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# Long-term effects of whole-body vibration in trained adolescent swimmers. Does it increase strength, power or swimming performance?

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| Complete List of Authors: | Muniz-Pardos, Borja; University of Zaragoza, Physiatry and Nursing; GENUD (Growth Exercise NUtrition and Development) Research Group, Gomez-Bruton, Alejandro; University of Zaragoza, Physiatry and Nursing; GENUD (Growth Exercise NUtrition and Development) Research Group, ; Centro de Investigacion Biomedica en Red Fisiopatologia de la Obesidad y Nutricion; Instituto Agroalimentario de Aragón<br>Matute-Llorente, Ángel; University of Zaragoza, Physiatry and Nursing; GENUD (Growth Exercise NUtrition and Development) Research Group, ; Centro de Investigacion Biomedica en Red Fisiopatologia de la Obesidad y Nutricion; Instituto Agroalimentario de Aragón<br>González-Agüero, Alex; University of Zaragoza, Physiatry and Nursing; GENUD (Growth Exercise NUtrition and Development) Research Group, ; Centro de Investigacion Biomedica en Red Fisiopatologia de la Obesidad y Nutricion; Instituto Agroalimentario de Aragón<br>Gómez-Cabello, Alba; Centro Universitario de la Defensa Zaragoza; GENUD (Growth Exercise NUtrition and Development) Research Group, ; Centro de Investigacion Biomedica en Red Fisiopatologia de la Obesidad y Nutricion; Instituto Agroalimentario de Aragón<br>Casajus, Jose; University of Zaragoza, Physiatry and Nursing; GENUD (Growth Exercise NUtrition and Development) Research Group, ; Centro de Investigacion Biomedica en Red Fisiopatologia de la Obesidad y Nutricion; Instituto Agroalimentario de Aragón<br>Vicente-Rodríguez, German; University of Zaragoza, Physiatry and Nursing; GENUD (Growth Exercise NUtrition and Development) Research Group, ; Centro de Investigacion Biomedica en Red Fisiopatologia de la Obesidad y Nutricion; Instituto Agroalimentario de Aragón |
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**Title:** Long-term effects of whole-body vibration in trained adolescent swimmers. Does it increase strength, power and swimming performance?

**Running head:** Whole-Body Vibration training in swimmers

**Abstract**

***Purpose***: To examine the effects of a 6-month whole-body vibration (WBV) training on lower-body strength (LBS), lower-body power (LBP) and swimming performance in adolescent trained swimmers. ***Methods***: Thirty-seven swimmers (23 males, 14 females; 14.8 ± 1.3 y) were randomly assigned to the WBV (n= 20) or the control group (n=17). Isometric LBS (knee extension and half-squat) and LBP (vertical and horizontal jumps and 30 m sprint) tests were performed before and after the intervention period. Swimming performance times in 100 m were collected from official competitions. Since time x sex interaction was not found for any variable ($p > 0.05$), males and females were analysed as a whole. ***Results***: Within-group analyses showed a *most likely beneficial* moderate effect of WBV on isometric knee extension [effect size (ES)= 0.63], 30 m sprint test (ES= 0.62) and 100 m performance (ES= 0.25), although these were corresponded with comparable small to moderate effects in the control group (ES= 0.73, 0.71 and 0.20, respectively). The control group obtained a small *possibly beneficial* effect of swimming-only training on vertical jump performance, whereas no effect was observed in the WBV group. *Unclear* effects were observed for the rest of the variables assessed. Between-group analyses revealed *unclear* effects of WBV training when compared to the control condition in all studied variables. ***Conclusions***: There is no current evidence to support the use of WBV training and therefore coaches and sports specialists should select other methods of training when the aim is to increase LBS, LBP or swimming performance.

***Keywords***: vibratory stimulus, athletic performance, dry-land strength, dry-land power, adolescence, chronic effect

## Introduction

Whole-body vibration (WBV) is an oscillatory training method widely used in sports centers [1]. This protocol has been described as the sinusoidal oscillations produced by industrial machines which are transmitted to the human body, enhancing the tonic vibration reflex that stimulates reflex muscle contraction [2], which can potentially improve the neuromuscular function [1]. The seminal research into the stress produced by WBV was focused on the health-related risks construction workers were exposed to [3,4]. From the late 90s, the study of this stimulus began to gain popularity in the field of sports science since a number of pioneering publications proposed WBV as an effective training method to increase lower-body strength (LBS) and lower-body explosive power (LBP) and, potentially, athletic performance [5–8].

The influence of LBP in short-distance swimming performance is well documented [9–12]. The instants when the swimmer has access to ground reaction forces (i.e., dive and turn phases) play a decisive role in overall swimming performance. Lyttle and Benjanuvatra stated that start performance can potentially account for as much as ~15% of the race time over a 100 m competition [13], highlighting the importance of maximizing LBP during the block start performance. A previous meta-analysis revealed positive chronic effects of WBV on LBP through both countermovement jump (CMJ) and squat jump performance, especially when the WBV intervention was longer than 12 weeks, with high frequencies (>30 Hz) and high amplitudes (>3 mm) applied [1]. Delechuse et al. compared the effects of a WBV training protocol with a conventional resistance training routine and, despite witnessing comparable effects on both dynamic and isometric LBS, the authors reported greater effects of the WBV group on LBP (CMJ height) in healthy adults [14]. Previous authors suggested that the physiological mechanisms behind these improvements might be due to neuromuscular adaptations, leading to improvements in motor unit firing and synchronization, synergist muscle contraction, antagonist muscle inhibition and adaptation of the reflex response [6,15].

