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# Dual-frequency whole body vibration enhances vertical jumping and change-of-direction ability in rugby players

Wen-Wen Yang [a,b], Li-Wei Chou [b], Wei-Han Chen [a,c], Tzyy-Yuang Shiang [d], Chiang Liu [a,*]

[a] *Graduate Institute of Sports Equipment Technology, University of Taipei, Taipei 111, Taiwan, China*
[b] *Department of Physical Therapy and Assistive Technology, National Yang-Ming University, Taipei 112, Taiwan, China*
[c] *Department of Physical Education, National Taiwan Normal University, Taipei 106, Taiwan, China*
[d] *Department of Athletic Performance, National Taiwan Normal University, Taipei 116, Taiwan, China*

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**Abstract**

*Background*: Traditional vertical and side-alternating whole body vibrations (WBV) can effectively improve muscle power performance but have a limited efficacy for enhancing change-of-direction (COD) ability. Novel dual-plate WBV uniquely providing various directions of movements with higher and distinctive frequencies for each leg may cause better acute effect on muscle power and short-shortening cycle efficacy contributing to COD ability. Therefore, the purpose of this study was to investigate the acute effect of dual- or single-frequency WBV on squat jumps (SJs), countermovement jumps (CMJs), eccentric utilization ratios (EURs), and COD ability in rugby players.
*Methods*: Fourteen male rugby players were recruited and performed a 4-min partial squat with three types of WBV protocols on a dual-plate WBV machine, including one dual-frequency WBV protocol (DFW) with the dominant leg receiving 35 Hz and the non-dominant leg receiving 45 Hz, and two single-frequency WBV protocols (SFWs) with 35 Hz or 45 Hz provided to both legs (SFW35Hz and SFW45Hz) on three different days.
*Results*: The results showed that all the vibration protocols significantly improved SJ and CMJ performances (SJ: $p = 0.008$; CMJ: $p < 0.001$), but did not significantly change EURs ($p > 0.05$). In addition, only the DFW significantly improved COD ability ($p = 0.001$).
*Conclusion*: A 4-min dual-frequency WBV session improved both vertical jumping and COD ability in rugby players, suggesting that this could be a potential warm-up protocol for athletes.


*Keywords:* Agility; Balance; Frequency; Strength; Stretch-shortening cycle; Training; Warm-up

## 1. Introduction

Whole body vibration (WBV) has become a reliable modality for enhancing muscular performance.[1,2] Most vibration-related research has indicated positive acute effects of muscle power following WBV,[3,4] which has been attributed to neural adaptation, including increased muscle activation and facilitated stretch reflex.[5] To date, there are two traditional types of WBV modalities: vertical WBV and side-alternating WBV. The traditional vertical WBV usually utilized higher vibration frequencies (30–50 Hz) and lower vibration amplitude (2–4 mm), resulting in vertical synchronous vibration to both legs and vertical direction movement of the body.[6] Conversely, the side-alternating WBV usually utilized lower vibration frequencies (15–30 Hz) and higher vibration amplitude (2–12 mm) applied alternately to the right and left legs, providing vertical and extra horizontal vibration forces resulting in various directions and asymmetric movements to the sides of the body.[6]

The parameters used in WBV could influence the neuromuscular responses induced and the efficacy of muscle power. For example, it has been documented that muscle activation of tibialis anterior was higher during vertical WBV than side-alternating WBV, but activation of lower limb extensor (vastus lateralis and gastrocnemius) was higher during side-alternating WBV than vertical WBV.[7] Additionally, higher vibration frequency could induce greater muscle activation and have positive effect on muscle power.[8,9] Thus, the differences in vibration methodology provide different perturbations of the body resulting in various acute effects on muscle power.

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* Corresponding author.
*E-mail address:* chiangliu1974@yahoo.com.tw (C. Liu).

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Fig. 1. Dual-plate whole-body vibration machine.

