Turk J Phys Med Rehab 2023;69(x):i-vi
DOI: 10.5606/tftrd.2023.10854
Available online at www.turkishjournalpmr.com

Original Article

High-frequency whole-body vibration activates tonic vibration reflex

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Received: March 24, 2022 **Accepted:** October 05, 2022 **Published online:** January 11, 2023

ABSTRACT

Objectives: The aim of this research was to examine whether high-frequency whole-body vibration activates the tonic vibration reflex (TVR).

Patients and methods: The experimental study was conducted with seven volunteers (mean age: 30.8±3.3 years; range, 26 to 35 years) between December 2021 and January 2022. To elicit soleus TVR, high-frequency (100-150 Hz) vibration was applied to the Achilles tendon. High-frequency (100-150 Hz) whole-body vibration and low-frequency (30-40 Hz) whole-body vibration were applied in quiet standing. Whole-body vibration-induced reflexes were recorded from the soleus muscle using surface electromyography. The cumulative average method was used to determine the reflex latencies.

Results: Soleus TVR latency was 35.6±5.9 msec, the latency of the reflex activated by high-frequency whole-body vibration was 34.8±6.2 msec, and the latency of the reflex activated by low-frequency whole-body vibration was 42.8±3.4 msec ($F_{(2, 12)}$=40.07, p=0.0001 , η^2=0.87). The low-frequency whole-body vibration-induced reflex latency was significantly longer than high-frequency whole-body vibration-induced reflex latency and TVR latency (p=0.002 and p=0.001, respectively). High-frequency whole-body vibration-induced reflex latency and TVR latency were found to be similar (p=0.526).

Conclusion: This study showed that high-frequency whole-body vibration activates TVR.

Keywords: Latency, muscle spindle, muscle strength, vibration.

Whole-body vibration (WBV) is an exercise modality in which subjects are exposed to mechanical vibrations through a vibrating platform. Subjects stand on a platform or plate that produces sinusoidal oscillations either in a vertical up and down motion (vertical movement) or angular motion (side-alternating [pivotal] movement). These movements result in vibrations transmitted indirectly to the body of the subject through the feet. When the body or body segment is subjected to these externally applied forces, skeletal muscle activity reflexively increases.[1-5] However, the neuronal circuitry and receptors of the WBV-induced muscular reflex (WBV-IMR) pathway are not definitively defined. It has been suggested by some authors that the neuromuscular effect of WBV can be explained by the tonic vibration reflex (TVR).[1,6-12] Tonic vibration reflex is a muscle spindle-based polysynaptic spinal reflex resulting from Ia afferent activation when a 100-150 Hz vibration is applied to the belly or the tendon of a muscle.[13-15]

In contrast to isolated muscle or tendon vibration, WBV is performed at <50 Hz, and the vibration is applied to the sole of the foot and transmitted to the targeted muscles through the feet.[3,4] The latency of the WBV-IMR was shown to be longer than the latency of the TVR.[1,2,5,16,17] On the other hand, it has been

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Cite this article as:
Kalaoğlu E, Bucak ÖF, Kökçe M, Özkan M, Çetin M, Atasoy M, et al. High-frequency whole-body vibration activates tonic vibration reflex. Turk J Phys Med Rehab 2023;69(x):i-vi.

reported that WBV activates either TVR or WBV-IMR, depending on vibration amplitude.[17] According to the hypothesis of this study, if high-frequency (>100 Hz) vibration is applied to the sole, TVR is activated in the target muscle. The purpose of this study is to test this hypothesis. There is currently no standardized vibration training guideline for the athlete or patient prescription. A complete understanding of the basic mechanisms underlying the neuromuscular effects of WBV can supply improvement in WBV training protocols.

PATIENTS AND METHODS

The experimental study was conducted at the Istanbul Physical Therapy Rehabilitation Training and Research Hospital between December 2021 and January 2022. Seven healthy recreationally active young adult males (mean age: 30.8±3.3 years; range, 26 to 35 years) volunteered to participate in this study. The mean body height was 180.4±5.3 cm. Initially, 30 Hz, low-amplitude (1.2 mm) WBV with a duration of 30 sec was applied to each participant for familiarization purposes. A low-frequency WBF, high-frequency WBV, and Achilles tendon vibration were then applied in a quiet standing position in random order to negate any order/time effect. The participants rested for 3 min between low-frequency WBV, high-frequency WBV, and tendon vibration. The study protocol was registered with ClinicalTrials.gov (NCT05209945).

