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Research article

Effects of Foam Roller, and Massage Ball with and Without Vibration on Squat Load-Velocity Profile of Resistance Trained Adults

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Abstract

Self-massage tools such as foam rollers and massage balls are widely used in warm-ups and recovery, but their effects on dynamic strength tasks like squatting remain unclear. To compare the effects of a foam roller (FR), massage ball (MB), and vibrating massage ball (MBV) versus a control condition on squat load velocity profiles and associated electromyographic (EMG) activity in resistance-trained individuals. In this crossover study, fourteen experienced resistance-trained participants performed four experimental conditions: FR, MB, MBV, and control. After an initial session for incremental load testing and protocol familiarization, each participant performed eight back squats before and after each experimental session, while movement velocity, hip vertical displacement (range of motion), and EMG of the vastus lateralis and semimembranosus were recorded. MBV produced a significant increase in quadriceps EMG during the fastest repetition ($\beta = 0.107$; $p = 0.003$). In contrast, all interventions elicited a reduction in the second fastest repetition versus control (FR: $\beta = -0.033$, $p = 0.005$; MB: $\beta = -0.025$, $p = 0.029$; MBV: $\beta = -0.036$, $p = 0.002$). Moreover, both FR and MBV similarly decreased third fastest repetition and mean velocities relative to control (FR: third fastest repetition $\beta = -0.025$, $p = 0.027$; mean $\beta = -0.046$, $p = 0.046$; MBV: third fastest repetition $\beta = -0.032$, $p = 0.005$; mean velocity $\beta = -0.031$, $p = 0.004$). There were no significant changes in the hip vertical displacement. All self-massage conditions modestly impaired squat velocity, with the MB showing the least detrimental effect on performance.

Key words: Self-myofascial release, force-velocity, recovery, warm-up, electromyography.

Introduction

Foam rollers (FR) and variations such as FR with vibration (VFR) are often used as a warm-up (Behm et al., 2020; Wiewelhove et al., 2019), cool-down strategy, or to improve recovery (Hendricks et al., 2019). Several meta-analyses evaluated FR effects in different populations (Alonso-Calvete et al., 2022; Medeiros et al., 2023; Skinner et al., 2020), showing a consensus for acutely (Konrad et al. 2021, 2022b) and chronically (>4 weeks of rolling) (Konrad et al. 2022a;c; 2024) improving range of motion (ROM), whereas there was no consensus for physical performance improvements.

FR have often been referred to as "self-myofascial release devices" suggesting that FR and other similar devices release myofascial constrictions accumulated from scar tissue, ischaemia-induced muscle spasms and other pathologies (Behm and Wilke, 2019). However, the forces or pressures applied by a FR (portion of body mass) or a roller massager (limited arm strength) may not be sufficient to release myofascial restrictions (Schleip, 2003a; 2003b; Behm and Wilke, 2019). The body mass or arm strength is distributed over a relatively large diameter cylinder with foam rolling resulting in a dispersion of pressure (force / area).

An alternative to rollers is the use of smaller diameter balls such as baseballs, tennis balls, or other similar "hard small" balls that would increase the pressure on the tissues. Benefits of massage balls (MB) are attributed to mechanical and physiological (e.g., reduce muscle tension, stimulate vasodilator actions of serotonin and histamine increasing blood and lymphatic input), as well as psychological (e.g., muscle and mental relaxation due to endorphins and serotonin release) effects (Lima and de Sousa, 2019). However, it seems the hardness or density is not the only factor as Cheatham and Stull (2018) examined three different density rollers and did not find significant differences in ROM or pain pressure threshold (PPT). On the other hand, two studies (Curran, et al. 2008; Cheatham and Stull, 2019) compared FR surface patterns. Significantly higher pressures (Curran et al. 2008), PPT and ROM (Cheatham and Stull, 2019) with multi-level grid contact than a smooth FR were reported. They attributed the superior effects with multi-level grid patterns to the surface architecture which may have induced greater tissue deformation (higher pressures). However, Kim et al. (Kim et al., 2019) reported that a soft inflatable rubber ball allowed the soft tissue to be pressed more deeply than a hard MB as the soft ball elicited lower muscle tension and discomfort. Hirose et al. (2025) used a soccer ball to massage the hamstrings at low (15 - 25% body weight) or higher (45 - 55%) pressures for 2-minutes reporting increased hip and knee ROM for at least 10-minutes with both pressures, with no sex differences. In contrast, rolling a 12 cm foam ball for 2-minutes on the pectoralis major at the onset of discomfort did not induce changes in ROM and muscle stiffness (Reiner et al., 2023). Interestingly they attributed the lack of effects to the small area of the applied pressure with the MB. Hence, there are few studies examining MB effects on performance and the few published articles do not provide a consensus.