Hortobagyi et al. [16] performed a further meta-analytical study of the acute and chronic effects of WBV on both LBP and athletic performance in competitive athletes of a wide range of ages representing different sports such as long distance running, rugby or sprinting. However, only one of the included studies examining long-term effects involved adolescent athletes (basketball players), which would be an important novelty of the present study given the limited research focusing on adolescents. Presumably, WBV training could increase LBP and it is worth noting that the contribution of this capability varies depending on the studied sport (i.e., different physiological needs) [17]. Consequently, it might be reasonable to argue that the benefit of WBV training on sports performance depends on the LBP demands during specific sport actions. The authors of this meta-analysis reported small chronic effects of WBV training on maximal force (effect size (ES)= 0.44), power (ES= 0.42) and athletic performance (ES= 0.45). However, there is no previous evidence examining the effects of WBV on swimming performance, which could potentially produce a greater transfer to the sports-specific action given the remarkable importance of the LBP capacity in overall short-distance swimming performance. Thus, the main aim of this randomized control trial was to determine the effects of a 6-month WBV training on LBS and LBP development, as well as swimming performance in trained adolescent swimmers. We hypothesized that the WBV group would enhance LBP and swimming performance to a greater extent than the control group.

## Methods

*Subjects*

Thirty-seven swimmers from four different swimming clubs of Zaragoza (Aragon, Spain) were finally included in the present study, in the framework of the RENACIMIENTO project [18]. The randomized allocation of these swimmers into the control and intervention groups was initially performed in SPSS with the whole sample (n= 98) included in the project. For this study, the following inclusion criteria determined the eligibility of the participants: swimmers between the ages of 12.5 and 17.5 years, Caucasian, healthy and free of injuries. The included athletes had swum more than 6 hours per week for at least 3 years and competed in regional to national level events, without practicing an additional sport simultaneously. Swimmers had to be involved in a 100 m official competition within 15 days near the testing sessions. Swimmers had a mean performance time 68.02±7.8 s in 100 m freestyle events, corresponding to a ~78% of the Spanish record for the same age-group swimmers.

*Anthropometric measurements and general information*

All participants had basic anthropometric measurements taken (body mass, weight, height). Participants were measured while wearing minimal clothing and without shoes to the nearest 0.1 cm (SECA 225, SECA, Hamburg, Germany) and weighted to the nearest 0.1 kg (SECA 861, SECA). Body mass index (BMI) was then calculated by dividing weight (kg) by squared height ($m^2$). An ad-hoc structured questionnaire was completed by all participants which included information related to swimming experience, swimming volume, in addition to medical history, previous injuries, evaluation of pubertal stage proposed by Tanner [19] and other personal data.

All procedures were approved by the Ethics Committee of Clinical Research from the Government of Aragón (C.I.PI11/0034; CEICA; SPAIN), and followed the international rules for research with humans, following the declaration of Helsinki

(1964) as revised in 2000 in Edinburgh. Parents or a legal guardian provided written consent and verbal assent from the participants was obtained. This study is part of a Randomized Controlled Trial [18] which is registered in a public database (www.clinicaltrials.gov) with the following register number: NCT02380664.

*Lower-body strength and power assessments and Swimming performance times*

Dry-land assessments and swimming performance records were collected before and after the 6-month intervention period. Participants performed a total of 2 LBS isometric tests (half squat and leg extension) and 3 LBP dynamic tests (30 m sprint test, horizontal jump and CMJ) with special emphasis in the assessment of the stretch and shortening cycle in the lower extremities.

Regarding the LBS isometric tests, maximum isometric strength (MIS) from the half-squat position was measured using a force platform (Kistler type 9260AA, Kistler instruments Ltd., Hampshire, UK). Participants were placed in a 90º half-squat position standing on the platform, performing 2 repetitions at MIS against a fixed bar with only the best repetition recorded. Two repetitions were allowed for this exercise instead of the 3 permitted for other exercises to prevent from any potential back injury during this maximal isometric test. A researcher supervised and encouraged the participant to push the bar as strong and quick as possible, always maintaining an adequate technique. In addition, MIS of the knee extensor muscles was measured using a strain gauge (MuscleLab, Force Sensor, Norway). The participant was sited with an anchorage placed on the distal third of the tibia. This anchorage was connected to the strain gauge, registering force data during the 6 s that the participant had to perform the maximum knee extension. Two attempts were permitted for each leg, with the best performance recorded.

Regarding the LBP dynamic assessments, participants performed a 30 m sprint running test, which consisted of two maximal efforts of 30 m running sprint with a ~3 min rest in between. Timing gates (Byomedic photoelectric cells, Spain, Barcelona) were placed along an indoor sports court separated by 30 m. The best performance was recorded. Although this is a non-specific test for a swimmer, the maximum acceleration during a short sprint has shown to be a reliable method to measure maximum LBP [20]. Additionally, horizontal jump test allowed to further assess explosive leg power. The participant stood behind the starting line with the legs slightly apart, jumping as far as possible allowing to swing his/her arms and bend his/her knees to aid the jump. Three attempts were performed, with the best performance recorded for further analyses. Finally, participants completed the CMJ test on a portable force platform (Kistler type 9260AA, Kistler instruments Ltd., Hampshire, UK). Participants stood with both hands on their hips to isolate the lower limb action, and performed a vertical jump with an earlier fast countermovement. Three attempts were permitted and the best performance was recorded for further analysis. The raw data from each jump was introduced in an Excel macro [21] to determine CMJ height ($CMJ_{HT}$). Firstly, take-off velocity (TOV) was calculated from the mechanical impulse and the time to reach this mechanical impulse. Then, jump height was calculated as follows:

$$CMJ_{HT} = (TOV^2)/(2 \cdot G)$$, where G is gravity.

