APPENDIX

to paper: Hartard M, Seiler A, Peter Spitzenpfeil P et al. Sex-specific response to whole-body vibration training: a randomized controlled trial. Biol Sport. 2022;39(1):207-217. https://doi.org/10.5114/biolsport.2021.102806. (link)

DISCUSSION

Neuromuscular theory of WBV

The transmission of vibration mechanical energy applicable to the skeletal muscle or tendon stimulates sensory receptors on muscle spindle primary endings (mainly Ia afferent nerve endings) [1, 2]. Direct excitation of the Ia afferent nerve endings of the muscle spindle, through the vibration of the muscle, stimulates the α-motor neurons, producing reflex contractions of this muscle [3]. The consequence is a tonic contraction of the muscle (i.e., tonic vibration reflex (TVR)) [4–10]. The primary recruitment of the α-motor neurons is done through signals from the brain to the muscles, and the α-motor neurons engender muscle contractions (i.e., TVR) [11, 12]. Neuromuscular spindles are habitually excited when a muscle is under a static stretch or speedily stretched or overstretched, leading to a rapid and powerful TVR [13]. Some studies reported that once a muscle is subject to vibration, the TVR is constantly excited by contracting and relaxing the muscle, until the vibration stimulus ends [14, 15]. Several studies have established a rise in electromyography activity in reaction to acute WBV, demonstrating that a rise in neuromuscular activity has happened under WBV [16–18]. Consequently, repeating this TVR cycle might improve voluntary skeletal muscle activation with the muscle "stiffening" in an effort to dampen out the consequence of vibration. By improving some facets of the neuromuscular system (e.g., muscle strength and power, speed, flexibility, body stability and composition) [19–34], WBV training improves both muscle performance and function whatever the sex, age and the training status.

Possible mechanisms underlying the effects of WBV training on cardiovascular function

Vibration stimulus excites the TVR and therefore activates and improves the neuromuscular system [16–18, 30]. This activation necessitates the turnover of energy in the muscle (metabolic activity), and therefore an upsurge in the request for energy. Generating the extra energy commanded by the muscle requires some adaptations of the HR and blood pressure and needs additional blood flow (BF) to be supplied to the skeletal muscle. Numerous studies have investigated the impacts of vibration training on cardiovascular function [8, 35–50]. Among these studies, some have indicated that several phenomena (e.g., itchiness, redness, erythema, and oedema) occurred transitorily during the first few sessions of WBV training [39, 42, 46–50]. According to some authors [36, 37, 39–43, 45, 47, 49, 51] the chief contributor of the aforementioned phenomena is the rise in BF.

The probable mechanisms underlying the effects of WBV training on arterial function and blood pressure are the improvement of endothelial and autonomic functions [52]. The possible mechanisms underlying the vasodilation effects of WBV exercise may be related to an acute increase in the production of vasodilatory substances including metabolites and nitric oxide [37, 53]. Another possible explanation is related to the fact that skin blood flow might also increase due to friction forces applied by the mechanical vibration on the endothelial cells at the cellular level [43]. WBV may acutely increase local nitric oxide production [53]. Nitrate administration decreases SBP via a reduction in vascular tone of small arteries independently from aortic pulse wave velocity (PWV) [54]. Figueroa et al. [55], have established that acute WBV diminished the increases in reflected wave magnitude, aortic SBP, leg and brachial-ankle PWVs during metaboreflex-induced sympathetic activation succeeding a continuous 4-min period of static squat. This suggests that vibration-related factors induced functional sympatholysis in the legs [55]. A previous study [52] showed that WBV training reduced the sympathovagal balance due to a simultaneous reduction in sympathetic and a rise in cardiovagal modulation. After WBV training, the reductions in sympathovagal balance and brachial-ankle PWV were powerfully linked [52]. Figueroa et al. [52] suggested that the improvement in brachial-ankle PWV would be moderately attributed to a reduction in sympathetic dominance after WBV training. The mechanisms responsible for the reduced arterial stiffness after WBV exercise training could be a localized improvement in arteries exposed to exercise and vibration [56]. In fact, a 10-min period of intermittent static exercises with WBV exercise training immediately reduces brachial-ankle and leg PWV [40, 57]. Moreover, short-term WBV training with and without exercise may decrease leg PWV through a greater discharge of local contraction-related vasodilatory factors and nitric oxide [53, 55]. The special decrease in leg PWV suggests that WBV exercise training may improve leg artery vasomotor tone [56]. The possible mechanisms underlying the impact of WBV exercise training on HR variability may include a rise in baroreflex sensitivity [58, 59]. The evidence strongly suggests that WBV exercise training limits the reduction in the spontaneous baroreflex sensitivity caused by prolonged head-down bed rest in healthy subjects [60]. An additional possible mechanism could be a rise in nitric oxide levels. Numerous lines of evidence indicate that nitric oxide may play a role in cardiac autonomic function by rising vagal and reducing sympathetic activity [61–63]. In fact, WBV exercise training was found to raise circulating nitric oxide [64, 65].