A variation of FR or MB is to add vibration to the rolling device. Local tissue vibration is purported to increase electromyography (EMG) activity promoting greater motor unit activation and firing frequencies, in-

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creased muscle spindle reflex and corticospinal excitation and if applied with resistance training may enhance maximum voluntary isometric contraction (MVIC) force, ROM and reduce perceived stiffness compared to traditional training alone (Germann et al., 2018). EMG responses to vibratory stimulation are highly dependent on the chosen parameters. For instance, in whole-body vibration protocols, increasing displacement from 2 to 4 mm and frequency from 20 to 60 Hz generally augments EMG activity in quadriceps, with increases up to ~50% MVC at the highest amplitudes and frequencies (Krol et al., 2011). This modulatory effect reflects enhanced tonic vibration reflexes and muscle-tuning strategies at higher mechanical stimuli (Rittweger, 2010).

Most rolling studies report similar ROM increases with FR or VFR (Cheatham et al., 2018; Lee et al., 2018; Lim et al., 2019; Griefahn et al., 2021; Kasahara et al., 2022; Nakamura et al., 2023; Kasahara et al., 2024), although Lim and Park (2019) found that VFR was more effective for increasing hamstrings (hip flexion) ROM. Cheatham (Cheatham et al., 2018) reported greater ROM and PPT with a VFR versus a non-vibrating roller. The enhanced ROM with both FR and VFR has been partially attributed to similar increases in PPT (Kasahara et al., 2022; 2024), however Cheatham et al. (2018) reported greater PPT with nonvibrating FR. A meta-analysis (8 studies) showed that VFR provided greater hip and knee ROM gains than FR (Park et al., 2021). A meta-analysis of 10 studies revealed that short duration VFR did not have significant effects on jump performance or isokinetic strength whereas there was some suggestion (no meta-analysis performed due to heterogeneity and small samples) that recovery of pain, fatigue, blood flow, and agility may be enhanced (Alonso-Calvete et al., 2022).

Thus, there is conflicting literature on the effectiveness of FR and MB on subsequent performance with no studies examining the effect of massage ball with vibration (MBV) on performance. Typical performance measures often involve MVIC forces, whereas human activities are predominately dynamic. The use of the load-velocity relationship is an effective way to detect changes in neuromuscular performance such as fatigue (Moura et al., 2024). To the best of our knowledge there are no studies investigating the load-velocity profile combined with EMG activity to measure fatigue or acute performance changes, with one study examining chronic training adaptations (Rodriguez-Rosell et al., 2021). This combination could provide valuable information to understand better what is generating possible changes in the load-velocity results. Therefore, the objective of this study was to compare FR, MB, MBV versus the control condition on a squat load velocity profile associated with EMG activity in resistance trained participants.

Methods

Experimental design

This cross-over, randomized, controlled, acute study involved five sessions. During the familiarization session, researchers collected participants' general information and conducted an incremental load test. In subsequent sessions, participants were randomly assigned to the experimental conditions: FR, MB, MBV, or control. In each experimental session, assessments were conducted both pre- and post-protocol to examine potential effects.

Participants

Fourteen resistance trained participants (Table 1) met the following inclusion criteria: age between 18 and 40 years, no injuries or pathologies affecting physical performance, and a minimum of three months of regular back squat practice. Additionally, participants had to demonstrate the ability to perform high-velocity back squats (≈ 1 m/s) with at least 20 kg. Age, sex, and foot dominance were self-reported. All participants received written and verbal explanation of the study's objectives and provided informed consent before participation. Ethical approval was granted by Memorial University of Newfoundland's University Interdisciplinary Committee on Ethics in Human Research (protocol number: 20231318-HK).

Due to the crossover study design, we performed the sample size calculation using G*power software 3.1.9.7 (Faul et al., 2009) based on the repeated measures within factors ANOVA using the results obtained by Moura et al. (2024) analyzing the mean propulsion velocity reduction in squat among male adults.

Table 1. Participants characteristics.

Variable	Sex (M/F)	Mean (SD)	95% CI Lower – Upper
Age (years)	Male	30.73 (12.96)	26.78 – 34.67
	Female	24.67 (1.77)	23.54 – 25.79
	Total	29.43 (12.10)	22.44 – 36.41
Body mass (kg)	Male	81.78	78.17 – 85.40
	Female	70.43 (13.88)	61.61 – 79.25
	Total	79.35 (13.46)	71.58 – 87.12
Height (meters)	Male	1.75 (0.05)	1.74 – 1.77
	Female	1.63 (0.10)	1.57 – 1.70
	Total	1.73 (0.08)	1.68 – 1.77
Body mass index (kg.m^{-2})	Male	26.61 (3.42)	25.57 – 27.65
	Female	26.13 (2.01)	24.84 – 27.41
	Total	26.50 (3.26)	24.62 – 28.39
Lifted load (kg)	Male	29.56 (10.36)	(26.41 – 32.71)
	Female	20.00 (-)	20.00 – 20.00
	Total	27.51 (10.26)	21.58 – 33.43

SD = standard deviation; CI = confidence interval.

We adopted Cohen's d effect size of 0.66 which was transformed to effect size f of 0.33, an alpha error of 0.5, and a power of 80% to compare all the moments of evaluation for the experimental conditions and we achieved a total of 10 participants as the minimum sample size necessary for this study.