The most recent performance times in 100 m freestyle swimming (performed up to 15 days near to the testing sessions, in a 25-m swimming pool) were collected from official competitions (reported by the regional swimming federation) and converted to the well-established International Swimming Federation (FINA) points [22] in order to standardize between swimming strokes and thus allow the comparison.

*Whole Body Vibration procedures*

The participants included in the WBV group performed both static and dynamic lower-body exercises on a vertical and synchronous vibration platform (Power Plate® Pro5; PowerPlate, Amsterdam, Netherlands) whereas the participants allocated in the control group were asked to maintain their habitual training routine throughout the intervention period. Participants included in the WBV group performed 3 sessions per week during a total of 24 weeks. Each training session was composed of 2 sets of 5 exercises (displayed in Figure 1), which were performed in the following order: 1) half squatting (bent knees at 120º) on the platform; 2) squat 90º; 3) dynamic squat from 120º - 90º bent knees at a range of 2 s up 2 s down; 4) static lunge with right foot in front; and 5) static lunge with left foot in front. This protocol was repeated twice during each session, taking around 15 min to complete the whole training session. A researcher supervised all training sessions throughout the 6-month WBV period to ensure the swimmer performed each session in a safe and appropriate manner. The training volume and intensity increased over the training period of 6 months, with the specific amplitudes, frequencies, durations and rests detailed in Figure 1.

[INSERT FIGURE 1 AROUND HERE]

*Statistical analysis*

Mean and standard deviation (SD) were calculated for each variable. Chi-square test was initially performed to identify any potential differences in the maturity status of the swimmers between groups pre-intervention. Males and females were analysed together since time x sex interaction did not reach significance for any DLS, DLP or performance variable ($p > 0.05$). All data was transformed logarithmically to reduce potential bias arising from non-uniformity error. The effect size (ES, 95% confidence interval) for each variable was calculated using the pooled pre-intervention SD. Threshold values for Cohen ES statistics were: > 0.2 (small effect); > 0.6 (moderate effect); > 1.2 (large effect) [23]. For within/between-groups comparisons, the chances that the differences in performance and measures of LBS were better/greater (ie., greater than the smallest worthwhile change [0.2 multiplied by the between-subjects SD, based on the Cohen *d* principle]), similar, or worse/smaller were calculated. Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; >5% to 25%, unlikely; >25% to 75%, possibly; >75% to 95%, likely; >95% to 99%, very likely and >99%, almost certainly [23]. If the chances of having beneficial/better and detrimental/poorer performances were both >5%, the true difference was assessed as unclear. Otherwise, we interpreted that change as the observed chance [23]. Finally, the reliability of the LBS and LBP tests was tested through the intraclass correlation coefficient (ICC).

## Results

*Subjects*

Although 98 swimmers were initially allocated into the control and intervention group, 61 were excluded from the present study for the following reasons: Eight swimmers declined to participate, 22 did not meet the inclusion criteria, 14 were excluded due to discontinued practice or disease over the experimental period, 12 swimmers were excluded for practicing additional sports, and five did not compete within 15 days near the testing sessions. A final sample of 37 adolescent swimmers (13 males and seven females allocated in the intervention group and 10 males and seven females allocated in the control group) was included in the present study, with the main personal and anthropometric data displayed in Table 1. Chi-square test showed no differences in the maturity status pre-intervention between groups ($p > 0.05$) and reliability tests showed a very high consistency of the LBS and LBP tests in this group of swimmers (all ICC > 0.9; Table 2).

[INSERT TABLE 1 AROUND HERE]

[INSERT TABLE 2 AROUND HERE]

*Whole Body Vibration training effects*

Within-group comparisons showed that the WBV group had a *most likely beneficial* small to moderate effect on knee extensors isometric strength, 30 m sprint running test and 100 m swimming performance after the 6-month training period (ES= 0.63, 0.62 and 0.25, respectively; Table 3). However, these effects were comparable to the *likely beneficial* small to moderate effect observed in the control group (ES= 0.73, 0.62 and 0.20, respectively; Table 3). In addition, the control group exhibited a *possibly beneficial* small effect after the 6-month period (ES= 0.27), whereas the WBV group did not (ES= 0.07). The rest of the strength- and performance-related variables showed no effects after the WBV period. In the between-groups analyses, unclear effects were observed in all variables when comparing the WBV group with the control group (Figure 2).

[INSERT TABLE 3 AROUND HERE]

[INSERT FIGURE 2 AROUND HERE]

**Discussion**

Contrary to our initial hypothesis, the main findings of this intervention study showed that a 6-month WBV training period (3 sessions per week with a gradually increased intensity) did not elicit additional improvements in neither LBS, LBP nor swimming performance when compared to the control group, in trained adolescent swimmers.

