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Muscle Activity of Superimposed Vibration in Suspended Kneeling Rollout

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Abstract: Training using instability devices is common; however, for highly trained athletes, a single device may not provide sufficient challenge. This study examines the effect of superimposed vibration in suspended kneeling rollout. Seventeen physically active participants performed the exercise with non-vibration, vibration at 25 Hz, and vibration at 40 Hz. Muscle activation of the pectoralis clavicularis, pectoralis sternalis, anterior deltoid, serratus anterior, infraspinatus, and latissimus dorsi was recorded during exercise, and the perception of effort was recorded after exercise (OMNI-Res scale). One-way repeated-measures analysis of variance (ANOVA) showed significant differences for the kneeling rollout ($p < 0.05$). Friedman's test showed significant differences in the OMNI-Res ($p = 0.003$). Pairwise comparison showed significant differences in the anterior deltoid ($p = 0.004$), latissimus dorsi ($p < 0.001$), infraspinatus ($p = 0.001$), and global activity ($p < 0.001$) between the 25 Hz and non-vibration conditions. It also showed significant differences between the 40 Hz and non-vibration conditions for pectoralis sternalis ($p = 0.021$), anterior deltoid ($p = 0.005$), latissimus dorsi ($p < 0.001$), infraspinatus ($p = 0.027$), and global activity ($p < 0.001$). The post hoc Conover pairwise comparison showed significant differences in the OMNI-Res only between the non-vibration and vibration at 40 Hz conditions ($p = 0.011$). Superimposed vibration increases the muscle activation of the upper limbs when performing the suspended kneeling rollout.

Keywords: electromyography; instability; overhead; suspension training; upper limb

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1. Introduction

Functional training has spread among the active population over the last few years, with the performance of individualised, perturbative, and challenging exercises [1]. Thus, the use of unstable environments has become popular and is recommended to prepare the athletes for these kinds of actions [2,3] and might be appropriate for athletes performing high-intensity upper-body actions such as throwing or hitting balls with precision (i.e., for the sports of volleyball, tennis, water polo, handball, basketball...) [4]. In this vein, unstable environments created using Swiss balls, BOSU®, TRX®, Freeman plates, or T-Bow® alter the muscle activity when performing different upper-body tasks. One of the most popular devices is the suspension strap, which is mainly represented by the TRX® brand. These devices require only one anchor point to be fixed, and allow the athlete to perform several exercises based on body weight [5]. Suspension training has been shown to increase muscle activation compared with the traditional equivalent in most muscle groups in different training tasks [6]. Beyond this increased global activation, core muscles seem to be the most activated under suspended conditions [6,7]. In this vein, one of the most studied exercises in suspension training is the push-up, which creates a greater muscle activation in the triceps brachii, posterior deltoid, and core muscles [7]. However, to challenge the pectoralis and anterior deltoid, it is advisable to use more stable conditions [7,8].

Beyond the use of unstable devices in resistance training, whole-body vibration (WBV) has been suggested as an effective alternative method for enhancing the neuromuscular system [9,10]. In the early 2000s, Cardinale and Bosco [11] warned of the need to explore the use of mechanical vibration in strength training programs. In their narrative review, the authors stated that vibration involuntarily increases muscle activity because of the damper effect that the soft tissues must carry out to absorb the vertical accelerations produced by the platform. Nevertheless, in another review about this topic, Issurin [12] supported the use of superimposed vibratory stimulation in order to enhance explosive strength and maximum dynamic force. Moreover, although the potential neuromuscular mechanisms are similar, the author distinguished WBV and local vibration as two different training paradigms. Although WBV platforms are commonly used to stimulate lower-limb muscles, placing the hands on the platform is the simplest way to increase upper-body muscle activity through vibration [13]. Grant and associates [14] recorded the muscle activation of fifteen different shoulder muscles performing press-ups and triceps dips. The muscles involved showed higher activity under vibrating conditions in both exercises. Additionally, the authors attached cables to the platform to transmit vibrations in different body and limb positions, with similar results. Grant and associates [14] also compared the effects of vibration by pulling a handle while flexing the shoulder under three conditions (with the subject on top of an off WBV platform, on top of a working WBV platform, and out of a working WBV platform) and observed a higher activity of most of the studied muscles under both vibration conditions. In contrast, Tankisheva and associates [15] observed significantly increased muscle activity in the biceps brachii, triceps brachii, deltoid, and upper trapezius when performing the biceps curl, but not when performing the triceps curl and lateral raise, thus suggesting the direction of the arm movement with respect to the direction of vibration to explain such differences. Furthermore, Moras and associates [16] created a vibratory bar and reported higher muscle activity in the bench press static position under the 45 Hz vibration condition. This new vibration device allows a change in the angle at which the vibration is applied. Similarly, Ni and associates [17] stated that the vibration direction affects muscle activation. In their study, higher muscle activity was observed when vibration was perpendicularly transmitted to the target muscles.

Research on new challenging strength and conditioning methods combining different demanding sources has led to vibration superimposition onto unstable devices. Observing the acute effects of superimposing vibration, Marín and Hazell [18] compared the muscle activation of the gastrocnemius medialis, vastus medialis oblique, vastus lateralis, rectus abdominis, and multifidus muscles, with athletes performing an isometric half squat in four different stable and vibrating conditions; thus, the researchers observed significant increases on a wobble board at 30 Hz. Moreover, Aguilera-Castells and associates [19] compared the muscle activation of a Bulgarian squat under four conditions: (1) with the back foot on a bench and the front foot on the floor, (2) with the back foot on a TRX® and the front foot on the floor, (3) with the back foot on a TRX® and the front foot on a BOSU®, and (4) with the back foot on a TRX® and the front foot on a WBV platform.

