynamic ROM was found for three out of the four vibration loads (1.6–2.1%). VS using load parameters of 5 mm amplitude, 44 Hz, 49.4 m s^{-2} resulted in the greatest mean ROM improvement, however, this was not significantly different to the increases observed for the other loading parameters. The VS treatment effects (effect sizes ~1.2 and greater) in these studies were for the most part larger than the treatment effects found in research using more traditional stretching methods.
Conclusions: Segmental vibration in combination with various stretching techniques may offer interesting options in terms of improving ROM in the short and long term.

Keywords: Performance; Musculotendinous; Flexibility; Vibratory stimulation

1. Introduction

Vibration and its role in occupational science, rehabilitation science, and most recently sports science, have received a great deal of investigation. With regards to sports science, the effect of vibratory stimulation (VS), in particular whole-body vibration, on muscle function and performance has been the focus of much recent research interest. For example, VS has been found to significantly enhance acute maximal isometric and dynamic strength by between 3.2% and 49.8% (Delecluse, Roelants, & Verschueren, 2003; Issurin, Liebermann, & Tenenbaum, 1994; Torvinen, Kannus, Sievanen, Jarvinen, Pasanen, & Kontulainen, 2002), increase power output by between 7% and 13% (Bosco, Cardinale, & Tsarpela, 1999; Bosco, Cardinale, Tsarpela, & Locatelli, 1999; Bosco, Lacovelli, Tsarpela, Cardinale, Bonifazi, & Tihanyi, 2000), increase vertical jump height by between 2.5% and 8.1% (Bosco et al., 2000; Cochrane & Stannard, 2005; Delecluse et al., 2003; Torvinen et al., 2002), and increase flexibility by up to 30% (Cochrane & Stannard, 2005; Issurin et al., 1994; Sands, McNeal, Stone, Russell, & Jemni, 2006; van den Tillaar, 2006). There have also been detrimental effects reported from vibration on performance. These include decreases of up to 9.2% in force output, 9.1% in vertical jump height (Rittweger, Beller, & Felsenberg, 2000), and 2.4% in voluntary muscle activation (de Ruiter, van der Linden, van der Zijden, Hollander, & de Haan, 2003).

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Most of the research in this area has used whole-body sinusoidal vibration (WBV) using frequencies ranging from 26 to 50 Hz, 1.25 to 10.5 mm amplitude, and accelerations of 0.5 to 17.0 m s^2. This is despite Bosco, Cardinale et al. (1999) finding segmental vibration to significantly improve average force, power and velocity of the arm flexor muscles. The lack of investigation into segmental vibration is coupled with a lack of research into the effect of vibration on range of movement (ROM). It is thought that VS may offer a means by which short- and long-term changes in ROM may be achieved. The findings of one study certainly support this contention. Following 3 weeks of flexibility training superimposed with vibration, Issurin et al. (1994) observed a significant increase in leg splits (8.7%) and trunk flexion (43.6%) compared to conventional stretching (1.2% and 5.8%, respectively) and a control group that performed no flexibility training. Subjects stood on one leg while placing the other in a hanging ring and completed 3–4 sets of static stretching (6–7 s) and one set of ballistic stretching (10–30 s). The underlying mechanisms responsible for the increase in flexibility were assumed to be one of the following: (1) an increase in pain threshold, (2) an increase in blood flow (accompanied by a temperature increase), or (3) a stimulation of the Golgi tendon organs (GTO). Excitation of the GTO results in inhibition of the contraction, followed by relaxation of the muscle (Issurin et al., 1994). It appears that an increase in flexibility from vibration training has no effect on the length of the muscle or on the contraction of the muscle in opposition to the stretch. It seems more likely to have a central cause, namely, an increase in stretch tolerance. Such a contention is supported by the research of Ribot-Ciscar, Rossi-Durand, and Roll (1998). After tendon vibration (80 Hz for 30 s) muscle spindle activity decreased (3 s post vibration) and subjects perceived a stretched muscle as being less stretched than it actually was. This is an indication that vibration produced centrally localised neural changes as opposed to changes in the mechanical properties of the muscle itself.

Despite the paucity of research in this area it seems likely that segmental VS can improve ROM. However, it is unknown which loading parameters or vibratory waveforms are optimal for effecting acute or long-term ROM changes. Given this information, this study aimed to investigate the influence of four different segmental vibratory loads on dynamic ROM of the hamstring musculature.