Regarding the effects of WBV on LBS, our results showed small and wide-ranging effect sizes across the two isometric LBS exercises examined (CIs range= -0.35 to 0.85 and -0.49 to 0.97 for the intervention and control group, respectively). Seminal well designed (i.e., controlled and randomized) research into the effects of WBV on isometric LBS reported positive effects of a 12-week WBV training on knee extensors isometric strength (16.6%), with a similar improvement observed in a resistance training group (14.4%) [14]. However, the fact that this study only included untrained adult females makes difficult to compare with the trained swimmers from our study. Hortobagyi et al. performed a meta-analytical study of the effects of WBV on LBS only including trained individuals. One of the studies included in this meta-analysis [24] compared the effects of 4 weeks under three different training conditions (WBV training group, loaded WBV training group, and loaded training group) on the knee extensors isometric strength in elite track and field athletes. There was only a significant time x group interaction for the loaded WBV training group, hypothesizing that combining WBV loaded with a weight corresponding to the 75% of the maximal isometric strength enhances isometric LBS. Nevertheless, when examining the overall effects reported by the meta-analysis of Hortobagyi et al., uncertain chronic effects were found from WBV protocols of similar characteristics (frequency range= 25 to 40 Hz; amplitude range= 1.5 to 6 mm; acceleration range= 5.4 to 29.6 g) on maximal voluntary force from the lower extremities (ES range= -0.19 to 0.87) [16].

When examining the effects of WBV on LBP, unclear effects were also observed. Similar to the effects seen on LBS, the effect sizes found on the 3 LBP variables were small and widely varied (ES range: -0.19 to 0.62 and -0.06 to 0.71 for the intervention and control group, respectively). It is worth noting that the control group showed larger improvements for CMJ performance when compared to the WBV group (ES = 0.27 and 0.07, respectively). However, the higher CMJ initial values of the intervention group at baseline (+ 3 cm on average) might have inhibited any improvement of the WBV training stimulus in CMJ performance due to a potentially reduced potential to improve, as previously suggested [1]. These results are in disagreement with Manimmanakorn et al. [1], who found moderate positive effects of WBV on LBP (CMJ performance; mean ES= 0.77). This review and meta-analysis also included studies with non-athletic participants; it is therefore likely that these less trained individuals had superior improvements from WBV training than competitive trained athletes. Manimmanakorn et al. [1] also revealed that the vibration exposure in each training session should be more than 10 min to maximize the benefits from WBV, which is longer than the durations selected for the present study (durations from 7.5 min to 8 min per session). A more recent meta-analysis examined the chronic effects of WBV on LBP at frequencies ranging from 25 to 40, amplitudes from 4 to 8 mm and accelerations from 10 to 39 g, over training periods from 4 to 15 weeks [16]. Only three out of nine studies included in this meta-analysis showed positive effects of WBV on LBP, highlighting the inconsistencies in the results deduced from a wide range of effect sizes (ES range: -1.01 to 1.32). Although the comparisons between WBV studies should be considered with caution due to the wide variety of protocols, sports and exercise tests used, the present findings do not support the use of WBV as an effective method to enhance either LBS or LBP in trained adolescent swimmers. Concurrently, this lack of effect on muscle function is in concordance with the lack of effect of the same WBV protocol on several bone markers (i.e., bone strength and structure) in this group of swimmers [25].

Finally, although we witnessed small positive effects of WBV on swimming performance (ES= 0.25), this improvement was not different from the observed in the control group (ES= 0.20). We therefore hypothesize that the addition of WBV training does not elicit any LBS, LBP or swimming performance improvements in adolescent swimmers. The traditional swimming training and the maturity changes over the intervention period were the sole reason for the minor improvements obtained after the intervention period. Although previous studies have examined the effects of WBV on athletic performance in other sports such as basketball, track and field sprinting, long distance running or rugby [24,26–29], the present research is the first to examine the chronic effects of WBV on swimming performance. A quantitative analysis of the effects of WBV of these five studies [16] reported small and varying effects on athletic performance (ES range= -035 to 0.93), with only two out of the five showing a significant group by time interaction [24,28]. These results are supported by additional reviews that consider the current WBV paradigm unlikely to produce any additional benefits to the performance of trained competitive athletes [30,31]. A further difficulty in the interpretation of these results lies on the wide variety in the WBV protocol designs (i.e., frequencies, amplitudes and accelerations), which complicates the identification of the optimal dose that would elicit sufficient levels of muscle activation from WBV. In relation to this, a recent study [32] pointed out that the magnitude of the response to the vibration stimulus (as measured through electromyography) to generate acute increases in muscle strength is individualized. These authors concluded that the individualized vibratory stimulus of each athlete should be determined in advance to maximize the benefits from this training method. A final point to consider is the use of the handle bars in the vibration platform during the WBV training. Previous research used hands-free exercises during the vibration routine to prevent from any potential reduction in the vibratory load [33], however, we allowed swimmers to gently handle the bars with their hands just to ensure a sufficient balance to avoid any risk of fall.

**Practical applications**

Considering the current state of knowledge and the findings of the present study, we do not recommend swimming coaches and trainers to use this method to improve LBS, LBP or swimming performance given the unclear and inconsistent effects of WBV training. Nevertheless, there are some drawbacks that could affect the results of this study and the reader and further studies should consider. The main limitation of this study is attributed to the small sample size finally included. The reason for this remarkable drop out was mainly because swimmers failed to meet some relevant inclusion criteria, especially because of the wide range of swimming experience, weekly training volumes and age. Future studies using larger samples should consider dividing them into subgroups according to different maturity status to examine possible differences in the response to the vibration stimulus. Another important limitation of this study is the lower initial values observed in the control group, which could have given this group a greater potential to improve. Thus, further research including more homogeneous and larger samples would be recommended to confirm these results. In our study, we used progressive loading throughout the 6-month WBV training period to elicit continuous adaptations, however, more frequent follow-up assessments (e.g., at weeks 6, 12 and 18) could have shown more thorough and reliable information about the response to WBV over time. An active control group to counterbalance the extra workload performed by the intervention group was not included and would have been appropriate to determine the true effects of WBV. However, even performing a higher workload, WBV did not elicit any extra improvement. We encourage future research to apply individualized frequencies and longer exposures per session to withdraw final conclusions on the effectiveness of this practice, focusing on the muscle adaptations and the transfer to the sports-specific action.