Results showed that the use of a TRX® is not sufficient to increase muscle activation (rectus femoris, biceps femoris, gluteus medius, vastus medialis, and vastus lateralis of the front leg; and rectus femoris of the rear leg); however, combining the use of a BOSU® or a vibrating platform increased the activity of the analysed muscles. Recently, a new vibratory device placed at the anchor point of a suspension strap has been developed. Aguilera-Castells and associates [20] compared the muscle activity (rectus femoris, biceps femoris, semitendinosus, gluteus maximus, and gastrocnemius medialis and lateralis) in a supine bridge and a hamstring curl exercise without vibration, and with vibration at 25 Hz and 40 Hz and 8 mm of amplitude. A significantly higher muscle activity was observed in the musculature closest to the vibration exposure point at 25 Hz. Similarly, Buscà and associates [21] analysed the activity of the dominant upper-limb musculature, as well as the external oblique, under three conditions: (1) non-vibration, (2) vibration at 25 Hz, and (3) vibration at 40 Hz. Results showed higher muscle activity in the external oblique, triceps brachii, anterior deltoid, and clavicular portion of the pectoralis major at 40 Hz. In addition, the external oblique and anterior deltoid muscles also showed significant increases at 25 Hz, and the sternal portion of the pectoralis major showed higher activity at 25 Hz.

Kneeling rollout is considered a core exercise [22–24] that can be performed using suspension devices. The use of an ab wheel [25–27], a Swiss ball [28,29], a suspension device [30,31], and placing the hands on the ground while maintaining their position [31] have been reported in the literature. All these authors analysed the core muscles, obtaining the highest values for the rectus abdominis, closely followed by the external oblique, and much lower values for the lumbar paraspinal muscles.

To the best of our knowledge, no previous studies have considered kneeling rollout as an overhead action, recording the muscular activity of the periscapular muscles in this position, which has been considered a risky position for the glenohumeral joint and is often repeated in throwing sports actions. Therefore, the aim of the present study was to compare the pectoralis sternalis and clavicularis, anterior deltoid, serratus anterior, latissimus dorsi, and infraspinatus activity when performing a kneeling rollout taking a suspension strap, between the non-vibration condition and vibration at 25 Hz and at 40 Hz. It is hypothesised that superimposing vibration at the higher frequency (40 Hz) will increase muscle activation compared to the other two conditions. It is also hypothesised that the highest vibration condition will be scored as the most demanding in the OMNI-Res scale, when compared to the lower frequency and the non-vibration condition.

2. Materials and Methods

2.1. Design

In order to determine the effects of superimposed vibration on the shoulder musculature, a cross-sectional study was conducted. The participants performed suspended kneeling rollout under three different conditions: (1) non-vibration, (2) vibration at 25 Hz, and (3) vibration at 40 Hz. In all conditions, muscle activation of the pectoralis sternalis and clavicularis, anterior deltoid, serratus anterior, latissimus dorsi, and infraspinatus was recorded. Muscle activation was normalised and then expressed as a percentage of maximum voluntary isometric contraction (% MVIC). In addition, the subjective perception of exertion was recorded using the OMNI-Res scale for the suspended kneeling rollout exercise [32].

2.2. Participants

Seventeen participants were voluntarily recruited to take part in the study, comprising 13 males (n = 13; mean age = 24 ± 2 years; height = 1.77 ± 0.06 m; body mass = 76.59 ± 9.13 kg; body mass index = 24.37 ± 2.62 kg·m^{-2}) and 4 females (n = 4; mean age = 22 ± 1 years; height = 1.72 ± 0.06 m; body mass = 68.90 ± 14.13 kg; body mass index = 23.30 ± 4.65 kg·m^{-2}). All subjects were physically active in accordance with the World Health Organization's guidelines [33], trained a minimum of three times per week, and were usually trained with suspension devices. The content of the training sessions was mainly composed of full-body strength exercises, combining suspension training, free weights, and weight stack machines. If participants did not perform a minimum of 90 min of physical activity per week or if their suspension training experience was less than one year, they were excluded from the study. They were also excluded from the sample if they had musculoskeletal, neuromuscular, or cardiovascular injuries or any medical contraindication to physical activity. All participants were asked to avoid high-intensity strength and conditioning sessions for 24 h prior to the test session. They were also asked to refrain from consuming any stimulant beverage (i.e., caffeine) four hours before the session. The protocols followed the principles of the Declaration of Helsinki (revised in Fortaleza, Brazil, 2013), and the study was approved by the Ethics and Research Committee Board of the Blanquerna Faculty of Psychology and Educational and Sport Sciences at Ramon Llull University in Barcelona, Spain (ref. number 1819034D).

2.3. Procedures

A familiarisation session was held one week before the data collection session (Figure 1) at the same time of day. This began with an explanation of the exercise and a subsequent reading of the informed consent form by the research team to ensure understanding, which was then signed by the participant. Subsequently, the participants' age, height, weight, and leg length (defined as the distance between the anterosuperior iliac spine and the medial malleolus of the tibia) were recorded. Additionally, the volume of weekly activity, experience with the use of suspension training, and both injury history and any medical contraindications were enquired about. Furthermore, upper-limb dominance was established as the arm that throws a ball at maximum speed. Finally, two sets of five repetitions of the suspended kneeling rollout were performed for each of the three conditions (non-vibration, vibration at 25 Hz, and vibration at 40 Hz), and the necessary corrections were made to ensure that all sets were performed with the correct technique. On the day of data collection, electrodes (Biopac EL504 disposable Ag-AgCl) were placed in the pectoralis (sternalis and clavicularis), anterior deltoid, serratus anterior, latissimus dorsi, and infraspinatus of the dominant arm [34]. Before this, the participants' skin was cleaned with 96% alcohol and shaved if necessary for the correct placement of the electrodes. Each pair of electrodes was placed at a distance of two centimetres and a reference electrode was placed on top of the iliac crest, following the SENIAM guidelines [35]. Subsequently, a standardised warm-up began with two sets of ten repetitions of the chest fly, two sets of fifteen internal shoulder rotations with an ABD of 90° and elbow flexion of 90°, two sets of twenty pulses with an ABD of 120° and elbow flexion of 60°, and finally two times of performing a 30 s plank. MVIC tests were then performed for each analysed muscle. Subsequently, the surface electromyography (sEMG) signal was normalised for the pectoralis (sternalis and clavicularis), anterior deltoid, serratus anterior, latissimus dorsi, and infraspinatus. While the participants performed a set of five repetitions of the suspended kneeling rollout under vibration and non-vibration conditions, the activation of the aforementioned muscles were registered. The exercise trials were conducted in random order and a 2 min rest period was provided to avoid fatigue between conditions (no vibration, vibration at 25 Hz, and vibration at 40 Hz). The vibration frequencies were established following the recommendations of Ritzmann and associates [36] for WBV and similar procedures in precedent studies [20,21]. Furthermore, Hazell and associates [37] stated that the activity of several muscles was enhanced at frequencies from 20 Hz to

