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ORIGINAL ARTICLE

Upper-body vibration as part of warm-up: its effect on throwing velocity in elite adolescent handball players

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Abstract

Purpose The purpose of this study was to examine the acute effects of 40-Hz upper-body vibration at two different amplitudes, added to the warm-up process, on throwing velocity in elite adolescent handball players.

Methods Seventeen elite male adolescent handball players (16.4 ± 0.7 years, mean ± SD) were exposed to two upper-body vibration protocols at 40 Hz (3 × 15 s), one with a 2-mm amplitude and one with a 4-mm amplitude, in a random crossover design. The athletes applied the standard pre-game warm-up, followed by three ball throws from a seated position. A radar gun was used to evaluate throwing velocity and the best shot was chosen. Then the vibration protocol was applied and, immediately afterwards, throwing velocity was retested. The two protocols were set 48 h apart.

Results Results revealed statistically significant improvement ($p < 0.001$) of throwing velocity after both vibration protocols.

Conclusion In conclusion, upper-body vibration at a frequency of 40 Hz and amplitude of either 2 mm or 4 mm may be considered as an addition to the regular warm-up in elite adolescent handball players, resulting in improved ball throwing velocity.

Keywords Team sports · Upper limb vibration · Warm-up · Handball shot · Power

Introduction

Warm-up routines are considered essential and are applied prior to every athletic activity for athletes to be optimally prepared to achieve best performance in subsequent athletic activity [31]. This is achieved via a variety of responses such as elevation of core and muscle temperature, increased blood flow to the muscles and faster nerve conduction [1, 2]. Furthermore, well-structured warm-up protocols are widely thought to enhance subsequent athletic performance [14].

Superimposed vibration during exercise is considered as a method that can be implemented in warm-up protocols. Different types of vibration have been used, such as whole-body vibration and vibration of a tendon or a body part [17, 25], eliciting increases in strength and power either acutely or after a short [7] or long-term application [11, 23]. A series of mechanisms have been reported to underpin the responses to vibration, the most cited among them being a muscular effect, the so-called tonic vibration reflex, which causes compensatory muscle contractions via excitation of primary endings of muscle spindles and activation of α motor neurons [3].

The acute effect of vibration has received much attention in the last decades. Studies have found that vibration may enhance sprint start velocity [27], repetitive horizontal jump distance and velocity [5], and countermovement jump performance in both elite and recreational athletes [8, 9].

Given the potential of vibration exercise as an alternative warm-up modality to augment explosive performance, the majority of studies have focused on lower limb performance. Research on the acute effect of vibration on upper limb performance is sparse. Whole-body vibration stimuli have resulted in less increased electromyographic activity of upper compared to lower body muscles [15]. Additionally, a significant positive acute effect on the power of shoulder joint muscles and biceps brachii peak power was revealed after local vibration [4, 16]. Thus, it seems that vibration

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targeted to an upper-body muscle or muscle group may be more beneficial to power/strength of upper limbs than whole-body vibration.

Conditioning exercises previously used, as an addition to the warm-up, were mainly resistance exercises. Therefore, it is interesting to examine whether a local vibration exercise on upper limbs during warm-up can affect upper-limb power performance such as throwing velocity of handball players. Throwing is a fundamental handball skill, as it leads to scoring a goal. Furthermore, it is a multi-joint movement and examining it would provide essential information about the acute effect of vibration on complex movements of the upper limbs. As warm-up protocols are more effective when they are sport specific, the primary aim of this study was to examine whether a throwing specific vibration exercise, implemented in a typical warm-up, can augment throwing velocity in adolescent handball players. Furthermore, as the choice of appropriate vibration parameters is crucial for maximizing performance [19], the second purpose of this study was to compare the effectiveness of two vibration amplitudes.

Methods

Experimental approach to the problem

This investigation used a cross-sectional study design. We asked each subject to complete two testing sessions. During the first testing session, we measured anthropometric variables. After warm-up, participants performed three shots from seated position. Then they completed the vibration protocol of either 2 or 4 mm amplitude and after that their throwing velocity was retested. During the second testing session, after warm-up, participants performed three shots from seated position. Then the remaining vibration protocol (of 2 mm if the amplitude applied at the first session was 4 mm and vice versa) was applied and after that their throwing velocity was retested. The order of the two testing sessions was randomized.