A novel dual-plate WBV machine (Fig. 1) consists of two isolated platforms with separate vibration motors and can provide different frequencies to each leg (dual-frequency WBV). This dual-plate WBV machine can generate higher vibration frequency (30–50 Hz) with lower vibration amplitude (2 mm). The features of single-frequency and traditional vertical WBVs are similar, both of which provide a vertical direction movement to the body, and may cause the same effect on muscle power. On the contrary, the dual-frequency WBV provides vertical vibration with different frequencies for each leg, which induces the beats phenomenon. This unique feature of the dual-frequency WBV creates both vertical and horizontal vibration forces which are asymmetric perturbations of the body, leading to different challenges in movement control, which is similar to side-alternating WBV. However, compared with traditional WBVs, this novel dual-frequency WBV provides higher vibration frequency and various directions of movement, which could potentially provide more neural adaptation and a more rapid rise of muscle temperature in lower extremities and contribute to enhancement in muscle power. Moreover, bilateral strength asymmetry between dominant and non-dominant sides is commonly observed in athletes due to handedness, training or specific sport demands[10] and this asymmetry is related to sport performances and injuries.[11,12] This dual-frequency WBV can apply a lower and a higher frequency to the dominant and non-dominant legs, which may be a better way to minimize the effect of bilateral strength imbalance in lower extremities. However, the efficacy of dual-frequency and single-frequency WBVs on muscular performance in athletes has not been investigated.

Muscle power of lower extremities is an important attribute of rugby players to push, pull, cut, and jump during games,[13] and is commonly estimated by means of the vertical jump test.[14] It has been well documented that WBV is an effective modality for improving squat jumps (SJs) and countermovement jumps (CMJs).[3,9,15] Moreover, short-shortening cycle (SSC) efficiency, also as an indicator of muscle power, is an essential ability in rugby players.[16] The ratio of the height of CMJs to that of SJs, called the eccentric utilization ratio (EUR), is used to estimate SSC efficiency.[16] WBV could facilitate stretch reflexes to improve muscle activation,[5] which may also benefit the EUR. Reasonably, the dual-frequency WBV and single-frequency WBV should potentially improve vertical jumping and EUR among rugby players.

Agility, containing both decision-making and change-of-direction (COD) ability components, is also important for rugby players to rapidly accelerate, decelerate, and alter direction during sprinting in response to a stimulus or a ball during a real game.[17] COD ability is related to the muscle power of lower extremities.[18] It appears that traditional WBVs could have a positive effect on COD ability; however, previous studies have reported no acute or short-term positive effects. Torvinen et al.[3] showed that COD ability (shuttle run) did not improve after acute side-alternating WBV (vibration frequency of 15–30 Hz, amplitude of 10 mm). Cloak et al.[19] demonstrated that a bout of 30-s vertical WBV (40 Hz; 8-mm peak-to-peak amplitude) also did not provide any benefit to the 505 test. In addition, Cochrane et al.[20] reported no enhancement in the 505 test after a 9-session side-alternating WBV training course (vibration frequency of 26 Hz and amplitude of 12 mm). The absence of the improvement in COD ability may be due to only limited stimulation provided by traditional WBVs. However, the dual-frequency WBV that can provide various direction and asymmetric movements and higher frequencies may cause a better acute effect on muscle power and SSC efficacy, and subsequently COD ability.

Traditional WBVs can effectively improve muscle power performance but have a limited efficacy for enhancing COD ability. A novel dual-plate WBV with different frequencies applied to each leg may cause better muscle power and result in enhanced COD ability. However, the efficacy of dual-plate WBV on muscle power and COD ability is unclear. Therefore, the purpose of this study was to investigate the acute effect of dual-frequency and single-frequency WBVs in rugby players on SJs, CMJs, EUR, and COD ability. Enhancing muscle power and COD ability are critical for rugby players, and dual-plate WBV may prove a reliable and effective method for players and coaches.

## 2. Methods

### 2.1. Participants

Fourteen male rugby players (age: 18–23 years; height: 175.6 ± 6.6 cm; mass: 84.2 ± 11.2 kg; playing experience: >3 years; dominant leg: right leg) were recruited from Taipei Physical Education College rugby team, one of the top three teams at the university tournament level in Taiwan, China. Experiments were conducted during the beginning of their off-season training period. During the intervention, no players had neuromuscular injuries or musculoskeletal problems. Before the experiment, all participants agreed to and completed an informed consent form. The Institutional Review Board of the Taipei Physical Education College approved the experimental procedures for this study.