45 Hz. The suspended kneeling rollout pace was standardised at 40 beats per minute (bpm) using a metronome (Pro Metronome application, version 3.13.2; EUM Lab-Xannin Technology Gmbh, Hangzhou, China). After each exercise condition, participants were asked to complete the OMNI-Res scale.

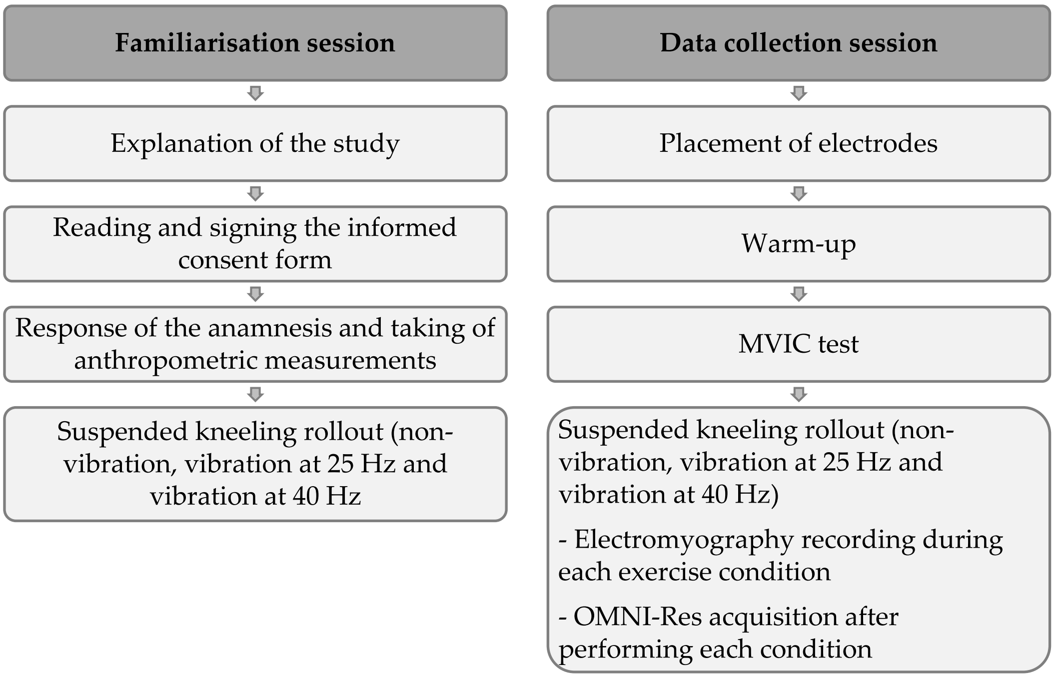

Figure 1. Procedure diagram. MVIC: maximum voluntary isometric contraction.

Suspended kneeling rollout was performed following the recommendations of Dawes [5] (Figure 2). The starting position of the exercise was adjusted according to the length of each participant's leg. Thus, the height of the suspension straps (TRX Suspension Trainer; Fitness Anywhere, San Francisco, CA, USA) and the distance from the knees to the suspension device were both set to 40% of the leg length. The TRX® was placed perpendicular to the ground in the starting position. The participant must lean the body forward without separating the handles, grabbing with the hands in a prone position, and holding the extension in the elbow until touching a pike situated at 140% of the leg length from the knees. The body must be aligned from the head to the knees throughout the entire run. A linear transducer (WSB 16k-200; ASM Inc., Moosinning, Germany) was used to identify the phases of movement, which was fixed around the TRX® grips.

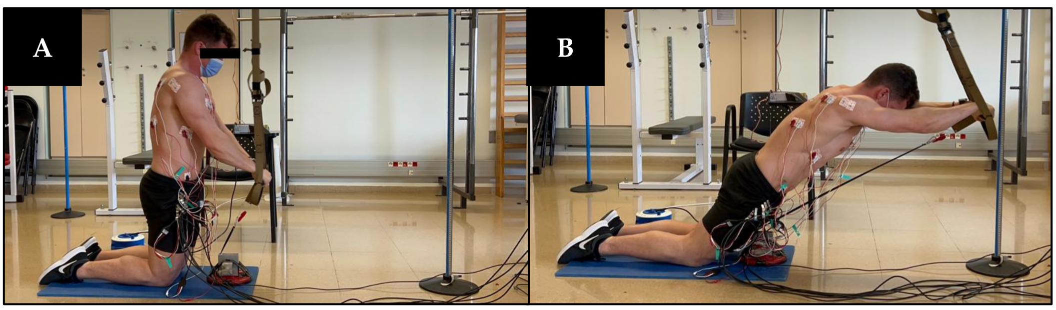

Figure 2. Suspended kneeling rollout. The image on the left represents the initial position (**A**) and the image on the right represents the final position (**B**).