REFERENCES

1. Hagbarth KE, Eklund G. Tonic vibration reflexes (TVR) in spasticity. Brain Res 1966: 2(2): 201–203.
2. Shinohara M. Effects of prolonged vibration on motor unit activity and motor performance. Med Sci Sports Exerc 2005: 37(12): 2120–2125.
3. Granit R, Henatsch HD, Steg G. Tonic and phasic ventral horn cells differentiated by post-tetanic potentiation in cat extensors. Acta Physiol Scand. 1956: 37(2–3): 114–126.
4. Bongiovanni LG, Hagbarth KE. Tonic vibration reflexes elicited during fatigue from maximal voluntary contractions in man. J Physiol 1990: 423: 1–14.
5. Burke D, Hagbarth KE, Lofstedt L, Wallin BG. The responses of human muscle spindle endings to vibration during isometric contraction. J Physiol 1976: 261(3): 695–711.
6. Burke D, Hagbarth KE, Lofstedt L, Wallin BG. The responses of human muscle spindle endings to vibration of non-contracting muscles. J Physiol 1976: 261(3): 673–693.
7. Claus D, Mills KR, Murray NM. The influence of vibration on the excitability of alpha motoneurones. Electroencephalogr Clin Neurophysiol 1988: 69(5): 431–436.
8. Johnston RM, Bishop B, Coffey GH. Mechanical vibration of skeletal muscles. Physical therapy 1970: 50(4): 499–505.
9. Martin BJ, Park HS. Analysis of the tonic vibration reflex: influence of vibration variables on motor unit synchronization and fatigue. Eur J Appl Physiol Occup Physiol 1997: 75(6): 504–511.
10. Mester J, Spitzenfeil P, Schwarzer J, Seifriz F. Biological reaction to vibration--implications for sport. J Sci Med Sport 1999: 2(3): 211–226.
11. Cunnington R, Windischberger C, Deecke L, Moser E. The preparation and execution of self-initiated and externally-triggered movement: a study of event-related fMRI. NeuroImage 2002: 15(2): 373–385.
12. Naito E, Kinomura S, Geyer S, Kawashima R, Roland PE, Zilles K. Fast reaction to different sensory modalities activates common fields in the motor areas, but the anterior cingulate cortex is involved in the speed of reaction. J Neurophysiol 2000: 83(3): 1701–1709.
13. Wilcock IM, Whatman C, Harris N, Keogh JW. Vibration training: could it enhance the strength, power, or speed of athletes? J Strength Cond Res 2009: 23(2): 593–603.
14. Totosy de Zepetnek JO, Giangregorio LM, Craven BC. Whole-body vibration as potential intervention for people with low bone mineral density and osteoporosis: a review. J Rehabil Res Dev 2009: 46(4): 529–542.
15. 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): 1–11.
16. Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. J Strength Cond Res 2003: 17(3): 621–624.
17. Abercromby AF, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Variation in neuromuscular responses during acute whole-body vibration exercise. Med Sci Sports Exerc 2007: 39(9): 1642–1650.
18. Hazell TJ, Jakobi JM, Kenno KA. The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. Appl Physiol Nutr Metab 2007: 32(6): 1156–1163.
19. Mahieu NN, Witvrouw E, Van de Voorde D, Michilsens D, Arbyn V, Van den Broecke W. Improving strength and postural control in young skiers: whole-body vibration versus equivalent resistance training. J Athl Train 2006: 41(3): 286–293.
20. Stewart JA, Cochrane DJ, Morton RH. Differential effects of whole body vibration durations on knee extensor strength. J Sci Med Sport 2009: 12(1): 50–53.
21. Torvinen S, Kannu P, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Jarvinen TL, Jarvinen M, Oja P, Vuori I. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. Clin Physiol Funct Imaging 2002: 22(2): 145–152.
22. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 2003: 35(6): 1033–1041.
23. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. Int J Sports Med 2004: 25(1): 1–5.
24. de Ruiter CJ, van der Linden RM, van der Zijden MJ, Hollander AP, de Haan A. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. Eur J Appl Physiol 2003: 88(4–5): 472–475.
25. Erskine J, Smillie I, Leiper J, Ball D, Cardinale M. Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men. Clin Physiol Funct Imaging 2007: 27(4): 242–248.
26. Bosco C, Colli R, Introini E, Cardinale M, Tsarpela O, Madella A, Tihanyi J, Viru A. Adaptive responses of human skeletal muscle to vibration exposure. Clin Physiol 1999: 19(2): 183–187.
27. Fagnani F, Giombini A, Di Cesare A, Pigozzi F, Di Salvo V. The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. Am J Phys Med Rehabil 2006: 85(12): 956–962.
28. Cochrane DJ, Stannard SR. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. Br J Sports Med 2005: 39(11): 860–865.
29. Bazett-Jones DM, Finch HW, Dugan EL. Comparing the effects of various whole-body vibration accelerations on counter-movement jump performance. J Sports Sci Med 2008: 7(1): 144–150.
30. Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, Viru A. Hormonal responses to whole-body vibration in men. Eur J Appl Physiol 2000: 81(6): 449–454.
31. Cochrane DJ, Stannard SR, Sargeant AJ, Rittweger J. The rate of muscle temperature increase during acute whole-body vibration exercise. Eur J Appl Physiol 2008: 103(4): 441–448.
32. Cormie P, Deane RS, Triplett NT, McBride JM. Acute effects of whole-body vibration on muscle activity, strength, and power. J Strength Cond Res 2006: 20(2): 257–261.
33. Di Giminiani R, Tihanyi J, Safar S, Scrimaglio R. The effects of vibration on explosive and reactive strength when applying individualized vibration frequencies. J Sports Sci 2009: 27(2): 169–177.
34. Torvinen S, Sievänen H, Järvinen TA, Pasanen M, Kontulainen S, Kannus P. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. Int J Sports Med 2002: 23(5): 374–379.
35. Maloney-Hinds C, Petrofsky JS, Zimmerman G. The effect of 30 Hz vs. 50 Hz passive vibration and duration of vibration on skin blood flow in the arm. Med Sci Monit 2008: 14(3): CR112–116.
36. Herrero AJ, Menendez H, Gil L, Martin J, Martin T, Garcia-Lopez D, Gil-Agudo A, Marin PJ. Effects of whole-body vibration on blood flow and neuromuscular activity in spinal cord injury. Spinal cord 2011: 49(4): 554–559.
37. Herrero AJ, Martin J, Martin T, Garcia-Lopez D, Garatachea N, Jimenez B, Marin PJ. Whole-body vibration alters blood flow velocity and neuromuscular activity in Friedreich's