Whole-body vibration

Whole-body vibration was performed in a quiet standing position (Figures 1a, b). A low-frequency (30-40 Hz), low-amplitude (1.2 mm) WBV was applied using a PowerPlate Pro5 device (PowerPlate International, Amsterdam, the Netherlands). Whole-body vibration frequencies of 30, 35, and 40 Hz, each lasting 30 sec with 3-sec rest intervals, were applied in random order. The high-frequency (100-150 Hz), low-amplitude (0.9 mm) WBV was applied by using a custom-made vibrator. Whole-body vibration frequencies of 100, 135, and 150 Hz, each lasting 30 sec with 3-sec rest intervals, were applied in random order.

Tendon vibration

To elicit soleus TVR, local vibration was applied to the mid-point of the right Achilles tendon by using a custom-made vibrator in a quiet standing position (Figure 1c). Approximately 0.5 kg of force was applied to maintain the vibrator head in contact with the skin during vibration. Three vibration frequencies (100, 135, and 150 Hz) were administered in random order each lasting for 30 sec with 3-sec rest intervals.

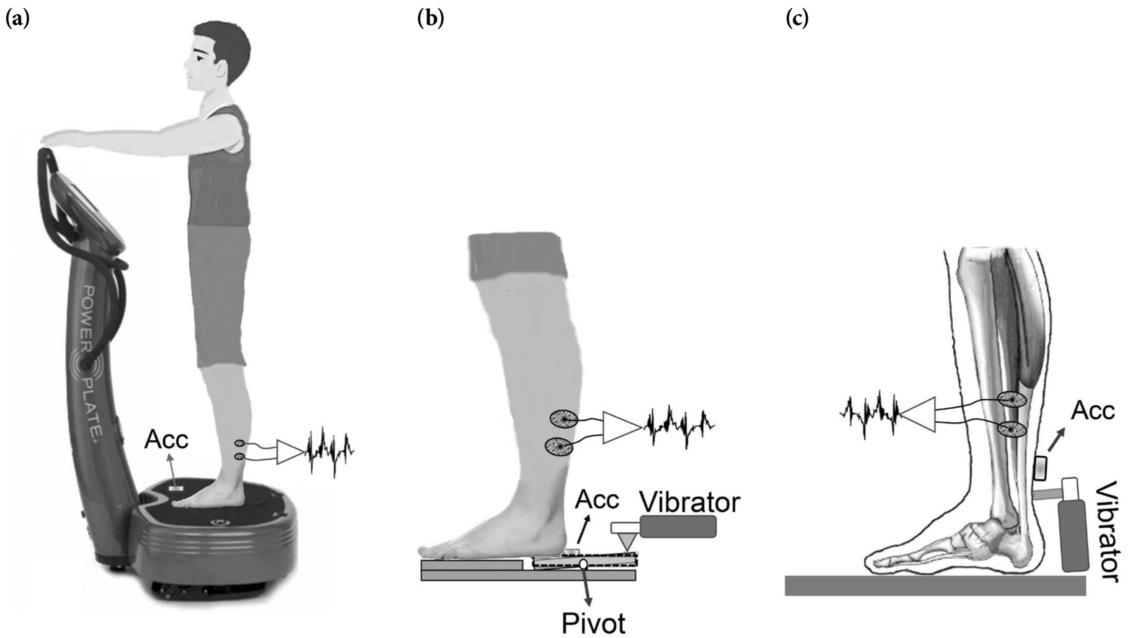

Figure 1. Experimental vibration setup. **(a)** Low-frequency WBV, **(b)** high-frequency WBV applied to the heel, and **(c)** Achilles tendon vibration. An Acc was fixed on a vibration plate and mounted on the Achilles tendon. To record reflex response, a pair of surface EMG electrodes was placed on the soleus muscle.

WBV: Whole-body vibration; Acc: Accelerometer.

Tendon reflex

The tendon reflex was elicited using an electronic reflex hammer (ELCON Medical Instruments GmbH, Tuttlingen, Germany) in a quiet standing position. Tendon reflex latency and TVR latency are similar spindle-based reflexes.[5] In this study, tendon reflex latency was used as a reference to describe the TVR reflex.