A device was placed between the suspension strap and ceiling anchorage to superimpose vibration on the suspension straps. This device comprises a rotating electric motor that transmits movement to a connecting rod, resulting in a vertical displacement of 8 mm (peak-to-peak).

2.4. MVIC Trials

MVIC trials were performed on the dominant arm to normalise the EMG signal. In each of the three trials, the MVIC was held for five seconds, with participants progressively recruiting for two seconds and holding the MVIC for a further three seconds; between sets, the participant rested for three minutes. The highest value among the three repetitions was considered the MVIC [38]. MVIC positions were determined according to Konrad [39]. For the pectoralis sternalis and pectoralis clavicularis, a horizontal adduction against a fixed bar with 90° elbow flexion was performed with the participant in a supine position with the back resting on a bench. For the anterior deltoid, a shoulder flexion was performed with the participant seated on a bench, a fixed bar was adjusted to maintain the shoulder at 90° of flexion, and the same position was used for the latissimus dorsi, with the participant performing a single-arm shoulder extension with a 90° shoulder and elbow; on this occasion, a handle attached to a strap was used. For the infraspinatus, the participants remained in a standing position while performing shoulder external rotations; the handle was fixed to an invincible point at the elbow height to ensure that the elbow flexion was 90°. In addition, for the serratus anterior, the participant was asked to apply force to push a fixed bar while in a supine decubitus position on a weight bench with a fixed shoulder joint flexion of 90°. The elbow was maintained extended during the manoeuvre.

2.5. sEMG Assessment

The sEMG signal was recorded and analysed during the performance of each suspended kneeling rollout condition (no vibration, vibration at 25 Hz, and vibration at 40 Hz) using a six-channel BIOPAC MP-150 (sampling rate: 1.0 kHz) and AcqKnowledge 4.2 software (BIOPAC System, Inc., Goleta, CA, USA). The sEMG signal was band-pass filtered at 10–500 Hz using a 4th order Butterworth filter at 50 Hz. The recommendations of Borges and associates [40] were followed to remove motion artifacts using additional notch filters for the 25 Hz and 40 Hz vibrations. The signal was then smoothed with the root mean square (RMS) algorithm, with a window of 150 ms and an overlap of 50 ms, and then normalised to the maximum smoothed value previously obtained in the MVIC trials for each muscle group and expressed as a percentage of MVIC (%MVIC).

2.6. OMNI-Res

In the familiarisation session, the Perceived Subjective Exertion Scale (OMNI-Res) was introduced to participants [32]. The scale ranges from 0 (extremely easy) to 10 (extremely hard). For the participants, 0 was explained as not exercising and 10 as not being able to perform even one more repetition of the exercise. After performing the suspended kneeling rollout under each condition, the participants were asked to answer an integer between 0 and 10 according to their perception of the effort.

2.7. Data Analysis

For muscle activation analysis, the first and last repetitions of the suspended kneeling rollout were excluded by averaging the maximum muscle activation of the three repetitions. For a better understanding of the activation records (% of MVIC), the values were categorised as follows: >60% MVIC, very high activation; 41–60% MVIC, high activation; 21–40% MVIC, moderate activation; and <21% MVIC, low activation [29]. The global activity variable was calculated as the global mean of the six analysed muscles.

2.8. Stadistical Analysis

All analyses were performed using R Statistical Software (v4.3.1; R Core Team 2021; 16 June 2023). Muscle activation variables (continuous) were analysed using the rstatix R package (v0.7.2; 2023). The OMNI-Res variable (discrete ordinal) was analysed using the PMCMRplus R package (v1.9.10; 2023). The effsize R package (v0.8.1; 2020) was used to compute all experiment effect sizes. All dependent variable data were expressed as mean ± standard deviation (SD). Statistical significance was set at $p < 0.05$. The power analysis of the sample size showed an effect size of 0.42 SD with an alpha level of 0.05, and a power of 0.95 using G Power Software 3.1 (University of Dusseldorf, Germany).

A one-way repeated-measures analysis of variance (ANOVA) was used to determine the effect of suspended kneeling rollout on muscle activation (pectoralis clavicularis, pectoralis sternalis, anterior deltoid, serratus anterior, latissimus dorsi, and infraspinatus, as well as global activity). Prior to the analysis, muscle activation variables were tested for normality using the Shapiro–Wilk test. Where data were right-skewed and there was sufficient evidence to reject the null hypothesis of normality (pectoralis sternalis, anterior deltoid, serratus anterior), a logarithmic transformation was applied to help make the data conform better to the assumptions of normality and homoscedasticity. After applying the transformations, all variables met the normality assumption. Mauchly's test was used to assess the sphericity assumption, and in the case of factors that violated the sphericity assumption, the Greenhouse–Geisser sphericity correction was applied. A post hoc *t*-test with the Bonferroni correction was carried out in the case of a significant main effect. Cohen's d (d) effect size was calculated with 90% confidence intervals (CI) [41]. The effect size was interpreted as trivial (d < 0.2), small (d ranging from 0.2 to 0.6), moderate (d ranging from 0.6 to 1.2), large (d ranging from 1.2 to 2.0), and very large (d > 2.0) [42].

For the OMNI-Res variable, a non-parametric Friedman test was performed. The assumptions to use this test were met by design on this variable based on the experiment. The statistic resulting from the Friedman test was approximated as a chi-squared distribution with k-1 degrees of freedom. In case of significant main effects, a novel test proposed by Eisinga and associates [43] was carried out. Eisinga and associates [43] provide an exact test for the pairwise comparison of Friedman rank sums implemented in R. The Eisinga c.s. exact test offers a substantial improvement over the available approximate tests, especially if the number of groups (k) is large and the number of blocks (n) is small. Cliff's delta (d) non-parametric effect size measure with 90% CI was calculated [44]. This measure assesses the magnitude of differences between two groups based on ordinal data, ranging from −1 to 1, where values closer to −1 or 1 indicate larger differences between groups.