Measures

Incremental load test and squat velocity

Participants began with a 3-minute warm-up on a stationary cycle ergometer (70 rpm, 0.5 KP resistance) and a specific warm-up comprising five squat jumps and five fast body mass squats (without jumping). An incremental load test was then conducted to determine participants' load-velocity profiles and estimate the optimal load for achieving a 1 m/s velocity (Sanchez-Medina and Gonzalez-Badillo, 2011).

Using a linear position transducer (Chronojump®, Boscosystem, Barcelona, Spain; 1,000 Hz sampling rate), participants performed back squats starting with the barbell positioned on the upper trapezius. Feet were shoulder-width apart and rotated outward (~30°). Participants executed squats with an upright posture, descending in ~2-seconds until the femur was parallel to the ground (or as deep as possible if parallel could not be reached). After a 1-second pause, participants ascended as quickly as possible without lifting their feet.

Each load was tested through 3 - 6 repetitions for lighter weights and 1 - 3 for heavier weights. The velocity of each repetition was recorded, with the highest value retained for analysis (Sanchez-Medina and Gonzalez-Badillo, 2011). Loads were incrementally increased, with 3-minute rest periods between initial loads and 5-minute rest periods for heavier loads. Testing concluded when participants achieved a velocity between 0.3 - 0.4 m/s.

Electromyographic activity

Electromyographic (EMG) activity of the vastus lateralis and semimembranosus was measured to evaluate co-activation patterns during the back squat. Skin preparation involved shaving, cleaning, and abrasion of the target areas, followed by electrode placement (1-cm Ag/AgCl electrodes, MediTrace 133, Kendall, Toronto, Ontario). A reference electrode was positioned on the lateral femoral condyle of the dominant leg. Noise signals were maintained below 0.05 mV across all sessions.

EMG signals were recorded at a 2000 Hz sampling rate (Biopac System Inc., MP150WSW, Holliston, MA) and filtered (10 - 500 Hz bandpass filter). Root mean square (RMS) values were calculated for the concentric squat phase. Amplification was set at ×1000 (input impedance: 2 MΩ; common-mode rejection ratio: >110 dB; noise: <5 µV).

Experimental protocol

In the first session, participants performed the incremental load test and familiarized themselves with the experimental conditions (FR, MB, MBV, and control). Familiarization involved two sets of 30-second rolling exercises using body weight for each device, targeting the quadriceps and gluteus muscles. The FR, MB and MBV were rolled over the length of the muscles (quadriceps: from superior to the patella to the most proximal segment of quadriceps, gluteals: ischial tuberosity to greatest protuberance around mid-gluteals). Rolling was performed as recommended at a metronome-guided rhythm of 2 seconds per direction (Behm et al., 2020).

During experimental sessions, participants replicated the warm-up procedure from the first session. Pre-test protocol involved eight back squats using the estimated optimal load for 1 m/s. Participants then completed four sets of 30-second rolling exercises (gluteus and quadriceps, alternating sides) using the assigned device. Specifically, the participants used a FR device (Theraband; Akron Ohio USA: 30 cm length, 15 cm diameter, rounded ridge every 5 cm, closed-cell expanded polypropylene foam), MB (10.16 cm diameter and 0.68 kg (© 2025, MyoStorm, Utah USA), and the same ball was used in the MBV session with a vibration amplitude of 2 millimeters and frequency of 100 Hertz. Post-test protocol measurements involved pain perception and rate of perceived exertion were assessed using a visual analog scale and an adapted 10-point Borg scale, respectively. Also, participants repeated eight back squats post-protocol to measure velocity and EMG activity (Sanchez-Medina and Gonzalez-Badillo, 2011).

Range of motion in the squat action (vertical barbell displacement)

Hip vertical displacement (used as a proxy for hip and knee range of motion [ROM]) was monitored during the squat action using a linear position transducer (Chronojump®, Boscosystem, Barcelona, Spain; 1,000 Hz sampling rate). For the analysis, we used both the maximum and mean vertical displacement (ROM) across the repetitions performed in the set prior to the experimental procedure and in the set following the experimental procedure.

Repetition velocity

Repetition velocity was monitored during the squat action using a linear position transducer (Chronojump®, Boscosystem, Barcelona, Spain; 1,000 Hz sampling rate). Participants were instructed to perform the concentric phase of the movement as quickly as possible. For analysis, we used the first, second, and third fastest repetitions, as well as the mean velocity across the entire set. Measurements were taken in the set performed before and after the application of the experimental protocol.

Statistical analysis

Data analysis was conducted using Jamovi software (v2.6.23). Continuous descriptive data were presented as estimated marginal means (standard deviation) and 95% confidence intervals. The inferential analysis was based on a generalized linear mixed model with a Gamma distribution due to the asymmetry in the data. The effects were presented as estimates representing the average differences between post- and pre-protocol measurements, as well as the differences among the experimental conditions. Fixed effects included condition (FR, MB, MBV, and control), time (pre- and post-test), and their interaction. Random intercepts were included considering the id variable to emphasize the average data. Significant fixed effects were further explored using pairwise comparisons based on the regression coefficients with statistical significance set at $p < 0.05$.