Data acquisition

The surface electromyography (sEMG) recorded from the right soleus muscle, and acceleration data were collected simultaneously using a data acquisition and analysis system (PowerLab® software; ADInstruments, Oxford, United Kingdom). Disposable self-adhesive bipolar Ag/AgCl (Covidien Kendall, Dublin, Ireland) surface electrodes were placed on the right soleus belly 4 cm apart.[18] The skin overlying the muscle was shaved, light abrasion was applied, and the skin was cleaned with alcohol to reduce skin resistance.

To determine soleus TVR latency, a light piezoelectric accelerometer (LIS344ALH; ECOPACK®, Mansfield, TX, USA) was firmly fixed using adhesive tape on the skin overlying the right Achilles tendon. To determine low-and high-frequency WBV-IMR latencies, an accelerometer was firmly mounted on the vibration platform (Figure 1). The acceleration and sEMG signals were recorded at a sampling frequency of 20 kHz.

Accelerometer recordings were filtered with a high-pass filter set at 5 Hz. Surface electromyography data obtained during low-frequency WBV were bandpass filtered at 80-500 Hz to reduce vibration-induced movement artifacts and then full-wave rectified.[19] Similarly, sEMG data obtained during high-frequency WBV and tendon vibration were bandpass filtered at 160-500 Hz and then full-wave rectified. Reflex latencies were then calculated by using the cumulative average method.[16] All latencies were normalized to the body height of each participant. Latency was expressed in milliseconds (msec).

Determination of reflex latencies

The cumulative average method is a unique mathematical instrument capable of determining the latency of reflexes induced by the high-frequency sinusoidal stimulation of the neuromuscular system, such as WBV and tendon vibration stimulation.[16] The peaks of spikes in the rectified EMG were marked as the trigger points to be used in a spike-triggered averaging scheme. Spike-triggered averaging was performed using these peaks in the EMG data as triggers and acceleration data as sources. The averaging process covered 75 msec of the acceleration data preceding the trigger and 15 msec after. This process was performed separately for each of the three vibration frequencies. The average acceleration curves plotted for each frequency were then superimposed to obtain

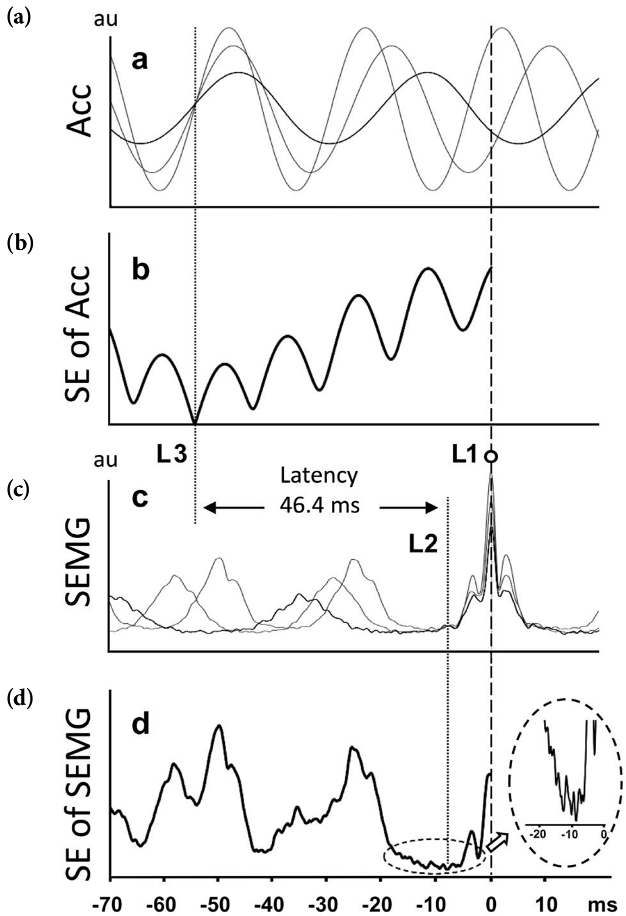

Figure 2. Determination of reflex latency using the cumulative averaging method. **(a)** Three averaged Acc curves, each representing different vibration frequencies. **(b)** Standard error curve of three averaged acceleration sinusoidal curve. **(c)** Three averaged rectified EMG traces, each representing different vibration frequencies. **(d)** Standard error curve of three averaged rectified EMG traces. The empty circle and Line-1 (L1) represent the peak of spikes in the rectified EMG data as the trigger point. Line-2 (L2) represents the lowest value on the SE curve for the EMG data, indicating the onset point of the reflex response to the vibration stimulus. Line-3 (L3) represents the lowest value on the SE curve for the acceleration data, indicating the effective stimulus time point.