3. Results

A fixed effect of the exercise condition was found on the pectoralis sternalis [$F_{(2,32)} = 3.757$, $p = 0.034$], anterior deltoid [$F_{(2,32)} = 7.833$, $p = 0.002$], latissimus dorsi [$F_{(2,32)} = 16.017$, $p < 0.001$], infraspinatus [$F_{(2,32)} = 8.404$, $p = 0.001$], and global activity [$F_{(2,24)} = 12.794$, $p < 0.001$], but not for the pectoralis clavicularis [$F_{(2,32)} = 2.89$, $p < 0.07$] or serratus anterior [$F_{(2,32)} = 2.35$, $p < 0.112$].

The pairwise comparison, in Table 1, showed that in the suspended kneeling rollout, the effects of superimposed vibration at 25 Hz were significantly higher than those of the non-vibration condition with a small effect for the anterior deltoid ($p = 0.004$, $d = 0.29$, CI: −0.30; 0.87), a large effect for the latissimus dorsi ($p < 0.001$, $d = 0.90$, CI: 0.29; 1.51), and a medium effect for the infraspinatus ($p = 0.001$, $d = 0.62$, CI: 0.03; 1.22) and the global activity ($p < 0.001$, $d = 0.71$, CI: 0.11; 1.30). The superimposed vibration on the suspension straps at 40 Hz showed a significant small effect compared to the non-vibration condition for the pectoralis sternalis ($p = 0.021$, $d = 0.30$, CI: −0.29; 0.88), anterior deltoid ($p = 0.005$,

$d = 0.41$, CI: −0.18; 0.99), and infraspinatus ($p = 0.027$, $d = 0.46$, CI: −0.13; 1.05). Likewise, a significant medium effect for the latissimus dorsi ($p < 0.001$, $d = 0.69$, CI: 0.10; 1.29) and global activity ($p < 0.001$, $d = 0.68$, CI: 0.08; 1.28) was found under superimposed vibration at 40 Hz compared to the non-vibration condition. The graphical representation of Cohen's d can be found in Figures 3–5.

Table 1. The sEMG activity for each analysed muscle in suspended kneeling rollout. Data are expressed as a % MVIC.

Muscle Group	Suspended Kneeling Rollout		
	Non-Vibration Mean ± SD	**Vibration at 25 Hz Mean ± SD**	**Vibration at 40 Hz Mean ± SD**
Pectoralis clavicularis	23.5 ± 16.6	30.3 ± 20.2	30.1 ± 18.9
Pectoralis sternalis	25.5 ± 14.7	27.4 ± 17.7	30.7 ± 19.7 [a]
Anterior deltoid	3.3 ± 2.6	4.2 ± 3.8 [a]	4.8 ± 4.5 [a]
Serratus anterior	24.9 ± 13.2	26.7 ± 16.6	28.5 ± 17.2
Latissimus dorsi	20.7 ± 10.1	31.2 ± 13.0 [a]	28.5 ± 12.3 [a]
Infraspinatus	26.0 ± 11.3	34.3 ± 15.1 [a]	32.5 ± 16.8 [a]
Global activity	20.6 ± 6.5	25.7 ± 7.7 [a]	25.9 ± 8.6 [a]

SD: standard deviation; [a] significantly different compared to non-vibration.

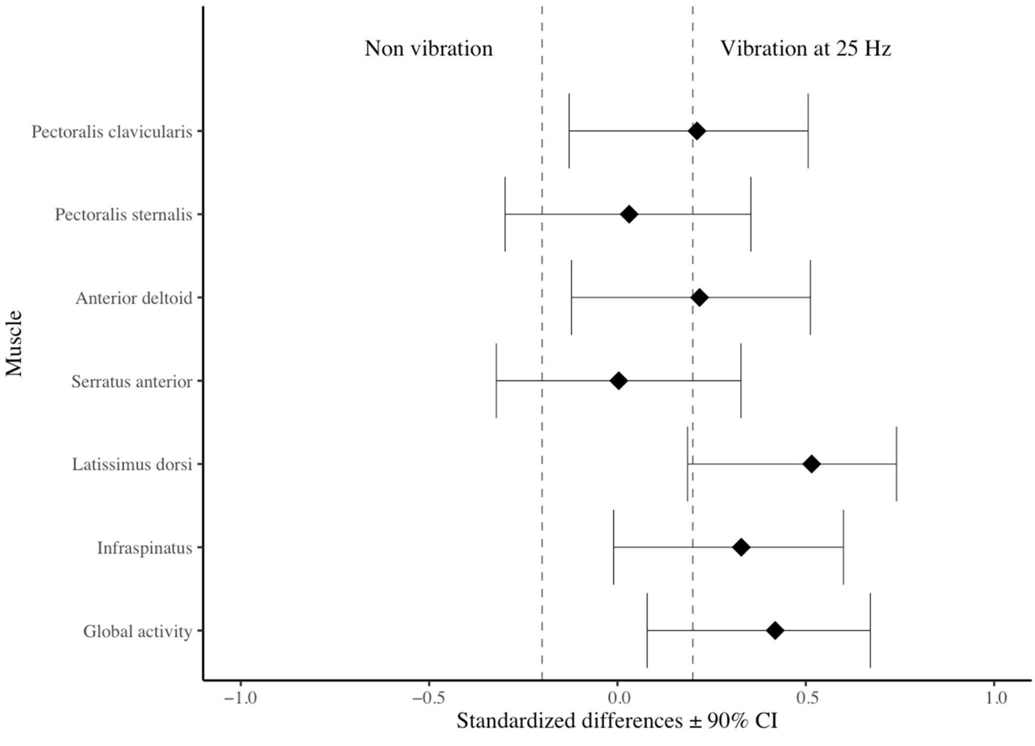

Figure 3. Acute effects on sEMG activity of superimposed vibration at 25 Hz and non-vibration in the suspended kneeling rollout. The lines represent the 90% confidence interval (CI) for the effect of superimposed vibration at 25 Hz on the suspended kneeling rollout. Dotted lines represent the smallest threshold.