Results

Fourteen participants completed the study protocol, comprising three women and eleven men. Upon completion, when asked about their preference regarding the protocol, five participants chose to use the MBV, while nine preferred the FR. Anthropometric characteristics are detailed in Table 1.

In our comparative analysis, significant interaction effects between time and condition were observed for quadriceps EMG RMS during the fastest repetition (χ^2 = 12.203; p = 0.007), second fastest repetition (χ^2 = 12.007; p = 0.007), third fastest repetition (χ^2 = 9.222; p = 0.026), and mean speed (χ^2 = 9.156; p = 0.027) (Table 2 and Table 3).

Specifically, the quadriceps EMG RMS during the fastest repetition showed an increase over time with the MBV, averaging 0.107 millivolts higher than MB (p = 0.003). For second fastest repetition, all conditions exhibited a performance reduction compared to control: MBV (β = -0.036; p = 0.002), MB (β = -0.025; p = 0.029), and FR (β = -0.033; p = 0.005) (Table 2 and Table 3).

Similarly, in the third fastest repetition, reductions in velocity were noted for the MBV (β = -0.032; p = 0.005) and FR (β = -0.025; p = 0.027) relative to control. Lastly, mean velocity decreased following the use of the MBV (β = -0.031; p = 0.004) and FR (β = -0.046; p = 0.046) (Tables 2 and 3). Additionally, there were no effects for maximum (χ^2 = 0.691; p = 0.875) or mean vertical displacement (ROM) (χ^2 = 2.669; p = 0.446) (Table 2 and Table 3). Detailed interaction effects, including time variation coefficients for comparisons among conditions and the control group, are presented in Table 2 and the detailed descriptive information for the variables analyzed are showed in Table 3.

Table 2. Condition vs. Time interaction effects for the main variables comparing the variation among post and pre moments for all the conditions compared to the control.

Variable	Post- vs. Pre-test Time Effect	β	SE	95% CI Lower- Upper	z	p
Maximum Range of Motion (cm)	MBV vs. Control	0.235	0.641	-1.040 – 1.507	0.366	0.715
	MB vs. Control	-0.278	0.643	-1.550 – 0.998	-0.433	0.666
	FR vs. Control	-0.141	0.636	-1.400 – 1.120	-0.222	0.825
Mean Range of Motion (cm)	MBV vs. Control	-0.859	0.541	-1.933 – 0.215	-1.587	0.116
	MB vs. Control	-0.416	0.543	-1.494 – 0.662	-0.765	0.446
	FR vs. Control	-0.593	0.539	-1.662 – 0.447	-1.099	0.274
1st Fastest Repetition (m·s^{-1})	MBV vs. Control	-0.024	0.052	-0.128 – 0.080	-0.459	0.647
	MB vs. Control	-0.025	0.053	-0.129 – 0.079	-0.478	0.634
	FR vs. Control	-0.024	0.053	-0.128 – 0.080	-0.457	0.649
1st Fastest Repetition Quadriceps Maximum RMS (µV)	MBV vs. Control	0.053	0.041	-0.028 – 0.133	1.294	0.199
	MB vs. Control	-0.054	0.044	-0.142 – 0.034	-1.218	0.226
	FR vs. Control	-0.045	0.043	-0.131 – 0.042	-1.027	0.307
1st Fastest Repetition Hamstrings Maximum RMS (µV)	**MBV vs. Control**	**0.145**	**0.061**	**0.024 – 0.266**	**2.373**	**0.020**
	MB vs. Control	0.100	0.061	-0.021 – 0.221	1.642	0.104
	FR vs. Control	0.070	0.061	-0.051 – 0.191	1.154	0.251
2nd Fastest Repetition Maximum Velocity (m·s^{-1})	**MBV vs. Control**	**-0.036**	**0.012**	**-0.059 – -0.013**	**-3.106**	**0.002**
	MB vs. Control	**-0.026**	**0.011**	**-0.048 – -0.003**	**-2.221**	**0.029**
	FR vs. Control	**-0.033**	**0.012**	**-0.056 – -0.010**	**-2.873**	**0.005**
2nd Fastest Repetition Quadriceps Maximum RMS (µV)	MBV vs. Control	0.036	0.039	-0.040 – 0.113	0.941	0.349
	MB vs. Control	-0.001	0.042	-0.084 – 0.081	-0.028	0.978
	FR vs. Control	0.018	0.042	-0.064 – 0.101	0.438	0.662
2nd Fastest Repetition Hamstrings Maximum RMS (µV)	MBV vs. Control	-0.002	0.011	-0.023 – 0.019	-0.173	0.863
	MB vs. Control	0.006	0.010	-0.014 – 0.025	0.578	0.564
	FR vs. Control	0.008	0.010	-0.012 – 0.028	0.762	0.448
3rd Fastest Repetition Maximum Velocity (m·s^{-1})	**MBV vs. Control**	**-0.032**	**0.011**	**-0.054 – -0.010**	**-2.885**	**0.005**
	MB vs. Control	-0.017	0.011	-0.038 – 0.005	-1.522	0.131
	FR vs. Control	**-0.025**	**0.011**	**-0.046 – -0.003**	**-2.244**	**0.027**
3rd Fastest Repetition Quadriceps Maximum RMS (µV)	MBV vs. Control	0.075	0.039	-0.002 – 0.153	1.921	0.058
	MB vs. Control	0.008	0.040	-0.071 – 0.087	0.206	0.837
	FR vs. Control	0.013	0.040	-0.067 – 0.093	0.322	0.748
3rd Fastest Repetition Hamstrings Maximum RMS (µV)	MBV vs. Control	0.120	0.061	-0.001 – 0.242	1.962	0.053
	MB vs. Control	0.050	0.061	-0.071 – 0.171	0.816	0.416
	FR vs. Control	0.033	0.061	-0.089 – 0.154	0.533	0.596
Mean Velocity (m·s^{-1})	**MBV vs. Control**	**-0.031**	**0.010**	**-0.051 – -0.010**	**-2.961**	**0.004**
	MB vs. Control	-0.018	0.010	-0.039 – 0.002	-1.771	0.080
	FR vs. Control	**-0.021**	**0.010**	**-0.041 – -0.001**	**-2.023**	**0.046**