Acc: Acceleration; SE: Standard error; EMG: Electromyography; SEMG: Surface electromyography.

a cumulative average curve (Figure 2a). The standard errors (SEs) of the averaged acceleration data belonging to three vibration frequencies were calculated for each of the 1500 bins in the averaging window from -75 to the trigger. The lowest SE point was determined in the SE curve to indicate the "effective stimulation time" point in the cumulative averaged curve of the acceleration (Figure 2b). This averaging procedure was also performed to determine the onset time of the reflex response in EMG recordings (Figures 2c, d). The lowest SE on the cumulated average of the EMG trace was considered the time point where the reflex responses to the vibration were most synchronized and hence the onset of the reflex response. The reflex latency was calculated as the period between the effective stimulus time point and the onset of the EMG spike (Figure 2).[16]

Statistical analyses

The effect size was calculated by G*Power version 3.1.9.4 software (Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany). Effect sizes (partial eta squared) were categorized as follows: small effect=0.01; medium effect=0.06; large effect=0.14.[20] Post hoc power analysis was performed using the G*Power software.

The data were analyzed with PASW version 18.0 (SPSS Inc., Chicago, IL, USA). The normal distribution of the data was tested using the Shapiro-Wilk test. The mean and standard deviation were calculated for each continuous variable. For the comparison of the mean of latency data repeated measures with variance analysis were used. The level of statistical significance was set at $p<0.05$.

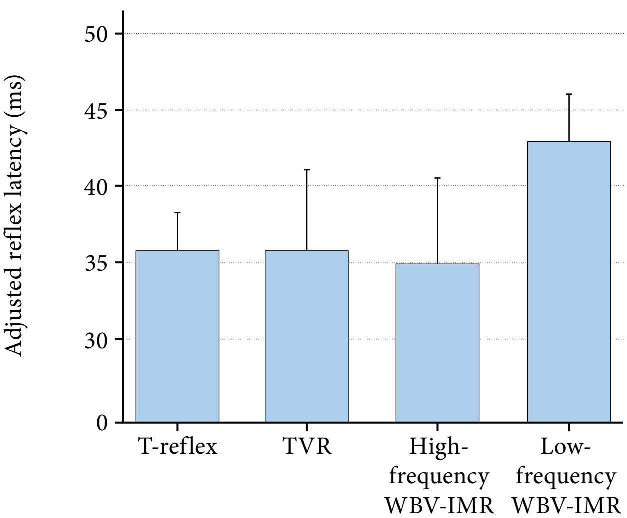

Figure 3. The latency of low-frequency WBV-IMR, high-frequency WBV-IMR, TVR, and tendon reflex for soleus muscle (error bar with a 95% confidence interval).

ms: Millisecond; T-reflex: Tendon reflex; TVR: Tonic vibration reflex; WBV-IMR: Whole-body vibration-induced muscular reflex.

RESULTS

The mean TVR latency was 35.6±5.9 msec, low-frequency WBV-IMR latency was 42.8±3.4 msec, and high frequency WBV-IMR latency was 34.8±6.0 msec. Analysis of variance showed a significant difference among these latencies ($F_{(2,\ 12)}=40.07$, $p=0.0001$, $\eta^2=0.87$). Post hoc pairwise analysis showed that the low-frequency WBV-IMR latency was significantly longer than the high-frequency WBV-IMR latency and TVR latency ($p=0.002$ and $p=0.001$, with Bonferroni correction, respectively). There was no significant difference between the high-frequency WBV-IMR latency and TVR latency ($p=0.526$ with Bonferroni correction; Figure 3).

The calculated partial eta squared was 0.87, nonsphericity correction epsilon (Greenhouse-Geisser) was 0.630, the total sample size was 7, and the alpha error probability was 0.05. According to these parameters, the post hoc achieved power of this study was 1.0.

DISCUSSION

The spinal reflex activated by WBV differs depending on the vibration amplitude.[17] This study showed that the vibration parameters that determine the reflex activated by WBV were not only amplitude but also vibration frequency. The results of this study showed that TVR was activated when high-frequency WBV was applied, but longer latency WBV-IMR was activated when low-frequency WBV was applied.