ataxia. Clin Physiol Funct Imaging 2011: 31(2): 139–144.
38. Lohman EB, 3rd, Sackiriyas KS, Bains GS, Calandra G, Lobo C, Nakhro D, Malthankar G, Paul S. A comparison of whole body vibration and moist heat on lower extremity skin temperature and skin blood flow in healthy older individuals. Med Sci Monit 2012: 18(7): CR415–424.
39. Hazell TJ, Thomas GW, Deguire JR, Lemon PW. Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise. Eur J Appl Physiol 2008: 104(5): 903–908.
40. Otsuki T, Takanami Y, Aoi W, Kawai Y, Ichikawa H, Yoshikawa T. Arterial stiffness acutely decreases after whole-body vibration in humans. Acta Physiol (Oxf) 2008: 194(3): 189–194.
41. Stewart JM, Karman C, Montgomery LD, McLeod KJ. Plantar vibration improves leg fluid flow in perimenopausal women. Am J Physiol Regul Integr Comp Physiol 2005: 288(3): R623–629.
42. Kerschan-Schindl K, Grampp S, Henk C, Resch H, Preisinger E, Fialka-Moser V, Imhof H. Whole-body vibration exercise leads to alterations in muscle blood volume. Clin Physiol 2001: 21(3): 377–382.
43. Lohman EB, 3rd, Petrofsky JS, Maloney-Hinds C, Betts-Schwab H, Thorpe D. The effect of whole body vibration on lower extremity skin blood flow in normal subjects. Med Sci Monit 2007: 13(2): CR71–76.
44. Lohman EB, 3rd, Bains GS, Lohman T, DeLeon M, Petrofsky JS. A comparison of the effect of a variety of thermal and vibratory modalities on skin temperature and blood flow in healthy volunteers. Med Sci Monit 2011: 17(9): MT72–81.
45. Lythgo N, Eser P, de Groot P, Galea M. Whole-body vibration dosage alters leg blood flow. Clin Physiol Funct Imaging 2009: 29(1): 53–59.
46. Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. J Am Geriatr Soc 2004: 52(6): 901–908.
47. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000: 20(2): 134–142.
48. Russo CR, Lauretani F, Bandinelli S, Bartali B, Cavazzini C, Guralnik JM, Ferrucci L. High-frequency vibration training increases muscle power in postmenopausal women. Arch Phys Med Rehabil 2003: 84(12): 1854–1857.
49. Broadbent S, Rousseau JJ, Thorp RM, Choate SL, Jackson FS, Rowlands DS. Vibration therapy reduces plasma IL6 and muscle soreness after downhill running. Br J Sports Med 2010: 44(12): 888–894.
50. Cronin JB, Oliver M, McNair PJ. Muscle stiffness and injury effects of whole body vibration. Physical Therapy in Sport 2004: 5(2): 68–74.
51. Rittweger J. Vibration as an exercise modality: how it may work, and what its potential might be. Eur J Appl Physiol 2010: 108(5): 877–904.
52. Figueroa A, Gil R, Wong A, Hooshmand S, Park SY, Vicil F, Sanchez-Gonzalez MA. Whole-body vibration training reduces arterial stiffness, blood pressure and sympathovagal balance in young overweight/obese women. Hypertens Res 2012: 35(6): 667–672.