The Friedman test showed a main effect of exercise condition on the OMNI-Res [$X^2_{(12)} = 11.451$, $p = 0.003$].

The post hoc Conover pairwise comparison in Figure 6 shows that the perception of effort was significantly higher for the suspended kneeling rollout with vibration frequency at 40 Hz (4.6 ± 1.3, $p = 0.001$, $d = -0.46$, CI: −0.69; −0.13) than for the non-vibration condition (3.4 ± 1.6). Moreover, non-significant differences were found under the vibration frequency at 25 Hz condition (4.2 ± 1.7) compared to other conditions. Figure 6 shows the OMNI-Res for each suspended kneeling rollout condition represented as a boxplot.

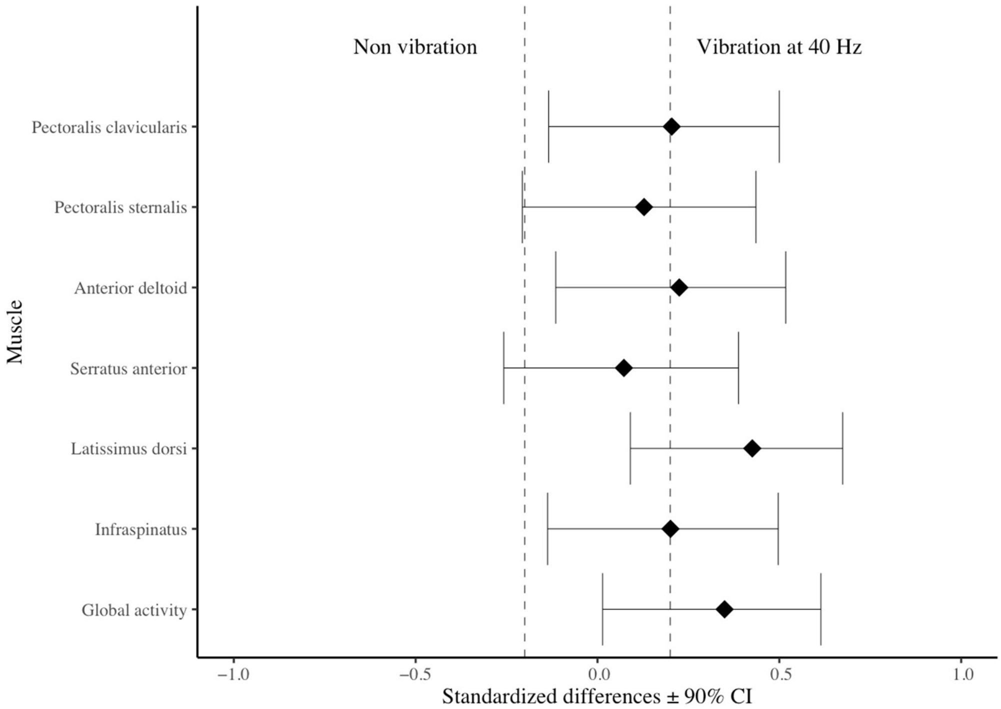

Figure 4. Acute effects on sEMG activity of superimposed vibration at 40 Hz and non-vibration in the suspended kneeling rollout. The lines represent the 90% confidence interval (CI) for the effect of superimposed vibration at 40 Hz on the suspended kneeling rollout. Dotted lines represent the smallest threshold.

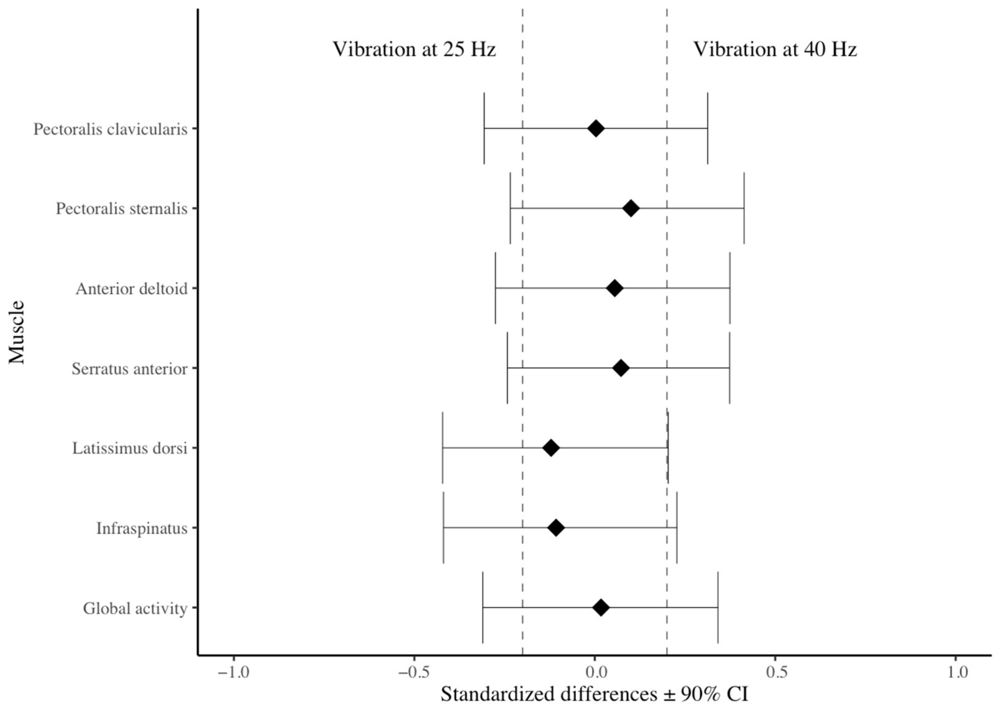

Figure 5. Acute effects on sEMG activity of superimposed vibration at 25 Hz and 40 Hz in the suspended kneeling rollout. The lines represent the 90% confidence interval (CI) for the effect of superimposed vibration at 40 Hz. Dotted lines represent the smallest threshold.