2. Methods

2.1. Participants

Ten male participants (mean ± SD, age 22.7 ± 3.6 yr, height 181.2 ± 6.51 cm, mass 84.9 ± 12.3 kg) volunteered to participate in this study. All participants competed competitively in sports at a club level. The participants read and signed a consent form prior to all testing which had been approved by the Auckland University of Technology Ethics Committee. The participants all passed the same exclusion criteria prior to testing, and were unable to fully extend their knee with 90° hip flexion.

2.2. Equipment

A vibratory machine, consisting of an oscillatory platform powered by a motor (see Fig. 1) was used for this study. The machine was designed specifically for segmental vibration training and allowed six different vibration settings.

Prior to testing, an accelerometer (Sensotec Model JTF, Ohio) and a computer-based data acquisition and analysis programme (LabView Version 6.1; National Instruments, Austin, Texas) were used to determine the frequency, amplitude, and accelerations associated with each setting (see Table 1 and Fig. 2). It was decided after analyzing the frequencies in Table 1, that 4 vibration settings (Settings 2–5) would be used to compare the effects of these vibratory loading parameters on ROM. Following this selection, the vibration settings were renamed for ease of reporting. Setting 2 on the machine became Setting 1, Setting 3 became Setting 2 and so forth and will be termed as such for the remainder of this paper.

A custom-made frame was attached to a plinth, which was used to control hip movement throughout the ROM testing (see Fig. 3). ROM was assessed using a digital video camera (DCR-TRV27E, Sony Corporation, Japan) positioned perpendicular to the hip positioned

Fig. 1. Vibration machine.

on the plinth at a standardised height (1.5 m) and distance (3.0 m) from the plinth on a tripod. Video footage was later analysed using siliconCOACH (Version 6.5.1.0; siliconCOACH Ltd., Dunedin, NZ) to determine the active ROM at the knee joint during testing.

2.3. Procedures

Prior to testing, a pilot study investigated the error of measurement associated with static and dynamic ROM assessment. Both techniques were found to be equally reliable and there were no significant differences between the static and dynamic ROM measures. For this reason and for face validity purposes, dynamic ROM assessment (ICC $\geqslant$0.89, CV$<$2.1%) was used in this study.

All assessments were performed by an experienced physiotherapist. Each testing occasion consisted of the subject having their right leg marked with a black permanent marker at the lateral epicondyle of the knee and lateral malleolus of the ankle. A third marker was placed on the plinth vertically aligned with the greater trochanter, and the right leg was fixed to the custom made frame with a belt. The participant's left leg was strapped to the table to stabilise the pelvis and avoid lumbar flexion during testing (see Fig. 3).

The participants completed a 5-min warm-up, consisting of a light jog at an intensity which the subject estimated to be 40% of their maximal speed, or such that they could hold a light conversation whilst jogging. After this standardised warm-up, the subject maximally extended, and then flexed their right leg at 1 s intervals for 10 repetitions, as verbally cued by the video-camera operator. Following the ROM assessment, the subject placed the thigh of the testing leg on the vibration machine for 30 s, where post-vibration dynamic ROM measures were taken. Vibration setting order was randomised and was blinded from the participant. The outline of the experimental procedures is summarised in Fig. 4.

The procedure was then replicated for each subject following a 15-min rest period. Fifteen minutes was chosen as previous research has shown that this was the length of time required for the return of the normal stretch reflex of the triceps surae muscle following prolonged static stretches (Avela, Kyrolainen, & Komi, 1999). Also, Ribot-Ciscar et al. (1998) found a complete recovery of resting and stretch sensitivity of muscle spindles following vibration after 40 s. Hence it was agreed that any neuromuscular effect from the previous

Table 1
Characteristics of the six vibratory settings

Machine setting	Post-measurement revised setting number	Peak acceleration ($m\,s^{-2}$)	Amplitude (mm)	Frequency (Hz)
1		17.9	3	10
2	1	19.3	3	14
3	2	33.2	3	24
4	3	42.2	3	34
5	4	49.4	5	44
6		60.9	5	47