## Conclusions

The results from this randomized controlled trial revealed that the WBV protocol selected for this study had no additional chronic effects on LBS, LBP and athletic performance, when compared to the control group, in trained adolescent swimmers. In our study, we used similar WBV intensities and volumes than previously reported with other sports, and we obtained comparable inconsistent results also with swimmers. Although the addition of WBV to the swimmer´s training routine seems unnecessary to increase strength or power, less trained individuals appear to benefit from this practice [1].



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**References**

1. Manimmanakorn N, Hamlin MJ, Ross JJ, Manimmanakorn A. Long-term effect of whole body vibration training on jump height: meta-analysis. *J Strength Cond Res*. 2014; 28(6):1739-1750.
2. Cardinale M, Bosco C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev*. 2003; 31(1):3-7.
3. Helmkamp JC, Talbott EO, Marsh GM. whole body vibration - a critical review. *Am Ind Hyg Assoc J*. 1984; 45(3):162-167.
4. Conway GE, Szalma JL, Hancock PA. A quantitative meta-analytic examination of whole-body vibration effects on human performance. *Ergonomics*. 2007; 50(2):228-245.
5. Bosco C, Colli R, Introini E, et al. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol*. 1999; 19(2):183-187.
6. Bosco C, Iacovelli M, Tsarpela O, et al. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol*. 2000; 81(6):449-454.
7. Torvinen S, Kannu P, Sievänen H, et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging*. 2002; 22(2):145-152.
8. Issurin V, Tenenbaum G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sport Sci*. 1999; 17(3):177-182.
9. Swaine IL. Arm and leg power output in swimmers during simulated swimming. *Med Sci Sport Exerc*. 2000; 32(7):1288-1292.
10. West DJ, Owen NJ, Cunningham DJ, Cook CJ, Kilduff LP. Strength and power predictors of swimming starts in international sprint swimmers. *J Strength Cond Res*. 2011; 25(4):950-955.

11. Beretić I, Đurovic M, Okičić T, Dopsaj M. Relations between lower body isometric muscle force characteristics and start performance in elite male sprint swimmers. *J Sports Sci Med*. 2013; 12(4):639-645.

12. Muniz-Pardos B, Gomez-Bruton A, Matute-Llorente A, et al. Non-Specific Resistance Training and Swimming Performance: Strength or Power? A Systematic Review. *J Strength Cond Res*. 2019; In press.

13. Lyttle A, Benjanuvatra N. Start right? A biomechanical review of dive start performance. http://www.coachesinfo.com/category/swimming/321/.

14. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sport Exerc*. 2003; 35(6):1033-1041.

15. Torvinen S, Kannus P, Sievänen H, et al. Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sport Exerc*. 2002; 34(9):1523-1528.

16. Hortobagyi T, Lesinski M, Fernandez-Del-Olmo M, Granacher U. Small and inconsistent effects of whole body vibration on athletic performance: a systematic review and meta-analysis. *Eur J Appl Physiol*. 2015; 115(8):1605-1625.

17. Izquierdo M, Hakkinen K, Gonzalez-Badillo JJ, Ibanez J, Gorostiaga EM. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *Eur J Appl Physiol*. 2002; 87(3):264-271.

18. Gomez-Bruton A, Gonzalez-Aguero A, Casajus JA, Vicente-Rodriguez G. Swimming training repercussion on metabolic and structural bone development; benefits of the incorporation of whole body vibration or pilometric training; the

RENACIMIENTO project. *Nutr Hosp*. 2014; 30(2):399-409.

19. Tanner JM, Whitehouse RH, Takaishi M. Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. II. *Arch Dis Child*. 1966; 41(220):613-635.
20. Chelly SM, Denis C. Leg power and hopping stiffness: relationship with sprint running performance. *Med Sci Sport Exerc*. 2001; 33(2):326-333.
21. Ferragut-Fiol C, Cortadellas J, Arteaga R, Calbet J. Predicción de la altura de salto vertical. Importancia del impulso mecánico y de la masa muscular de las extremidades inferiores. *Eur J Hum Mov*. 2003; (10):7-22.
22. FINA Points | fina.org - Official FINA website. Available from http://www.fina.org/content/fina-points.
23. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sport Exerc*. 2009; 41(1):3-13.
24. Wang H-H, Chen W-H, Liu C, Yang W-W, Huang M-Y, Shiang T-Y. Whole-body vibration combined with extra-load training for enhancing the strength and speed of track and field athletes. *J Strength Cond Res*. 2014; 28(9):2470-2477.
25. Gómez-Bruton A, González-Agüero A, Matute-Llorente A, et al. Effects of whole body vibration on tibia strength and structure of competitive adolescent swimmers: A Randomized Controlled Trial. *PM&R*. 2018; 10(9):889-897.
26. Fort A, Romero D, Bagur C, Guerra M. Effects of whole-body vibration training on explosive strength and postural control in young female athletes. *J Strength Cond Res*. 2012; 26(4):926-936.
27. Suarez-Arrones L, Tous-Fajardo J, Núñez J, Gonzalo-Skok O, Gálvez J, Mendez-Villanueva A. Concurrent repeated-sprint and resistance training with

superimposed vibrations in rugby players. *Int J Sport Physiol Perform*. 2014; 9(4):667-673.