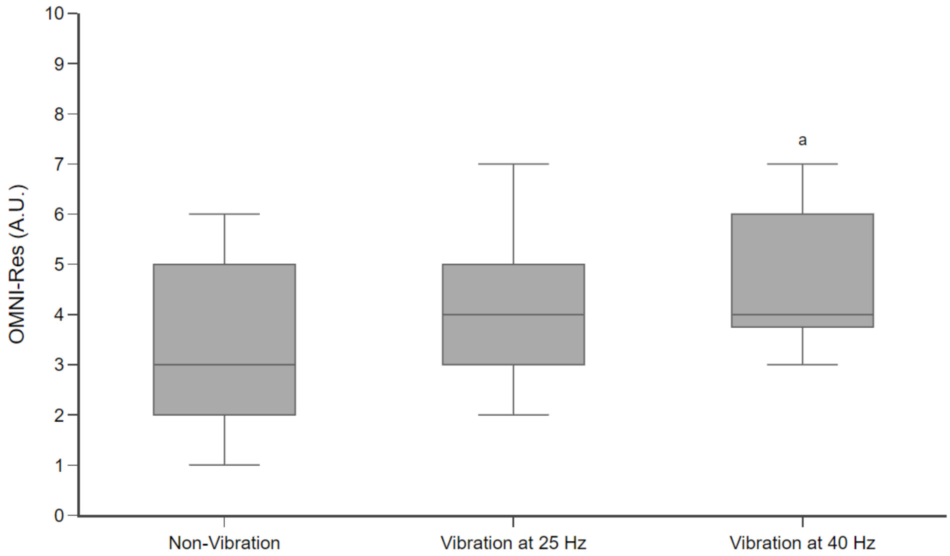

Figure 6. OMNI-Res for suspended kneeling rollout. a: significantly different compared to non-vibration. A.U.: arbitrary units.

4. Discussion

This study analysed the effects of superimposed vibration on the periscapular musculature during suspended kneeling rollout, which is considered a core exercise [22–24], and obtained high activation values in this musculature [26–31]. Previously, vibration combined with suspension straps was used in the upper extremities [21]; however, this is the first study to use it in an overhead exercise. The results demonstrated an increase in muscle activation in response to vibration; however, no discernible differences were observed between the two vibration frequencies in terms of global activation. The hypothesis that a frequency of 40 Hz would be more demanding was not supported by the data. This finding suggests that, while vibration may enhance muscle activation, higher frequencies do not guarantee greater muscle stimulation. Likewise, the hypothesis that perceived exertion would be greater at higher frequencies was confirmed. The findings of this study indicate that the implementation of superimposed vibrations may be a viable strategy for enhancing the strength of the periscapular muscles in their role as glenohumeral stabilisers.

The main hypothesis of the study has been confirmed, showing a significant moderate increase in muscle activation in global activity when vibration is superimposed at frequencies of 25 Hz (d = 0.71, CI: 0.11; 1.3) and 40 Hz (d = 0.68, CI: 0.08; 1.28), compared to the non-vibration condition. These results add to the evidence that vibration is a useful tool for increasing upper-body muscle activation [13–16,21]. Nevertheless, no significant differences were observed between the two frequencies, although they did not exhibit the same response in all the evaluated muscles. Several authors have found differences between the frequencies used, 25 Hz and 40 Hz [20,21], and 30 Hz and 50 Hz [18], but these differences were reported in particular muscles in each study and did not represent the general trend. These variations could be explained by the proximity of the resonance frequency, known as the frequency at which a muscle accumulates energy, in this case, vibration [45]. The muscles of the body act as dampers by absorbing this vibration through the damping effect. Therefore, the transmission of vibrations depends on the direction of vibration, body position, stiffness, and damping effect [17,45,46].

The muscle activity of the latissimus dorsi significantly increased in both vibration conditions, with a moderate increase at 25 Hz (d = 1, CI: 0.29; 1.51) and 40 Hz (d = 0.69, CI: 1; 1.29) compared to the non-vibration condition (Table 1). On the contrary, Grant and associates [14] recorded muscle activation while performing push-ups and triceps dips on a vibrating platform and found significant differences only in the lower latissimus dorsi fibres when performing push-ups at 35 Hz. This finding might be attributed to the low involvement of the latissimus dorsi in horizontal adduction and shoulder flexion compared with the high involvement of the latissimus dorsi in shoulder extension [47].

The infraspinatus has also shown significant differences in both vibratory conditions compared to non-vibration, with a small effect at 25 Hz (d = 0.62, CI: 0.03; 1.22) and 40 Hz (d = 0.46, CI: −0.13; 1.05) (Table 1). Similarly, Grant and associates [14] reported significant differences when performing triceps dips on a vibrating platform at 35 Hz, whereas muscle activity was moderate (21–40% MVIC) in the present study. Moreover, Grant and associates [14] reported moderate (21–40 MVC) and high activation (41–60% MVIC) when performing triceps dips and isometric shoulder flexion with vibration, respectively. However, when performing press-ups, the activation was low (<21% MVIC). These results are relevant because the concern for reducing shoulder injuries in overhead athletes has led to studies on the involvement of the infraspinatus in several exercises [48–52]. These studies reported higher activation of this muscle, thus reaching very high values (>60% MVIC) in some of them. In fact, the infraspinatus acts as a fixator of the shoulder joint in overhead actions, as it does in suspended kneeling rollout or triceps dips. It should be noted that suspended kneeling rollout was not performed at high intensity in the present study (Figure 6); therefore, the exercise could be repeated in a more challenging way, for instance, by changing the position, range of motion, the pace, etc.