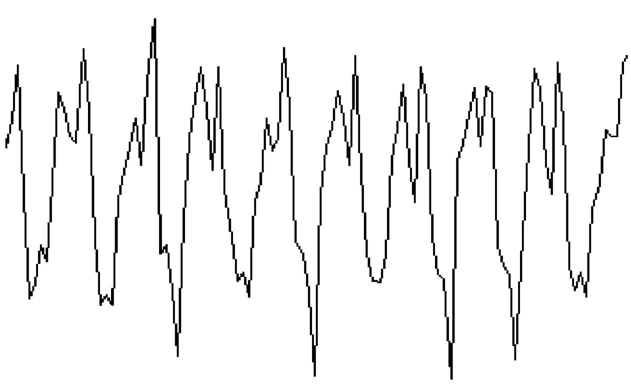

Fig. 2. Typical random waveform of vibratory device.

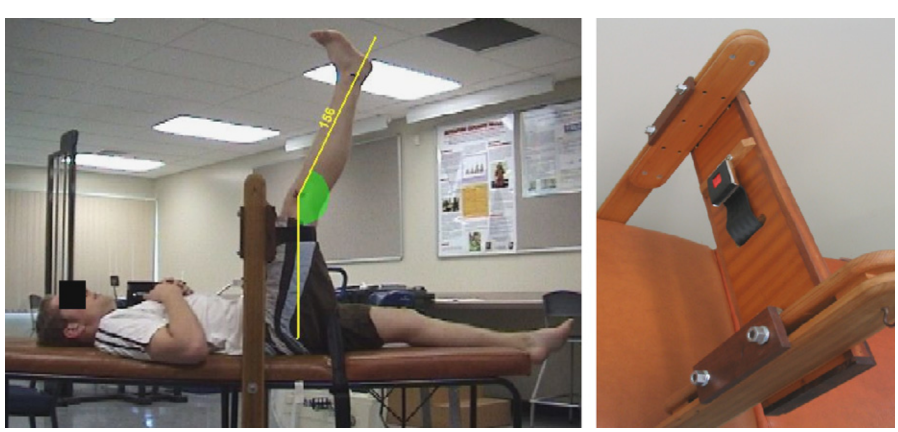

Fig. 3. Frame for limiting hip flexion, with fixation belt magnified.

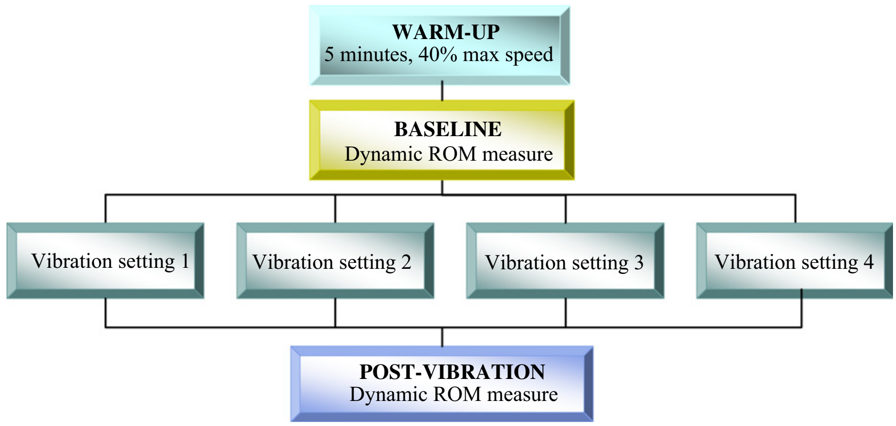

Fig. 4. Study design.

setting should have disappeared by the completion of the 15-min period. The participants returned on a separate occasion for the assessment at the other two vibration settings. All assessments occurred within 5 days.

2.4. Statistical analysis

All statistical procedures were performed by Sigma-Stat (Version 3.1; Systat Software Inc, Richmond, California, USA). Descriptive statistics were used to profile the frequency, amplitude, and gravitational forces associated with the four different vibration settings. Effect sizes (ES) were calculated (post-test mean−pre-test mean/pooled pre-test SD). A two factor repeated measures ANOVA (intervention × time) with post hoc comparisons was used to determine whether any vibration setting produced a significantly greater ROM change. Statistical significance was set at an alpha level of $p \leqslant 0.05$.