At present, the frequency of commercial WBV devices is <50 Hz, and commercial WBV devices with a frequency above 100 Hz are not available.[3,4] In previous studies using WBV devices operating in the 25-50 Hz frequency band, it has been reported that the latency of the reflex activated by WBV is longer than that of muscle-spindle-based reflexes.[1,2,5,16,17] In this study, as in previous studies, it was determined that low-frequency WBV activates long-latency WBV-IMR. The reflex activated by high-frequency WBV was investigated for the first time in this study. High-frequency WBV has been shown to activate TVR.

Local vibration or tap applied to the muscle belly or tendon is well known to activate the muscle spindles. Muscle spindles are innervated by primary endings (i.e., Ia afferents) and secondary endings (i.e., II afferents). The muscle spindle primary endings are sensitive to vibrations, whereas the secondary endings are much less sensitive. The rate of discharge of primary endings is proportional to vibration frequency in a one-to-one manner for all frequencies up to 150 Hz. For higher frequencies, the discharge of primary endings has been shown to be disharmonious.[21-23] The TVR is a muscle spindle-based polysynaptic spinal reflex activated by 100-150 Hz frequency vibration.[13-15] In this study, high-frequency vibration was applied in the 100-150 Hz band. Latency measurements showed that both high-frequency tendon vibration and high-frequency WBV activate TVR.

Since there was no available method to measure the latency of the reflex response activated by high-frequency sinusoidal mechanical stimuli, reflex latency measurements could not be made in previous vibration studies. The cumulative average method has been proposed to overcome this problem.[16] In this study, the latency of reflexes activated by low-frequency and high-frequency vibration was measured using the cumulative average method. The sampling rate was 20 kHz for both accelerometer and EMG recordings in the present study. This high sampling rate allowed latency measurements to be made with a sensitivity of 0.05 msec. Although this study's sample size was small, the effect size (partial eta squared) was large, and the study power (100%) was high. This is, to our knowledge, the first study concerning the high-frequency WBV-induced reflex.

In conclusion, the present study has shown that WBV can activate different spinal reflexes depending on the vibration frequency. Unlike a low-frequency WBV, a high-frequency WBV activates the TVR. Whole-body vibration is increasingly used in clinical or sportive rehabilitation due to its beneficial effects on the neuromuscular system. Defining the neurological mechanisms underlying the beneficial effects of WBV on muscle functions may make it possible to prescribe a more effective and efficient exercise program specific to the individual and medical condition in the field of sports and rehabilitation. In this context, future studies are needed to evaluate the effect of high-frequency WBV on muscle strength and performance.

Ethics Committee Approval: The study protocol was approved by the Health Sciences University Kanuni Sultan Süleyman Training and Research Hospital Clinical Research Ethics Committee Ethics Committee (date: 21.09.2021, no: KAEK/2021.10.260). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Conception and design, data collection, writing of manuscript, approval of the final version: E.K.; Conception and design data collection, critical review, approval of the final version: Ö.F.B.; Conception and design data collection, critical review, approval of the final version: M.K.; Data collection, critical review, approval of the final version : M.Ö., M.Ç.; Conception and design data collection, critical review, approval of the final version: M.A.; Conception and design, critical review, approval of the final version: L.A.; Conception and design, data collection, data analysis and interpretation, writing of manuscript, critical review, approval of the final version: İ.K.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

REFERENCES

1. Aydın T, Kesiktaş FN, Baskent A, Karan A, Karacan I, Türker KS. Cross-training effect of chronic whole-body vibration exercise: A randomized controlled study. Somatosens Mot Res 2020;37:51-8. doi: 10.1080/08990220.2020.1720635.
2. Cakar HI, Cidem M, Sebik O, Yilmaz G, Karamehmetoglu SS, Kara S, et al. Whole-body vibration-induced muscular reflex: Is it a stretch-induced reflex? J Phys Ther Sci 2015;27:2279-84. doi: 10.1589/jpts.27.2279.
3. Rawer R. Design Principles of Available Machines. In: Rittweger J, editor. Manual of Vibration Exercise and Vibration 326 Therapy. Nature Switzerland AG: Springer Cham; 2020. p. 39-55.
4. van Heuvelen MJG, Rittweger J, Judex S, Sañudo B, Seixas A, Fuermaier ABM, et al. Reporting guidelines for whole-body vibration studies in humans, animals and cell cultures: A consensus statement from an International Group of Experts. Biology (Basel) 2021;10:965. doi: 10.3390/biology10100965.
5. Yildirim MA, Topkara B, Aydin T, Paker N, Soy D, Coskun E, et al. Exploring the receptor origin of vibration-induced reflexes. Spinal Cord 2020;58:716-23. doi: 10.1038/s41393-020-0419-5.
6. Cochrane DJ. The potential neural mechanisms of acute indirect vibration. J Sports Sci Med 2011;10:19-30.
7. Hazell TJ, Kenno KA, Jakobi JM. Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. J Strength Cond Res 2010;24:1860-5. doi: 10.1519/JSC.0b013e3181ddf6c8.