28. Cheng C-F, Cheng K-H, Lee Y-M, Huang H-W, Kuo Y-H, Lee H-J. Improvement in running economy after 8 weeks of whole-body vibration training. *J Strength Cond Res*. 2012; 26(12):3349-3357.
29. Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *Int J Sport Med*. 2005; 26(8):662-668.
30. Cardinale M, Wakeling J. Whole body vibration exercise: are vibrations good for you? * Commentary. *Br J Sport Med*. 2005; 39(9):585-589.
31. Savelberg HH, Keizer HA, Meijer K. Whole-body vibration induced adaptation in knee extensors; consequences of initial strength, vibration frequency, and joint angle. *J Strength Cond Res*. 2007; 21(2):589.
32. Oliveira MP, Menzel HK, Cochrane DJ, et al. Individual responses to different vibration frequencies identified by electromyography and dynamometry in different types of vibration application. *J Strength Cond Res*. [Epub ahead of print] doi: 10.1519/JSC.0000000000002985
33. Osawa Y, Oguma Y. Effects of resistance training with whole-body vibration on muscle fitness in untrained adults. *Scand J Med Sci Sport*. 2013; 23(1):84-95.

Table 1. Personal and Anthropometric data.

Table 2. Intraclass correlation coefficient for the strength and power tests.

Table 3. Within-group changes in LBS, LBP and swimming performance after the 6-month WBV period.

Figure 1. Whole-body vibration exercises and protocol.

Figure 2. Effectiveness of the 6-month intervention period when compared to the control group to improve LBS, LBP and swimming. A reduction of time in 30 m running sprint test was interpreted as a positive effect. Trivial areas (shaded rectangles) were calculated from the smallest worthwhile change (further detailed in the methods section). Quality assessment and % of the chances of having better/similar/poorer effect in favour to the vibration group are also reported. CIs were set at 95%.

**Table 1 Personal and Anthropometric data, Mean ± SD**

| | All N= 37 | Males N= 23 | Females N= 14 | Control Group N= 17 | WBV Group N= 20 |
|---|---|---|---|---|---|
| **Age (y)** | 14.8±1.4 | 15.0±1.3 | 14.4±1.4 | 14.4±1.3 | 15.0±1.4 |
| **Height (cm)** | 167.3±11.2 | 172.5±8.5 | 158.7±9.7 | 166.3±10.6 | 168.1±11.8 |
| **Weight (kg)** | 56.9±11.5 | 61.6±9.5 | 49.2±10.4 | 55.7±12.3 | 58.0±11.0 |
| **Tanner Stage (I/II/III/IV/V)** | 0/2/9/21/5 | 0/0/7/11/5 | 0/2/2/10/0 | 0/1/4/11/1 | 0/1/5/10/4 |
| **Swimming Experience (y)** | 7.8±2.9 | 7.9±3.1 | 7.7±2.5 | 8.1±2.6 | 7.6±3.2 |
| **Training Volume (h/week)** | 10.3±1.9 | 10.1±1.9 | 10.7±1.9 | 10.2±2.3 | 10.4±1.5 |

Table 2 Intraclass correlation coefficient for the strength and power tests

| | ICC |
|---|---|
| MIS KE left | 0.950 |
| MIS KE right | 0.924 |
| CMJ | 0.972 |
| MIS Squat | 0.923 |
| 30 m sprint | 0.944 |
| Horiz Jump | 0.927 |

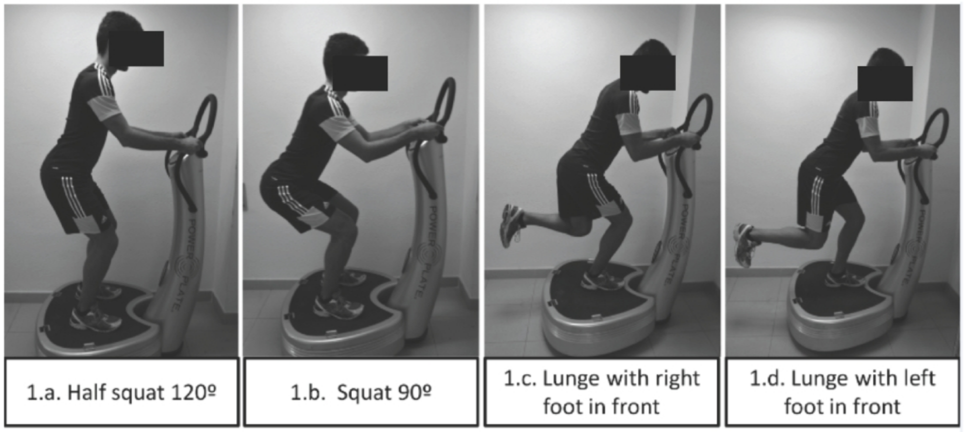
ICC=intraclass correlation coefficient; MIS squat=maximal isometric strength from half-squat position; MIS KE=maximal isometric strength of the knee extensors; CMJ=countermovement jump height; Horiz Jump=horizontal jump.