Comparisons in bold indicate significant effects with p < 0.05. Abbreviations: FR = foam roller; MB = massage ball; MBV = massage ball with vibration; β = estimate; SE = standard error; CI = confidence interval; z = statistic for the generalized linear mixed models

Table 3. Descriptive statistics for the main variables in the pre- and post-tests for all the conditions.

Variable	Condition	Pre (Mean ± SD) CI 95% [Lower - Upper]	Post (Mean ± SD) CI 95% [Lower – Upper]
Maximum ROM	CONTROL	61.8 ± 9.09 [57.1 - 66.6]	61.2 ± 9.09 [56.4 - 65.9]
	FR	60.9 ± 9.24 [56.0 - 65.7]	60.1 ± 9.24 [55.2 - 64.9]
	MB	62.6 ± 9.09 [57.8 - 67.3]	61.7 ± 9.09 [56.9 - 66.4]
	MBV	62.1 ± 9.13 [57.3 - 66.8]	61.6 ± 9.13 [56.9 - 66.4]
Mean ROM	CONTROL	58.2 ± 9.47 [53.2 - 63.1]	58.4 ± 9.47 [53.5 - 63.4]
	FR	57.6 ± 9.73 [52.5 - 62.7]	57.2 ± 9.73 [52.1 - 62.3]
	MB	58.9 ± 9.58 [53.9 - 63.9]	58.7 ± 9.58 [53.7 - 63.7]
	MBV	58.7 ± 9.65 [53.7 - 63.8]	58.1 ± 9.65 [53.0 - 63.2]
1st Fastest Repetition	CONTROL	1.07 ± 0.14 [0.999 - 1.14]	1.08 ± 0.14 [1.007 - 1.15]
	FR	1.05 ± 0.14 [0.977 - 1.13]	1.05 ± 0.14 [0.979 - 1.13]
	MB	1.05 ± 0.14 [0.979 - 1.13]	1.05 ± 0.14 [0.975 - 1.12]
	MBV	1.06 ± 0.14 [0.987 - 1.13]	1.04 ± 0.14 [0.97 - 1.12]
2nd Fastest Repetition	CONTROL	1.03 ± 0.14 [0.962 - 1.11]	1.05 ± 0.14 [0.977 - 1.12]
	FR	1.04 ± 0.14 [0.964 - 1.11]	1.02 ± 0.14 [0.947 - 1.09]
	MB	1.03 ± 0.14 [0.958 - 1.10]	1.02 ± 0.14 [0.948 - 1.09]
	MBV	1.04 ± 0.14 [0.968 - 1.11]	1.02 ± 0.14 [0.948 - 1.09]
3rd Fastest Repetition	CONTROL	1.02 ± 0.14 [0.946 - 1.09]	1.03 ± 0.14 [0.958 - 1.10]
	FR	1.02 ± 0.14 [0.943 - 1.09]	1.00 ± 0.14 [0.931 - 1.08]
	MB	1.01 ± 0.14 [0.937 - 1.08]	1.01 ± 0.14 [0.932 - 1.08]
	MBV	1.02 ± 0.14 [0.952 - 1.10]	1.00 ± 0.14 [0.932 - 1.08]
Mean Speed	CONTROL	1.04 ± 0.14 [0.97 - 1.11]	1.05 ± 0.14 [0.982 - 1.13]
	FR	1.03 ± 0.14 [0.962 - 1.11]	1.03 ± 0.14 [0.953 - 1.10]
	MB	1.03 ± 0.14 [0.959 - 1.10]	1.03 ± 0.14 [0.953 - 1.10]
	MBV	1.04 ± 0.14 [0.97 - 1.11]	1.02 ± 0.14 [0.951 - 1.10]
1st Fastest EMG RMS Quads	CONTROL	1.30 ± 0.64 [0.963 - 1.64]	1.28 ± 0.64 [0.944 - 1.62]
	FR	1.35 ± 0.65 [1.014 - 1.69]	1.29 ± 0.65 [0.951 - 1.63]
	MB	1.30 ± 0.65 [0.956 - 1.64]	1.23 ± 0.65 [0.884 - 1.57]
	MBV	1.19 ± 0.66 [0.845 - 1.54]	1.23 ± 0.67 [0.878 - 1.57]
1st Fastest EMG RMS Hams	CONTROL	10.2 ± 0.24 [10.1 - 10.4]	10.2 ± 0.24 [10.0 - 10.3]
	FR	10.2 ± 0.24 [10.0 - 10.3]	10.2 ± 0.24 [10.0 - 10.3]
	MB	10.1 ± 0.24 [10.0 - 10.3]	10.2 ± 0.24 [10.0 - 10.3]
	MBV	10.2 ± 0.24 [10.1 - 10.3]	10.3 ± 0.24 [10.1 - 10.4]
2nd Fastest EMG RMS Quads	CONTROL	1.38 ± 0.75 [0.991 - 1.78]	1.36 ± 0.75 [0.962 - 1.75]
	FR	1.38 ± 0.74 [0.994 - 1.77]	1.37 ± 0.74 [0.983 - 1.76]
	MB	1.34 ± 0.74 [0.954 - 1.73]	1.31 ± 0.74 [0.924 - 1.70]
	MBV	1.26 ± 0.75 [0.869 - 1.66]	1.27 ± 0.76 [0.875 - 1.66]
2nd Fastest EMG RMS Hams	CONTROL	253 ± 0.16 [0.171 - 335]	247 ± 0.16 [0.165 - 330]
	FR	220 ± 0.16 [0.137 - 303]	222 ± 0.16 [0.139 - 306]
	MB	203 ± 0.17 [0.116 - 290]	203 ± 0.17 [0.117 - 290]
	MBV	274 ± 0.15 [0.193 - 354]	266 ± 0.15 [0.186 - 346]
3rd Fastest EMG RMS Quads	CONTROL	1.34 ± 0.69 [0.978 - 1.70]	1.31 ± 0.69 [0.95 - 1.68]
	FR	1.31 ± 0.71 [0.94 - 1.68]	1.29 ± 0.71 [0.925 - 1.66]
	MB	1.37 ± 0.69 [1.009 - 1.73]	1.35 ± 0.69 [0.988 - 1.71]
	MBV	1.26 ± 0.70 [0.899 - 1.63]	1.31 ± 0.70 [0.945 - 1.67]
3rd Fastest EMG RMS Hams	CONTROL	10.2 ± 0.25 [10.1 - 10.4]	10.2 ± 0.25 [10.1 - 10.3]
	FR	10.2 ± 0.25 [10.1 - 10.3]	10.2 ± 0.25 [10.0 - 10.3]
	MB	10.2 ± 0.25 [10.0 - 10.3]	10.2 ± 0.25 [10.0 - 10.3]
	MBV	10.2 ± 0.25 [10.1 - 10.3]	10.3 ± 0.25 [10.1 - 10.4]