8. Krutki P, Mrówczyński W, Celichowski J, Bączyk M. Ia EPSPs in rat spinal motoneurons are potentiated after a 5-week whole body vibration. J Appl Physiol (1985) 2022;132:178-86. doi: 10.1152/japplphysiol.00519.2021.
9. Pollock RD, Woledge RC, Martin FC, Newham DJ. Effects of whole body vibration on motor unit recruitment and threshold. J Appl Physiol (1985) 2012;112:388-95. doi: 10.1152/japplphysiol.01223.2010.
10. Rittweger J. Vibration as an exercise modality: How it may work, and what its potential might be. Eur J Appl Physiol 2010;108:877-904. doi: 10.1007/s00421-009-1303-3.
11. Yang F. Application of vibration training in people with common neurological disorders. In: Rittweger J, editor. Manual of vibration exercise and vibration 326 therapy. Nature Switzerland AG: Springer Cham; 2020. p. 343-53.
12. Zaidell LN, Mileva KN, Sumners DP, Bowtell JL. Experimental evidence of the tonic vibration reflex during whole-body vibration of the loaded and unloaded leg. PLoS One 2013;8:e85247. doi: 10.1371/journal.pone.0085247.
13. De Gail P, Lance JW, Neilson PD. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. J Neurol Neurosurg Psychiatry 1966;29:1-11. doi: 10.1136/jnnp.29.1.1.
14. Eklund G, Hagbarth KE. Normal variability of tonic vibration reflexes in man. Exp Neurol 1966;16:80-92. doi: 10.1016/0014-4886(66)90088-4.
15. Matthews PB. The reflex excitation of the soleus muscle of the decerebrate cat caused by vibbration applied to its tendon. J Physiol 1966;184:450-72. doi: 10.1113/jphysiol.1966.sp007926.
16. Karacan I, Cakar HI, Sebik O, Yilmaz G, Cidem M, Kara S, et al. A new method to determine reflex latency induced by high rate stimulation of the nervous system. Front Hum Neurosci 2014;8:536. doi: 10.3389/fnhum.2014.00536.
17. Karacan I, Cidem M, Cidem M, Türker KS. Whole-body vibration induces distinct reflex patterns in human soleus muscle. J Electromyogr Kinesiol 2017;34:93-101. doi: 10.1016/j.jelekin.2017.04.007.
18. Tucker KJ, Türker KS. A new method to estimate signal cancellation in the human maximal M-wave. J Neurosci Methods 2005;149:31-41. doi: 10.1016/j.jneumeth.2005.05.010.
19. Sebik O, Karacan I, Cidem M, Türker KS. Rectification of SEMG as a tool to demonstrate synchronous motor unit activity during vibration. J Electromyogr Kinesiol 2013;23:275-84. doi: 10.1016/j.jelekin.2012.09.009.
20. Fritz CO, Morris PE, Richler JJ. Effect size estimates: Current use, calculations, and interpretation. J Exp Psychol Gen 2012;141:2-18. doi: 10.1037/a0024338.
21. Banks RW, Ellaway PH, Prochazka A, Proske U. Secondary endings of muscle spindles: Structure, reflex action, role in motor control and proprioception. Exp Physiol 2021;106:2339-66. doi: 10.1113/EP089826.
22. Brown MC, Engberg I, Matthews PB. The relative sensitivity to vibration of muscle receptors of the cat. J Physiol 1967;192:773-800. doi: 10.1113/jphysiol.1967.sp008330.
23. Roll JP, Vedel JP. Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. Exp Brain Res 1982;47:177-90. doi: 10.1007/BF00239377.