3. Results

The results of VS on the pre–post ROM measures of the four settings are shown in Table 2 as percent changes and pre–post degree changes. A significant increase in dynamic ROM was found for vibration setting 2 (1.6%, $p = 0.022$), setting 3 (2.0%, $p = 0.035$), and setting 4 (2.1%, $p = 0.007$). Even though VS using setting 4 (5 mm amplitude, 44 Hz, 49.40 m s^2) resulted in the greatest mean ROM improvements, this was not significantly different to the increases observed for settings 2 and 3.

It can be observed that individual participants responded differently to the VS within and between settings. For example, four participants decreased their ROM after vibration at setting 1 whereas only two participants decreased ROM for setting 4. The greatest changes in dynamic ROM were observed for participants 8 (4.7%) and 9 (5.1%) at setting 4, however, their responses were very different for other settings. It appears that different vibratory loads affected ROM in a non-systematic manner in each individual.

4. Discussion

The largest mean changes in ROM in this study were 2.1% (3.1°) using vibratory setting 4; however, this ROM increase was not significantly different to settings 2 and 3. The ES ranged from 1.15 to 1.77. Percent change and ES for changes in ROM have been calculated or reported for other interventions such as warm-up in ROM were for the most part less than those reported (4.9–10.3%—ES = 0.1–0.2) (de Weijer, Gorniak, & Shamus, 2003; Wenos & Konin, 2004), static stretching (4.6–16%—ES = 0.2–1.7) (de Weijer et al., 2003; DePino, WeBright, & Arnold, 2000; Power, Behm, Cahill, Carroll, & Young, 2004; Taylor, Waring, & Brashear, 1995), PNF stretching (5.3–20%—ES = 0.2–0.8) (Henricson, Fredriksson, Persson, Periera, Rostedt, & Westlin, 1984; Knappstein, Stanley, & Whatman, 2004; Spernoga, Uhl, Arnold, & Gansneder, 2001), and the combination of heat and stretches (4.8–21%—ES = 0.2–1.8) (de Weijer et al., 2003; Henricson et al., 1984; Taylor et al., 1995). The treatment effects in these earlier studies, however, were for the most part less than the large effects (~1.2 and greater) found in the current study. This difference can be attributed to the greater variability (standard deviations ranging from 3.5 to 11.8°) in the assessment procedures used in other research as compared with this study (0.9–5.9°).

The relatively small changes in ROM identified in this study post-VS, may be attributed to opposing responses of the passive and active components of the muscle. That is, vibration has been found to cause vasodilation of muscle capillaries, resulting in an increase in blood flow and intra-muscular temperature (Bosco, Colli, Introini, Cardinale, Tsarpela, & Madella, 1999;

Table 2
Pre–post difference, percentage changes and effect sizes between ROM measures, and vibration settings 1–4

Subject	1	2	3	4	5	6	7	8	9	10	Av. (SD) (Within groups)
Setting 1											
Pre–post change in dynamic ROM	3.5	1.8	−3.5	−2.7	−4.1	1.7	0.7	1.6	−3.6	2.5	0.2° (2.92)
% change	2.4	1.0	−2.7	−2.2	−2.6	0.4	0.8	0.9	−3.0	1.9	−0.2% (1.93)
Effect s	3.5	1.1	1.4	1.2	1.8	1.0	0.3	1.0	1.4	0.9	1.36
Setting 2											
Pre–post change in dynamic ROM	5.5	5.4	−0.5	2.4	4.1	1.0	2.7	−3.3	3.4	3.0	2.4° (2.71)
% change	3.6	3.8	−0.3	1.7	2.7	0.7	1.8	−2.0	2.4	1.9	1.6% (1.78)*
Effect size	2.6	2.1	0.2	1.3	1.3	0.6	1.2	1.2	2.7	0.8	1.4
Setting 3											
Pre–post change in dynamic ROM	5.7	5.4	0.1	3.0	2.7	−4.0	7.3	−1.7	4.5	5.8	2.9° (3.67)
% change	3.8	3.7	0.1	2.1	1.9	−2.6	5.1	−1.1	3.1	3.8	2.0% (2.46)**
Effect size	2.2	3.4	0.1	1.8	1.3	2.6	2.5	0.6	1.8	1.4	1.77
Setting 4											
Pre–post change in dynamic ROM	0.8	4.8	3.7	−0.1	−1.8	3.0	3.6	7.1	7.2	3.2	3.1° (2.90)
% change	0.5	3.3	2.5	−0.1	−1.2	1.9	2.4	4.7	5.1	2.1	2.1% (1.99)***
Effect size	0.3	2.4	1.1	0.0	0.5	1.1	0.9	2.2	2.1	0.9	1.15
Av. Effect size (Within participants)	2.15	2.25	0.70	1.08	1.23	1.33	1.23	1.25	2.00	1.00	