**Table 3 Within-group changes in LBS, LBP and swimming performance after the 6-month WBV period**

| | Pre-test | Post-test | Differences* % (95% CL) | Differences* Standardized (95% CL)† | Chances‡ | QA |
|---|---|---|---|---|---|---|
| Pre-Post WBV Group (N = 20; 13 males and 7 females) | | | | | | |
| **FINA 100** | 392.7±63.2 | 412.2±69.5 | 5.1 (-1.1; 11.7) | 0.25 (-0.05; 0.55) | 63/37/0% | Possibly Beneficial |
| **MIS SQ (N)** | 1420.2±511.8 | 1346.8±347.2 | -2.9 (-11.1; 6.0) | -0.09 (-0.35; 0.17) | 2/79/19% | Likely Trivial |
| **MIS KE (N)** | 947.3±230.6 | 1101.2±253.0 | 16.6 (10.5; 23.1) | 0.63 (0.41; 0.85) | 100/0/0% | Most Likely Beneficial |
| **CMJ (m)** | 0.29±0.07 | 0.30±0.06 | 1.7 (-4.5; 8.4) | 0.07 (-0.18; 0.31) | 14/85/2% | Unclear |
| **30 m (s)** | 4.96±0.45 | 4.68±0.42 | 5.6 (3.3; 8.0) | 0.62 (0.36; 0.89) | 100/0/0% | Most Likely Beneficial |
| **Horiz Jump (m)** | 1.99±0.28 | 1.94±0.30 | -2.8 (-5.6; 0.2) | -0.19 (-0.40; 0.01) | 0/52/47% | Possibly Harmful |
| Pre-Post Control Group (N = 17; 10 males and 7 females) | | | | | | |
| **FINA 100** | 360.5±95.8 | 380.9±105.3 | 5.6 (-1.0; 12.7) | 0.20 (-0.04; 0.44) | 51/49/0% | Possibly Beneficial |
| **MIS SQ (N)** | 1244.9±284.7 | 1172.7±253.5 | -5.5 (-11.1; 0.4) | -0.24 (-0.49; 0.02) | 0/38/62% | Possibly Harmful |
| **MIS KE (N)** | 896.5±203.3 | 1075.6±308.1 | 18.7 (11.9; 25.8) | 0.73 (0.48; 0.97) | 100/0/0% | Most Likely Beneficial |
| **CMJ (m)** | 0.26±0.04 | 0.27±0.04 | 3.9 (-1.0; 9.1) | 0.27 (-0.07; 0.60) | 66/34/0% | Possibly Beneficial |
| **30 m (s)** | 5.09±0.31 | 4.86±0.32 | 4.5 (1.2; 7.9) | 0.71 (0.18; 1.25) | 97/3/0% | Very Likely Beneficial |
| **Horiz Jump (m)** | 1.85±0.23 | 1.83±0.22 | -0.8 (-3.5; 1.9) | -0.06 (-0.26; 0.14) | 1/91/8% | Likely Trivial |

*All differences are presented as improvements (positive), so that negative and positive differences are in the same direction.
† Effect size.
‡ % of the chances of having better/similar/poorer values.

Abbreviations: CL=confidence limits; QA=quality assessment; 30 m=30 m sprint running test; Horiz Jump= horizontal jump; CMJ=countermovement jump; MIS KE=knee extension maximal isometric strength; MIS SQ=half squat maximal isometric strength; FINA 100= FINA points in 100m; WBV=whole-body vibration.




| | Sessions | Frequency (Hz) | Peak-to-peak displacement (mm) | Duration (s) | Rest (s) | Repetitions | Vibration total time (min) | Training total time (min) | Peak acceleration (g) |
|---|---|---|---|---|---|---|---|---|---|
| Month 1 | 12 | 30 | 2 | 45 | 45 | 2 | 7.5 | 15 | 3.6 |
| Month 2 | 12 | 30 | 4 | 45 | 45 | 2 | 7.5 | 15 | 7.2 |
| Month 3 | 12 | 32 | 4 | 45 | 45 | 2 | 7.5 | 15 | 8.2 |
| Month 4 | 12 | 34 | 4 | 60 | 60 | 2* | 8 | 16 | 9.3 |
| Month 5 | 12 | 36 | 4 | 60 | 60 | 2* | 8 | 16 | 10.4 |
| Month 6 | 12 | 38 | 4 | 60 | 60 | 2* | 8 | 16 | 11.6 |

Squat 120º, 90º and dynamic were performed twice, while lunge with each leg was only performed once

Figure 1. Whole-body vibration exercises and protocol [Figure used with permission (25)]

274x190mm (300 x 300 DPI)