FR = foam roller; MB = massage ball; MBV = massage ball with vibration; SD = standard deviation; CI = confidence interval, quadriceps = Quads, hamstrings = Hams., ROM = range of motion via hip vertical displacement

Similarly, in the third fastest repetition, reductions in velocity were noted for the MBV (β = -0.032; p = 0.005) and FR (β = -0.025; p = 0.027) relative to control. Lastly, mean velocity decreased following the use of the MBV (β = -0.031; p = 0.004) and FR (β = -0.046; p = 0.046) (Tables 2 and 3). Additionally, there were no effects for maximum (χ^2 = 0.691; p = 0.875) or mean vertical displacement (ROM) (χ^2 = 2.669; p = 0.446) (Table 2 and Table 3). Detailed interaction effects, including time variation coefficients for comparisons among conditions and the control group, are presented in Table 2 and the detailed descriptive information for the variables analyzed are showed in Table 3.

Discussion

The major findings of this study comparing FR, MB and MBV demonstrated no significant increases in maximum squat velocity in the fastest repetition nor in squat (hip) vertical displacement (ROM). Overall (mean velocity) and in the third fastest repetition, squat velocity was reduced with MBV and FR versus the control condition. Quadriceps

EMG RMS was also significantly reduced in the second fastest repetition with all three conditions versus control. The only change in EMG was an increase in hamstrings EMG in the fastest repetition. Initially, the findings would appear to suggest that the MB might be the recommended choice as there was no significant impairments in squat velocity with the exception of the second fastest repetition. However, as there was also no improvement in ROM, there was no apparent benefit of using a MB whereas there were deficits associated with MBV or FR. So, if the practitioner favours these types of devices, probably the MB could be the best option to not compromise the performance.