53. Maloney-Hinds C, Petrofsky JS, Zimmerman G, Hessinger DA. The role of nitric oxide in skin blood flow increases due to vibration in healthy adults and adults with type 2 diabetes. Diabetes Technol Ther. 2009: 11(1): 39–43.
54. Kelly RP, Millasseau SC, Ritter JM, Chowienczyk PJ. Vasoactive drugs influence aortic augmentation index independently of pulse-wave velocity in healthy men. Hypertension 2001: 37(6): 1429–1433.
55. Figueroa A, Gil R, Sanchez-Gonzalez MA. Whole-body vibration attenuates the increase in leg arterial stiffness and aortic systolic blood pressure during post-exercise muscle ischemia. Eur J Appl Physiol 2011: 111(7): 1261–1268.
56. Figueroa A, Kalfon R, Madzima TA, Wong A. Whole-body vibration exercise training reduces arterial stiffness in postmenopausal women with prehypertension and hypertension. Menopause 2014: 21(2): 131–136.
57. Figueroa A, Vicil F, Sanchez-Gonzalez MA. Acute exercise with whole-body vibration decreases wave reflection and leg arterial stiffness. Am J Cardiovasc Dis 2011: 1(1): 60–67.
58. Collier SR, Kanaley JA, Carhart R, Jr., Frechette V, Tobin MM, Bennett N, Luckenbaugh AN, Fernhall B. Cardiac autonomic function and baroreflex changes following 4 weeks of resistance versus aerobic training in individuals with pre-hypertension. Acta Physiol (Oxf) 2009: 195(3): 339–348.
59. Kouidi E, Vergoulas G, Anifanti M, Deligiannis A. A randomized controlled trial of exercise training on cardiovascular and autonomic function among renal transplant recipients. Nephrol Dial Transplant 2013: 28(5): 1294–1305.
60. Coupe M, Yuan M, Demiot C, Bai YQ, Jiang SZ, Li YZ, Arbeille P, Gauquelin-Koch G, Levrard T, Custaud MA, Li YH. Low-magnitude whole body vibration with resistive exercise as a countermeasure against cardiovascular deconditioning after 60 days of head-down bed rest. Am J Physiol Regul Integr Comp Physiol 2011: 301(6): R1748–1754.
61. Hare JM, Keaney JF, Jr., Balligand JL, Loscalzo J, Smith TW, Colucci WS. Role of nitric oxide in parasympathetic modulation of beta-adrenergic myocardial contractility in normal dogs. J Clin Invest 1995: 95(1): 360–366.
62. Zanzinger J, Czachurski J, Seller H. Inhibition of basal and reflex-mediated sympathetic activity in the RVLM by nitric oxide. Am J Physiol 1995: 268(4 Pt 2): R958–962.
63. Conlon K, Collins T, Kidd C. Modulation of vagal actions on heart rate produced by inhibition of nitric oxide synthase in the anaesthetized ferret. Exp Physiol 1996: 81(3): 547–550.
64. Humphries B, Fenning A, Dugan E, Guinane J, MacRae K. Whole-body vibration effects on bone mineral density in women with or without resistance training. Aviat Space Environ Med 2009: 80(12): 1025–1031.
65. Wong A, Alvarez-Alvarado S, Jaime SJ, Kinsey AW, Spicer MT, Madzima TA, Figueroa A. Combined whole-body vibration training and l-citrulline supplementation improves pressure wave reflection in obese postmenopausal women. Appl Physiol Nutr Metab 2016: 41(3): 292–297.