Participants

Seventeen male adolescent handball players without previous experience in vibration training volunteered to participate in the study. All athletes were healthy and had no musculoskeletal or other health problem. The participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. Additionally, parental or guardian signed consent was obtained. All procedures were approved by the responsible Institutional Review Board (IRB) and were in accordance with the ethical standards on human experimentation and with the Helsinki Declaration of 1975.

The study was conducted in the athletes' usual handball court. Prior to the warm-up protocol, anthropometric and cardiac parameters were measured (Table 1).

Procedures

The P-Vibe Professional 170005 Self Icon, USA vibration platform was used with a stimulus transfer frequency of 30–60 Hz and a displacement range of 2–4 mm. A handball size 3 (perimeter 58–60 cm, weight 425–475 g) was used for the throws. For throws to be performed from seated position, two chairs without arms were used. A radar gun (Sports Radar 3.0, Sports Electronics, Hinsdale, IL) was used to measure ball throwing velocity. The accuracy of the device, as defined by the manufacturer, was ± 0.1 km/h within a field of 10°. The radar gun was placed on a tripod behind the goalpost. The subjects were sitting 6 m away from the goalpost. This setup was chosen as the reliability of the device is higher when the measured object is moving towards the radar gun.

The two testing sessions took place 48 h apart, in random order and at the same time of the day, which was matched to the athletes' usual training time. The athletes started warming up in couples with a difference of 5 min from each other to avoid any interval between warm-up and test. Warm-up included free running, static stretching exercises for the entire body (stretching for 15 s in each position), passes and shots. After performing this warm-up for 25–30 min, throwing velocity was evaluated with the athlete seated in the chair and tied with a strap at the height of the rapier bone. Then the participant performed the upper-limb vibrating exercise (3 sets × 15 s with an interval of 15 s between sets, frequency of 40 Hz and range displacement 2 mm or 4 mm). The participant's position for performing the vibrating exercise was the same as that used to measure ball throwing velocity (Fig. 1). The athlete was seated in the chair, tied with a strap at the height of the rapier bone, having the preferred arm in throwing position with the shoulder

Table 1 Characteristics of participants (mean ± SD, $n = 17$)

Age (years)	16.4 ± 0.7
Height (cm)	177 ± 7
Body mass (kg)	70.5 ± 8.0
Training experience (years)	6.1 ± 1.6
Resting heart rate (bmp)	64 ± 8
Resting systolic blood pressure (mmHg)	121 ± 9
Resting diastolic blood pressure (mmHg)	73 ± 8
Arm width (cm)	183 ± 6
Palm width (cm)	20.1 ± 1.0

Fig. 1 Throwing position

Fig. 2 Position during vibration exercise

in 90° abduction [12], neutral rotation and gripping the belt that carried the vibration (Fig. 2). At the end of the vibrating exercise, the athlete performed three throws at a specific target (the goalpost) from a distance of 6 m from the same position. A 30-s interval was applied between the throws. All three throws were recorded and the best was selected (Fig. 3).

Three experienced coach examiners supervised the protocol and were responsible for the correct execution and exact duration of the warm-up, the parameter settings, the application of the vibrating exercise and the proper throwing technique.

Statistical analyses

Statistics were performed with the SPSS/PC 24.0 (SPSS, Chicago, IL) software. Mean and SD were calculated for all variables. Repeated-measures two-way analysis of variance was applied to examine the main effects of vibration amplitude (2 mm vs. 4 mm) and time (before vs. after the vibration exercise), as well as their interaction on throwing velocity. Alpha was set at 0.05. Eta squared (η^2) was used to estimate effect size. Test–retest reliability for all dependent variables was assessed by the intraclass correlation coefficient (ICC, including 95% CI), using a two-way mixed model ANOVA.

Results

A significant effect of time on throwing velocity was revealed [$F(1,16) = 35.9$, $p < 0.001$, $\eta^2 = 0.69$], as throwing velocity significantly increased in the post-vibration measurement compared to the pre-vibration measurement (Fig. 4). No significant effect of vibration amplitude was found [$F(1,16) = 1.6$, $p = 0.2$]. Likewise, no significant interaction of the two factors was found [$F(1,16) = 0.03$, $p = 0.9$]. The intraclass correlation coefficient (ICC) was 0.93 (95% confidence interval [CI] 0.82–0.90; $p < .001$).

Discussion

The results of this study revealed that an upper-body vibration protocol, implemented in a warm-up procedure, can increase ball throwing velocity in elite male adolescent handball players. Therefore, our first hypothesis for a positive effect of vibration at a frequency of 40 Hz as a warm-up exercise on throwing velocity was confirmed. On the contrary, our second hypothesis concerning the comparison of two vibration amplitudes was not confirmed as both protocols had the same positive effect on ball throwing velocity.