A lack of increase in ROM with foam rolling contradicts a number of reviews. A meta-analytical review by Wilke et al. (Wilke et al., 2020) examined the acute effects of FR vs. static stretching and found large magnitude FR-induced improvements in ROM that were comparable to stretching. They mentioned that FR may be less effective with men than women. Another meta-analysis on the acute effects of FR reported 7.2 ± 5.5% ROM increases soon following rolling with sustained improvements at 10- (7.6 ± 4.8%), 15- (10.5 ± 5.6%) and 20-minutes (5.9 ± 3.6%), following rolling (Konrad et al., 2022b). Warneke's meta-analysis (Warneke et al., 2024) also reported acute increases in ROM with both stretching and FR but they were not superior to the effects of a general warm-up. Similarly, systematic reviews of 49 articles (Hendricks et al., 2019), 14 articles (Cheatham et al., 2015), 10 articles (Mauntel et al., 2014), and another meta-analysis of nine randomized clinical trials (Webb and Rajendran, 2016) reported that FR or roller massager demonstrate joint ROM improvements. Interestingly, increases in hip flexor ROM have been documented with just 5-10s of rolling without performance impairments (Sullivan et al., 2013). Konrad et al.'s meta-analyses (Konrad et al., 2021; 2022c; 2024) on FR training reported moderate magnitude increases in ROM comparable with static stretching when rolling for 4 weeks or longer. However shorter durations of FR training were not effective in promoting an increased ROM.

A major variation between the aforementioned studies and the present study is the difference between measuring maximal, passive, static ROM of a single joint or muscle versus the ROM (hip vertical displacement) of a dynamic multi-articular squat action. In the present study, participants were not attempting to achieve the greatest ROM. They were instructed to descend in ~2-seconds (eccentric component) until the femur was parallel to the ground (or as deep as possible if parallel could not be reached) and then ascend to an erect posture. The eight squats performed could have induced some level of fatigue. Fatigue tends to decrease the joint ROM (Cheng and Rice 2013, Zhang et al. 2022), which may have countered the previously reported positive effects of rolling on ROM.

Furthermore, the absence of vertical displacement (ROM) differences enables us to assume that in a dynamic basic action such as a squat, there were no substantial alterations in the movement ROM, and this can be considered a positive result since all the participants performed the squat movement adequately. Besides, our results raise the question about the transference of improvements in ROM using static or passive measurements to real-world scenarios such as the squat exercise.

In accord with Konrad's FR training meta-analyses (Konrad et al., 2021; 2022c; 2024) showing non-significant improvements in ROM with less than 4 weeks of training, there are other acute original research studies that have not found significant ROM increases with FR. The lack of FR-induced increases in ROM (Vigotsky et al., 2015; Morales-Artacho et al., 2017, Beier et al., 2019; Henning et al., 2019; Agopyan et al., 2020; Baraket et al., 2021) may be attributed to an insufficient rolling duration with non-significant changes following 30-s (Kipnis, 2020; Nakamura et al., 2021), < , or 2-minutes (Couture et al., 2015; Kipnis et al., 2020) of rolling. DeBruyne et al. (2017) reviewed moderate to high quality studies indicating that there was limited evidence on FR effectiveness for augmenting hamstrings flexibility in asymptomatic physically active adults, but these possible flexibility gains might be improved by longer treatment durations and administration by a trained therapist. The duration of FR in the present study was 2-minutes (4 x 30-s), which is in alignment with the Behm et al. (2020) recommendations based on their regression equations predicting rolling prescriptions should involve 1 - 3 sets of 2 - 4-second repetition duration (time for a single roll in one direction over the length of a body part) with a total rolling duration of 30 - 120-second per set. Hence, the optimal rolling duration to substantially improve ROM is difficult to pinpoint based on the diversity of rolling durations and affiliated effects in the literature.

Other mitigating factors may be the amount of pressure applied. The FR used in the present study had a smooth exterior whereas a grid surface with smaller segment areas (Cheatham and Stull, 2019) and denser rollers (Cheatham and Stull, 2018) may induce higher pressures and be more effective for increasing ROM. Couture et al. (2015) suggested that the amount of pressure imparted by a roller as well as duration of treatment may impact outcomes. Furthermore as mentioned previously, the Wilke et al. (2020) meta-analysis indicated that FR may be less effective with men than women and the present study recruited a majority of young university aged males (3 women and 11 men). Furthermore, with only three women, sex could not be analyzed as a between subject factor and thus the combination of sexes would have contributed to greater heterogeneity (variability) in the ROM scores.

Squat mean velocity overall (mean velocity for all repetitions) was reduced with the MBV and FR versus the control condition, while maximum squat velocity was also impaired in the second fastest repetition with all three conditions versus control. Commonly, much of the literature reports no performance enhancements or adverse effects with rolling (Cheatham et al., 2015; Behm and Wilke, 2019; Behm et al., 2020; Behm, 2024). However, a meta-analysis of 19 studies reported small magnitude increases in knee extensors' concentric torque but no significant effects on isometric muscle strength, eccentric torque, or rate of force development with rolling self-massage (Furlan et al., 2024). Another Konrad meta-analysis (Konrad et al., 2022a) examining FR training effects (minimum 2 weeks) on performance revealed no significant performance changes independent of participant age, training duration, or total load of FR. In contrast, two research studies examining running velocity reported a large magnitude improvement in 800-m run time (6 repetitions of 30-second rolling duration at a frequency of 5-seconds per body part) (D'Amico and Paolone, 2017), while another study found a small magnitude improvement in the cost of running with a rolling frequency of 1 repetition of 60-seconds with a 2-second per body part (Giovanelli et al., 2018). A third study demonstrated no change in sprint velocity following 3 x 30-seconds repetitions of FR (Miller 2019). Other studies have reported improvements in jump height (proxy measure for power [force x velocity]) (Peacock et al., 2014; Drinkwater et al., 2019; Agopyan et al., 2020; Ahmed et al., 2024). These findings are in opposition to Gozobuyuk and Yukesoy, (2019), who reported FR-induced adverse effects on the knee extensors contraction speed, which they attributed to myofascial force transmission. Warneke et al. (2025) imposed 6-minutes of FR and observed that a high FR dosage could impair jump height performance. In summary, although there is more evidence for no significant performance changes with rolling, there are also individual original research articles that have presented both increases and decreases in velocity- or power-related performance.