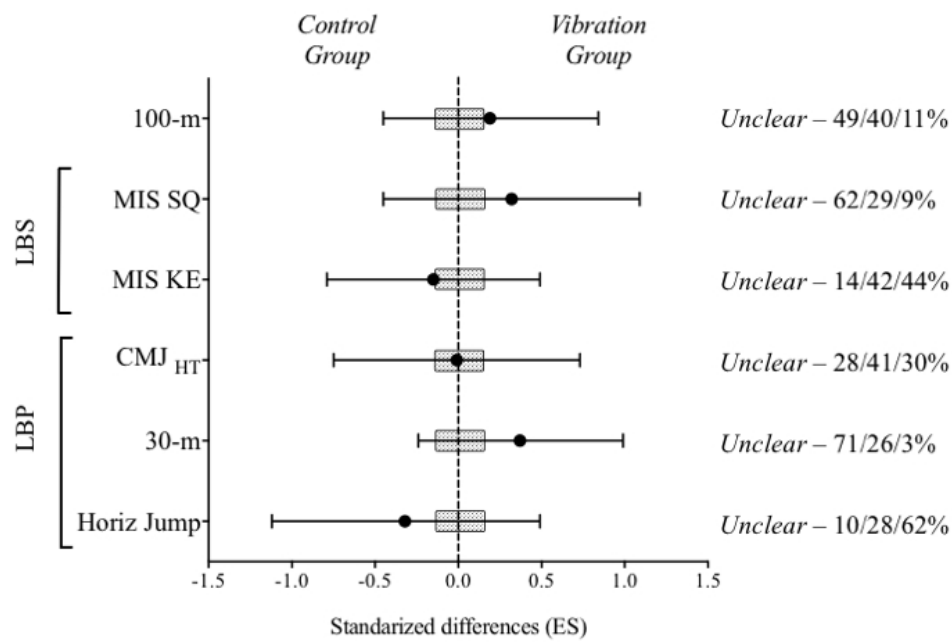



Figure 2. Effectiveness of the 6-month intervention period when compared to the control group to improve LBS, LBP and swimming. A reduction of time in 30 m running sprint test was interpreted as a positive effect. Trivial areas (shaded rectangles) were calculated from the smallest worthwhile change (further detailed in the methods section). Quality assessment and % of the chances of having better/similar/poorer effect in favour to the vibration group are also reported. CIs were set at 95%.

237x189mm (77 x 77 DPI)

**Supplementary Table 1**. Differences adjusting by pre-test values between the WBV and the control group following the WBV training period.

| | WBV group Mean (SD) n = 20 | CON group Mean (SD) n = 17 | *p* |
|---|---|---|---|
| FINA 100 | 398.02 (44.68) | 397.57 (44.78) | 0.976 |
| MIS SQ (N) | 1298.7 (180.4) | 1229.3 (180.7) | 0.257 |
| MIS KE (N) | 1074.7 (132.4) | 1106.7 (132.5) | 0.472 |
| CMJ (m) | 0.285 (0.03) | 0.280 (0.03) | 0.592 |
| 30 m (s) | 4.72 (0.28) | 4.81 (0.28) | 0.312 |
| Horiz Jump (m) | 1.88 (0.11) | 1.90 (0.12) | 0.537 |

**No significant differences between groups in any variable (p<0.05)**

30 m=30 m sprint running test; CON=control; Horiz Jump= horizontal jump; CMJ=countermovement jump; MIS KE=knee extension maximal isometric strength; MIS SQ=half squat maximal isometric strength; FINA 100= FINA points in 100m; WBV=whole-body vibration



**Supplementary Table 2**. Differences adjusting by pre-test values between the swimmers training before or after the swimming session following the WBV training period.

| | WBV BEFORE SW Mean (SD) n = 8 | WBV AFTER SW Mean (SD) n = 12 | CON Mean (SD) n = 17 |
|---|---|---|---|
| FINA 100 | 386.37 (44.83) | 405.60 (44.38) | 397.70 (44.82) |
| MIS SQ (N) | 1290.5 (181.5) | 1304.4 (186.2) | 1229.0 (183.4) |
| MIS KE (N) | 1096.6 (134.0) | 1059.7 (135.8) | 1107.0 (133.8) |
| CMJ (m) | 0.283 (0.03) | 0.286 (0.03) | 0.280 (0.03) |
| 30 m (s) | 4.78 (0.28) | 4.68 (0.28) | 4.81 (0.28) |
| Horiz Jump (m) | 1.91 (0.11) | 1.85 (0.11) | 1.90 (0.12) |

**No significant differences between groups in any variable (p<0.05)**

30 m=30 m sprint running test; CON=control; Horiz Jump= horizontal jump; CMJ=countermovement jump; MIS KE=knee extension maximal isometric strength; MIS SQ=half squat maximal isometric strength; FINA 100= FINA points in 100m; SW=swimming; WBV=whole-body vibration

**Supplementary Table 3**. Differences adjusting by pre-test values between the immature (Tanner stages 1 to 3) and mature (Tanner stages 4 and 5) swimmers following the WBV training period.

| | WBV vs. CON Tanner 1-3 | | WBV vs. CON Tanner 4-5 | | Tanner 1-3 vs. Tanner 4-5 WBV | |
|---|---|---|---|---|---|---|
| | WBV Mean (SD) n = 6 | CON Mean (SD) n = 5 | WBV Mean (SD) n = 14 | CON Mean (SD) n = 12 | Tanner 1-3 Mean (SD) n = 14 | Tanner 4-5 Mean (SD) n = 6 |
| FINA 100 | 364.48 (36.70) | 339.62 (36.90) | 414.25 (46.41) | 419.55 (46.47) | 408.32 (50.02) | 413.79 (48.04) |
| MIS SQ (N) | 1242.8 (116.1) | 990.9 (117.1) | 1332.0 (194.6) | 1317.6 (194.8) | 1366.3 (213.8) | 1338.4 (212.5) |
| MIS KE (N) | 990.8 (121.7) | 909.7 (124.8) | 1121.6 (141.6) | 1176.1 (141.6) | 1089.8 (124.5) | 1106.0 (124.5) |
| CMJ (m) | 0.290 (0.03) | 0.257 (0.03) | 0.282 (0.02) | 0.290 (0.02) | 0.308 (0.03) | 0.291 (0.03) |
| 30 m (s) | 4.83 (0.29) | 5.06 (0.29) | 4.66 (0.25) | 4.72 (0.26) | 4.78 (0.25) | 4.64 (0.25) |
| Horiz Jump (m) | 1.88 (0.11) | 1.83 (0.11) | 1.88 (0.12) | 1.92 (0.12) | 1.93 (0.13) | 1.94 (0.13) |

**No significant differences between groups in any variable (p<0.05)**

30 m=30 m sprint running test; CON=control; Horiz Jump= horizontal jump; CMJ=countermovement jump; MIS KE=knee extension maximal isometric strength; MIS SQ=half squat maximal isometric strength; FINA 100= FINA points in 100m; WBV=whole-body vibration