To the best of our knowledge, this is the first study to examine the effect of local vibration on throwing velocity in adolescent handball players. Therefore, it is difficult to directly compare the results of this study to those of other studies because of methodological differences. However, our results are in accordance with previous studies that have found a positive effect of vibration on various task performances. Body vibration as a conditioning protocol resulted in acute improvements in lower limb task performance, such as countermovement jump, speed, agility and flexibility [8, 9, 24] while other

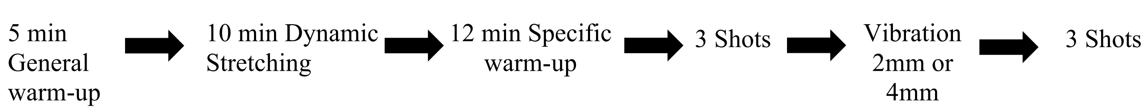

Fig. 3 Summary of the study design

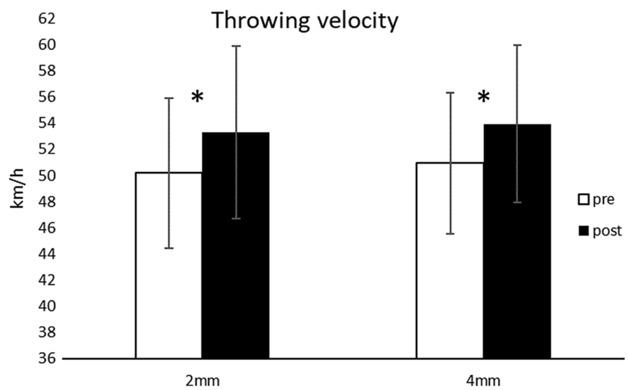

Fig. 4 Throwing velocity at the pre- and post-vibration measurements. *Significant difference between pre- and post-values at $p \leq 0.001$

studies have reported no beneficial acute effects of vibration [10, 29]. Concerning the effectiveness of whole-body vibration on upper limbs, Morel et al. [21] reached the conclusion that it can result in performance improvements, while Cochrane and Stannard [8] claimed, that when muscles are not directly or locally exposed to vibration, they present lower performance enhancement than muscles which are directly or locally vibrated. The current results correlate fairly well with Cochrane and Stannard [8] and further support the idea of the effectiveness of local vibration on upper-limb power performance.

Discrepancies in the literature may be also due to differences in vibration parameters such amplitude and frequency. Vibration intensity is determined by the frequency and amplitude applied and it has been suggested to affect the neuromuscular responses [19]. The frequency of 40 Hz used in the present study is within the range of frequencies that have resulted in the highest effect size (ES) regarding performance, as mentioned in the meta-analysis of Marin and Rhea [19]. Furthermore, small amplitudes (2–6 mm) resulted in smaller effects than larger amplitudes (8–10 mm) [19]. This can probably explain why the two protocols applied in this study did not differ in effectiveness. Both amplitudes used (2 mm and 4 mm) were in the range of amplitudes that are considered to have similar effect on performance and, therefore, they could not further enhance the already positive effect of 40-Hz frequency applied. However, the frequency of 40 Hz and the amplitudes of 2 and 4 mm are, as recently reported [18], both safe and effective. As the selection of the best combination of frequency and amplitude is crucial for performance enhancement, further research is needed to clarify which may be the optimal vibration parameters to acutely increase throwing velocity in handball players.

The results of this study corroborate earlier findings indicating that a vibration exercise implemented in a warm-up process can enhance performance and neuromuscular response in upper-limb muscles [20]. Although it was beyond the aim of this study to examine possible changes in electromyographic activity after the application of the vibration exercise, it seems possible for this to be a mechanism explaining the improved performance in throwing velocity after vibration. Additionally, antagonistic muscle relaxation [26] occurring during vibration could have probably resulted in improved motor coordination [13] and, as a consequence, in increased throwing velocity. Regardless of the underlying mechanism, it is clear that local vibration induces an acute increase in muscle power of upper limbs in adolescent handball players.