*Significant ($p = 0.022$).
**Significant ($p = 0.035$).
***Significant ($p = 0.007$).
Note: Effect size based on Cohen's scale where 0.0 = trivial, 0.2 = small, 0.6 = moderate, 1.2 = large, 2.0 = very large, 4.0 = nearly perfect, infinite = perfect. From *New view of statistics*: *Effects magnitude* by W. Hopkins. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html on July 7, 2005.

Kerschan-Schindl, Grampp, Henk, Resch, Preisinger, & Fialka-Moser, 2001). Such responses should increase ROM through decreased tissue viscosity (Cronin, Oliver, & McNair, 2004), and increased compliance (Tancred & Tancred, 1995). However, vibration has also been found to alter neural responses through enhancement of the stretch–reflex loop (Cardinale & Bosco, 2003), resulting in a tonic reflex contraction of the muscles in response to the stretching force (Matthews, 1966) and increased recruitment of motor units via activation of muscle spindles and polysynaptic pathways (De Gail, Lance, & Neilson, 1966). This neural influence could be detrimental to increased ROM, as an increase sensitivity of the stretch reflexes could limit the ROM, hence these two physiological responses to vibration could in essence limit or negate each others effect on ROM.

Another possible explanation for the relatively small changes in ROM is the nature of the waveform and vibratory loads used in this study. The only other studies on vibration and ROM changes, used VS at 44 Hz, 3 mm, and 22–30 m s^2 (Issurin et al., 1994). In the current study, segmental random waveforms were used and the loading parameters ranged from 3 to 5 mm amplitude, 10 to 47 Hz frequency, and 17.9 to 60.9 m s^2 acceleration. It is quite likely that these different vibratory waveforms (sinusoidal versus random) and loading parameters resulted in markedly different functional and performance responses as compared to other forms of VS. Furthermore, there may have been a greater acute change in ROM had the participants utilised a stretching protocol in combination with vibration. However, the aim of this study was to investigate whether segmental VS, as a stand-alone stimulus, offered any acute ROM benefits.

In terms of the individual responses, it can be observed from Table 2 that individuals responded differently to the varied vibration settings. The variation in the individual responses can be observed in the percent change (−3.0% to 5.0%) and ES (0.2–3.5). When the average effect size was calculated for each individual it was observed that for the majority of the participants in this study that VS had a large to very large effect (0.7–2.25). The largest effects were noted in participants 1 and 2 whilst participants 3 and 10 responded least to the VS.

This individual variability across different vibratory loads could be attributed to resonance. Resonance exists when the movement frequency of the stimulus is matched by the natural frequency of the musculotendinous unit (Wilson, Murphy, Walshe, & Ness, 1996). It has been reported that individuals have different resonant frequencies, which may explain the different responses to the vibratory stimulus (Wilson, Wood, & Elliott, 1991). Studies on workplace vibration have found inter-subject variability to have a large effect on transmissibility along with the different waveforms and magnitude of motion (Paddan & Griffin, 1998). For example, if a subject has a higher proportion of fat in their leg, there would be an expected increase in impedance of waveforms into the tissue. This could result in decreased resonance and hence reduced transmission of the waveforms into the tissue.

5. Conclusions

It was found that the vibratory loading parameters and random waveform used in this study significantly improved dynamic ROM, however, the percent improvement was relatively small and similar to the error associated with the measurement. Of interest therefore is the practical significance of the results. To answer this ES were calculated so as comparisons with past research could be made. The mean ES in response to the VS were larger than that of other interventions commonly used to increase ROM. However, it should be realised that individuals respond very differently to VS and other interventions may produce better increases in ROM. In comparison to other techniques used to increase ROM as reported in the literature, the segmental vibration device and associated segmental loading parameters used in this study would seem to offer acute ROM benefits at least similar to if not better than more traditional stretching techniques for the sample used in this study. Future research is needed to identify the effect of different vibratory loading parameters and waveforms, and combined stretching and vibratory training, on ROM.

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