Whereas there is abundant literature examining FR, there is far less regarding MB. For example, Ceviker et al. (2022) demonstrated that using body weight on a tennis ball for self-massage did not have an effect on jumping performance of taekwondo athletes. A larger diameter ball (soccer ball) improved ROM in both sexes, regardless of pressure intensity (Hirose et al., 2025). In contrast, there was no significant ROM and muscle stiffness changes following rolling massage with a smaller ball (approximately the size of a softball), however there was a decrement in shoulder flexion maximum voluntary isometric contraction (MVIC) peak torque (Reiner et al., 2023). They suggested that the lack of change in ROM might be attributed to the small area of applied pressure, whereas the MVIC peak torque deficit might be more related to the uncommon test configuration. While the greater length and diameter of a FR induces lower pressure, it does allow a greater coverage/massage of the entire muscle. A smaller diameter ball can provide increased pressure but may not apply that pressure over the entire muscle.

This is the first study to our knowledge to incorporate a MBV. Both the MBV and FR tended to have similar impairments to squat velocity while the MB also demonstrated impairments in the second fastest repetition in the present study. A review by Ferreira et al. (2023) indicated that vibrating massage guns either did not show improvements or showed a decrement in strength, balance, acceleration, agility, and explosive performance. Percussion guns have been found to reduce fatigue but did not affect movement velocity variables (Garcia-Sillero et al., 2021). Similarly, Cochrane (2013) reported that acute bouts of vibration enhanced the acceleration phase (1.5m) of a short-distance sprint, but had no significant effect on short-distance (3m & 5m) sprint or reactive agility performance.

The possible underlying mechanisms may be contradictory. A number of studies (Wilke et al., 2020) have reported decreases in the afferent excitability of the alpha motoneuron as measured with the Hoffman (H-) reflex with both non-vibrating FR (Young et al., 2018) and massage (Behm et al., 2013). MB- or FR-induced stretch reflex inhibition would decrease the ability fully activate muscles, negatively affecting force and power production (Wilke et al., 2020) such as with the squat load-velocity profile in the present study. On the other hand, it is reported that vibration increases muscle tone by enhancing the stretch reflex loop through muscle spindles reflex activation, positively influencing agonist muscle contraction while simultaneously inhibiting antagonists (Cochrane, 2011; Eckhardt et al., 2011; Dordevic et al., 2022). However, in the present study there was no significant changes in agonist (quadriceps) EMG, but an increase in hamstrings EMG in the fastest repetition. Greater co-contractions would impede the velocity of the intended squat movement and could be related to the high frequency of 100 Hz applied using the MBV and the low amplitude of 2 millimeters.

As with any study, there are always considerations or limitations. Fourteen participants including three women and eleven men would have increased the group variability making it more difficult to achieve significance, and the number of females was too small to enable the sex comparison. While all participants received a thorough familiarization session, had resistance training experience, and were competent at performing squats, they were not all equally experienced with FR and most were not very experienced with MB.

Conclusion

In conclusion, the non-vibrating FR and MB as well as the MBV did not affect ROM and generally reduced squat movement velocity, with the MB showing the least detrimental effect on performance. Although the literature tends to demonstrate rolling-induced ROM improvements with no significant performance effects, the 2-minute (4 x 30-s) intervention duration may have been insufficient to enhance ROM in a dynamic action such as squatting. Squat movement velocity decrements may be attributed to alterations in muscle activation (stretch reflex inhibition and/or increased co-contractions). Hence, 2 minutes of FR or MB do not provide ROM or movement velocity benefits before performing squat exercises. Further research is necessary regarding the effect of vibrating and non-vibrating MB on flexibility, and performance.

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Key points

- The non-vibrating foam roller and massage ball as well as the vibrating massage ball did not affect ROM and generally reduced squat movement velocity, with the massage ball showing the least detrimental effect on performance.
- There was an increase in hamstrings EMG in the fastest squat repetition.
- Squat movement velocity decrements may be attributed to alterations in muscle activation (stretch reflex inhibition and/or increased co-contractions). Further research is necessary regarding the effect of vibrating and non-vibrating massage ball on flexibility, and performance.
- If the practitioner favours these types of devices, the massage ball could be the best option to not compromise the performance.

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