Performance enhancement following a conditioning activity is a phenomenon referred to as post-activation potentiation (PAP) [32]. PAP was previously revealed in upper-body power following a preloading stimulus consisting of either 3 × 3 ballistic bench throws at 30% 1RM or 3 × 3 bench press at 87% 1RM [30]. On the contrary, adding upper-body vibration to the warm-up routine resulted in the same performance improvement as with either upper-body vibration or regular warm-up in master swimmers [22], whilst using five upper-limb vibration exercises caused no PAP on throwing velocity in climbers [6]. However, it is possible that the vibration exercises used in both aforementioned studies (which failed to cause PAP) lacked the specific muscular performance positions required to induce PAP. Thus, the desired effects of vibration were not transferred to the multi-joint movements of swimming and medicine ball throwing. It is generally accepted that the transfer of a training effect to performance is greater when a training exercise is specific to the competitive movement [28]. Thus, it can be assumed that the effectiveness of upper-body vibration in this study can be also attributed to the position attained during vibration, which was throwing specific. One point of consideration is the fact that a sham trial (simply holding the arm in the same position and for the same time as when vibration was applied) after the warm-up was not performed in order the contribution of specificity of movement in the enhancement of throwing velocity to be controlled.

In conclusion, upper-body vibration applied at a throwing position, at a frequency of 40 Hz using either 2 mm or 4 mm amplitude, may be considered as an addition to the regular warm-up in elite adolescent handball players resulting in improved ball throwing velocity.

Practical applications

Improving shooting velocity is one of the fundamental goals of both handball players and coaches. According to the results of this study, a vibration protocol of 40-Hz frequency and amplitude of either 2 or 4 mm applied at a seated throwing position may be implemented to the warm-up process in handball players resulting in acute enhanced ball throwing velocity. Furthermore, this finding may also have implications for throwing velocity training and practitioners/coaches may apply this protocol as an alternative addition to warm-up in athletes of other team sports when their goal is the acute potentiation of throwing performance. As vibration devices are of small volume and at an economical price, they can be easily obtained and used by sport clubs or/and practitioners/coaches.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest concerning this article.

Ethical approval Ethical approval was obtained from the local Human Research Ethics Committee at the local university (534/2010), in accordance with the Declaration of Helsinki.

Informed consent Before testing, the parents of the adolescent participants read and signed a written informed consent statement.