The anterior deltoid showed the lowest activation (<5% MVIC). However, it was also stimulated by superimposed vibration, showing a small effect at 25 Hz (d = 0.29, CI: −0.3; 0.87) and 40 Hz (d = 0.41, CI: −0.18; 0.99) compared to the non-vibration condition (Table 1). Buscà and associates [21] and Grant and associates [14] also recorded the effects of vibration on the anterior deltoid, observing significant differences at all frequencies used (25 Hz, 35 Hz, and 40 Hz) when performing the exercises studied with superimposed vibration or a vibration platform, respectively. In the aforementioned studies, the anterior deltoid was identified as one of the primary agonist muscles during exercises, such as push-ups, triceps dips, and isometric shoulder flexion. Consequently, the findings from these studies are pertinent to the present investigation, wherein superimposed vibration was found to stimulate the anterior portion of the deltoid, even though it was not a targeted muscle.

The pectoralis activity increased when superimposing vibration at 40 Hz in its sternalis portion (d = 0.3, CI: −0.4; 1) compared to the non-vibration condition. Although the clavicularis portion did not show statistical significance, the effect of the vibration was similar (d = 0.4, CI: −0.21; 0.96) (Table 1). This result is relevant because of the involvement of each portion in this exercise, given that the shoulder joint made flexion and extension in the suspended kneeling rollout. In this movement, the pectoralis clavicularis is the predominant portion [47], even though the portion that was stimulated by the vibration was the sternalis portion. Grant and associates [14] found significant differences in the pectoralis when performing press-ups and triceps dips on a 35 Hz vibration platform, even though the portion of the muscle was not specified. Buscà and associates [21] obtained significant differences at 25 Hz and 40 Hz compared to the non-vibration condition in the pectoralis sternalis, but only at 40 Hz compared to the non-vibration condition in the pectoralis clavicularis. These findings may support the proximity of the resonance frequency hypothesis [45]. These results suggest that vibration is a useful strategy for stimulating the pectoralis muscle, but it seems that when high degrees of shoulder flexion are reached, this effect is reduced in the pectoralis clavicularis muscle because the maximum pectoralis clavicularis activity was during the eccentric phase, decreasing in the last degrees of shoulder flexion when the pectoralis sternalis and latissimus dorsi reached the highest muscle activation.

Finally, the serratus anterior showed no significant differences between conditions (Table 1). Presumably, this muscle does not have a direct effect on the shoulder joint, and the vibration frequency is absorbed by the arm musculature, in accordance with the findings of Grant and associates [14]. Tsuruike and colleagues performed various exercises that achieved very high activation (>60% MVIC), indicating that vibration is an ineffective strategy to increase the activation of the serratus anterior muscle [48–50]. The observed results might be attributable to the distance between the serratus anterior and the vibration device, because it is absorbed by the arm muscles.

The perception of effort (OMNI-Res) when performing the suspended kneeling rollout showed values below 5 out of 10, with a great dispersion among participants, indicating that the exercise was performed at a moderate intensity [32]. However, a trend of increasing with increasing vibration was observed, thus reporting a significant increase ($d = -0.46$, CI: -0.69; -1.13) between the 40 Hz and non-vibration conditions (Figure 6). According to various authors, the perception of effort is heightened when superimposing vibration [20,21,53]. In these studies, increasing the frequency of vibration has also demonstrated a tendency to increase the perception of effort when performing different exercises, such as suspended push-ups, suspended glute bridge, suspended hamstring curls, and isometric squats. This was observed despite the different frequencies being presented in a random order. It is noteworthy that during the familiarisation session of the present study, some members of the sample expressed surprise at the vibration of the suspension straps, given that the vibration produced by the device is accompanied by a considerable amount of noise when no load is applied to the suspension straps. However, it should be borne in mind that the perceived effort was ultimately less than 5 on a scale of 10.

The findings of the present study offer a novel perspective on the kneeling rollout, suggesting that it is not solely a high-demanding core exercise. This study examines the demands placed on the shoulder during the performance of this exercise, as well as the impact of superimposing vibration on the suspension straps on the shoulder joint. Based on the findings, it is recommended that this exercise be used with superimposed vibration for a healthy and trained population with the aim of stimulating the shoulder stabilisers in high degrees of flexion. Nevertheless, it would be premature to extrapolate these results to specific overhead athletes, and even less so in the context of shoulder injury. The use of superimposition of vibration in suspended kneeling rollout can be used at the end of exercise progression to strengthen the periscapular muscles. Such progression could start with stable followed by suspended and stable with vibration kneeling rollout. Further research is required to gain a deeper understanding of the efficacy of this approach in these populations.

The present study had several limitations. First, although an overhead action was analysed, the sample was heterogeneous and not all participants were overhead athletes. However, all the participants were physically active and rated the exercise as easy, which means that the results obtained cannot be extrapolated to other intensities. Furthermore, the sample population consisted of 17 participants, which could have been larger. Finally, there were only six electromyographic reading channels, which limited the muscles that could be analysed.

Further research should deeply explore the effects of superimposing different vibration frequencies on other exercises performed at different intensities. Moreover, the long-term effects of superimposed vibrations should be studied in comparison with the same suspension-based training program without vibration.

5. Conclusions

Vibration superimposition is an effective strategy for increasing muscle activity in the upper limbs when performing kneeling rollout. Both vibration frequencies stimulated the muscles analysed (25 Hz and 40 Hz); however, there was no difference in the global activity between the two frequencies. Not all musculature analysed obtained the same response, with the muscles closest to the vibration device being the most stimulated (anterior deltoid, latissimus dorsi, and infraspinatus). In parallel, the subjective perception of exertion (OMNI-Res) increased slightly with vibration at 40 Hz.

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