References

1. Bishop D (2003) Warm up I. Sports Med 33(6):439–454. https://doi.org/10.2165/00007256-200333060-00005
2. Burnley M, Doust JH, Jones AM (2005) Effects of prior warm-up regime on severe-intensity cycling performance. Med Sci Sports Exerc 37(5):838–845. https://doi.org/10.1249/01.mss.0000162617.18250.77
3. Cardinale M, Lim J (2003) Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. J Strength Cond Res 17(3):621–624. https://doi.org/10.1519/1533-4287(2003)017<0621:eaovlm>2.0.co;2
4. Cochrane D (2016) The acute effect of direct vibration on muscular power performance in master athletes. Int J Sports Med 37(2):144–148. https://doi.org/10.1055/s-0035-1564104
5. Cochrane D, Booker H (2014) Does acute vibration exercise enhance horizontal jump performance? J Sports Sci Med 13(2):315–320
6. Cochrane DJ, Hawke E (2007) Effects of acute upper-body vibration on strength and power variables in climbers. J Strength Cond Res 21(2):527–531. https://doi.org/10.1519/R-18505.1
7. Cochrane DJ, Legg S, Hooker M (2004) The short-term effect of whole-body vibration training on vertical jump, sprint, and agility performance. J Strength Cond Res 18(4):828–832. https://doi.org/10.1519/14213.1
8. Cochrane DJ, Stannard S (2005) Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. Br J Sports Med 39(11):860–865. https://doi.org/10.1136/bjsm.2005.019950
9. Cormie P, Deane RS, Triplett NT, McBride JM (2006) Acute effects of whole-body vibration on muscle activity, strength, and power. J Strength Cond Res 20(2):257. https://doi.org/10.1519/R-17835.1
10. de Ruiter CJ, van der Linden RM, van der Zijden MJA, Hollander AP, de Haan A (2003) Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. Eur J Appl Physiol 88(4–5):472–475. https://doi.org/10.1007/s00421-002-0723-0
11. Delecluse C, Roelants M, Verschueren S (2003) Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 35(6):1033–1041. https://doi.org/10.1249/01.MSS.0000069752.96438.B0
12. Derbyshire D (2008) Physical factors influencing the throwing action in netball and cricket players. (Thesis)
13. Eklund G, Hagbarth KE (1966) Normal variability of tonic vibration reflexes in man. Exp Neurol 16(1):80–92. https://doi.org/10.1016/0014-4886(66)90088-4
14. Fradkin AJ, Zazryn TR, Smoliga JM (2010) Effects of warming-up on physical performance: a systematic review with meta-analysis. J Strength Cond Res 24(1):140–148. https://doi.org/10.1519/JSC.0b013e3181c643a0
15. Hazell TJ, Jakobi JM, Kenno KA (2007) The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. Appl Physiol Nutr Metab 32(6):1156–1163. https://doi.org/10.1139/H07-116
16. Hong J, Velez MT, Moland AM, Sullivan JA (2010) Acute effects of whole body vibration on shoulder muscular strength and joint position sense. J Hum Kinet 25:17–25. https://doi.org/10.2478/v10078-010-0027-0
17. Issurin VB, Tenenbaum G (1999) Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. J Sports Sci 17(3):177–182. https://doi.org/10.1080/026404199366073
18. Ji Q, He H, Zhang C, Lu C, Zheng Y, Luo XT, He C (2017) Effects of whole-body vibration on neuromuscular performance in individuals with spinal cord injury: a systematic review. Clin Rehabilit 31(10):1279–1291. https://doi.org/10.1177/0269215516671014
19. Marín PJ, Rhea MR (2010) Effects of vibration training on muscle power: a meta-analysis. J Strength Cond Res 24(3):871–878. https://doi.org/10.1519/JSC.0b013e3181c7c6f0
20. Mischi M, Cardinale M (2009) The effects of a 28-Hz vibration on arm muscle activity during isometric exercise. Med Sci Sports Exerc 41(3):645–653. https://doi.org/10.1249/MSS.0b013e31818a8a69
21. Morel DS, Marín PJ, Moreira-Marconi E, Dionello CF, Bernardo-Filho M (2018) Can whole-body vibration exercises in different positions change muscular activity of upper limbs? A randomized trial. Dose Response 16(4):1559325818804361. https://doi.org/10.1177/1559325818804361
22. Nepocatych S, Bishop PA, Balilionis G, Richardson MT, Hubner PJ (2010) Acute effect of upper-body vibration on performance in master swimmers. J Strength Cond Res 24(12):3396–3403. https://doi.org/10.1519/JSC.0b013e3181e8a4fe
23. Paradisis G, Zacharogiannis E (2007) Effects of whole-body vibration training on sprint running kinematics and explosive strength performance. J Sports Sci Med 6(1):44–49
24. Pojskic H, Pagaduan J, Uzicanin E, Babajic F, Muratovic M, Tomljanovic M (2015) Acute effects of loaded whole body vibration training on performance. Asian J Sports Med 6(1):e24054. https://doi.org/10.5812/asjsm.24054
25. Poston B, Holcomb WR, Guadagnoli MA, Linn LL (2007) The acute effects of mechanical vibration on power output in the bench press. J Strength Cond Res 21(1):199–203. https://doi.org/10.1519/R-19265.1
26. Ritzmann R, Krause A, Freyler K, Gollhofer A (2018) Acute whole-body vibration increases reciprocal inhibition. Hum Mov Sci 60:191–201. https://doi.org/10.1016/j.humov.2018.06.011
27. Roberts B, Hunter I, Hopkins TY, Feland B (2009) The short-term effect of whole body vibration training on sprint start performance in collegiate athletes. Int J Exerc Sci 2(4):264–268

28. Sale D, MacDougall D (1981) Specificity in strength training: a review for the coach and athlete. Can J Appl Sport Sci 6(2):87–92
29. Torvinen S, Sievänen H, Järvinen TA, Pasanen M, Kontulainen S, Kannus P (2002) Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. Int J Sports Med 23(5):374–379. https://doi.org/10.1055/s-2002-33148
30. West DJ, Cunningham DJ, Crewther BT, Cook CJ, Kilduff LP (2013) Influence of ballistic bench press on upper body power output in professional rugby players. J Strength Cond Res 27(8):2282–2287. https://doi.org/10.1519/JSC.0b013e31827de6f1
31. Woods K, Bishop P, Jones E (2007) Warm-up and stretching in the prevention of muscular injury. Sports Med 37(12):1089–1099. https://doi.org/10.2165/00007256-200737120-00006
32. Xenofondos A, Laparidis K, Kyranoudis A, Galazoulas Ch, Bassa E, Kotzamanidis C (2010) Post-activation potentiation: factors affecting it and the effect on performance. J Phys Educ Sport 28(3):32–38. https://doi.org/10.1017/CBO9781107415324.004