### *2.2. WBV protocols*

The dual-plate WBV machine used in this study was a custom-made prototype (Tonic Fitness Technology, Inc., Taiwan, China). Because the proven appropriate range of vibration frequency is from 30 to 50 Hz for the enhancement of muscular performances,[1,8] 35 and 45 Hz were utilized in the dual-plate WBV. Three types of paired frequency WBV protocols were tested, including one dual-frequency WBV protocol with different frequencies (DFW) and two types of single-frequency WBV protocols (SFWs) with the same frequency (SFW35Hz and SFW45Hz).

The presence of bilateral strength asymmetry of lower extremities between dominant and non-dominant legs is associated with sport performance and injuries,[11,12] and this asymmetry also influences the outcome of COD ability,[21] namely better performance while driving off the weaker (non-dominant) leg. Compared with lower frequency, previous studies have demonstrated that higher vibration frequency causes higher muscle activation and muscular performance.[8,9] To minimize the effect of bilateral strength asymmetry on performances, the DFW using dual frequencies was applied individually to the dominant leg at low frequency 35 Hz and to the non-dominant leg at high frequency 45 Hz, whereas the SFW35Hz used a single frequency and was applied to both legs at 35 Hz, and the SFW45Hz was applied to both legs at 45 Hz. The peak-to-peak vibration amplitude was set at 2 mm. Because 4–5 min WBV with isometric/static partial squatting (knees flexed at 60°) improved muscular performance and neuromuscular activity,[3,4,22] all participants performed 4 min of isometric/static partial squatting with knees flexed at 60° (monitored with a geometer) on the dual-plate WBV platform.

### *2.3. Procedures*

All participants randomly underwent a DFW, SFW35Hz, and SFW45Hz on 3 different days with at least 2 days of rest in between to avoid residual effects and fatigue. Agility tests and vertical jump tests were conducted before and after each of the three sessions (DFW, SFW35Hz, SFW45Hz). They did not perform any warm-up exercise to negate the possibility of influencing the results of this study but were familiarized with all the testing procedures 10 min prior to each vibration protocol.

All participants performed SJ, CMJ, and COD tests with a 60 s rest between tests. For the SJ test, participants firstly maintained a half squatting position for 3 s with their hands on their hips, and then jumped. To avoid the pre-stretching of muscle inducing SSC effect, knee angles during initial phase of jumping were monitored using a 10-camera Eagle motion system with EVaRT4.6.1 software (Motion Analysis Corporation, Santa Rosa, CA, USA) with four reflexive markers placed on their sacrum, greater trochanter of hip, lateral femoral epicondyle of knee, and lateral malleoli of ankle on their right legs. For the CMJ test, participants stood with hands on hips, then bent their knee to a squatting position and jumped as soon as possible. When players performed the jumping task, the position of reflexive marker on the sacrum of the participant was also recorded. Each participant performed two trials of SJ and CMJ tests with a 30-s rest between trials.

A 505 test (Fig. 2) is commonly used to assess the COD ability in rugby.[23] A timer was embedded in a customized system with one paired photoelectric switch (E3Z; Omron, Taiwan, China), which was placed on the two ends of line B to record time. The participants were asked to run from starting line A, passed through line B to initiate the timer, then reached line C, and finally returned to line B where the timer stopped. All participants were asked to perform turns-off with their dominant leg (their preferred kicking leg). The 505 test was repeated once with a 30-s rest between trials.

### *2.4. Data analysis*

The jump heights of SJ and CMJ were determined by the maximal vertical displacement (stand position to the highest position) from the sacrum marker. The motion analysis method to evaluate jumping height has already been validated and had high correlation to contact mat method in the previous study.[24] The EURs were calculated using the ratio of the height of CMJs to that of SJs to determine the usage of SSC efficiency when jumping. The 505 test performance was the duration of B-C-B (Fig. 2) per trial. All data were calculated for the mean of all trials to determine the net performance.

### *2.5. Statistical analyses*

SPSS statistic software 17.0 (SPSS Inc., Chicago, IL, USA) was used. A one-way repeated measure ANOVA was used in the comparison of the pretest baseline of all dependent variables among the three protocols. A two-way repeated measure ANOVA (3 WBV protocols × 2 time factors) was used to determine if there is difference in performance before and after three different WBV protocols. Finally, a Bonferroni method was used in the *post hoc* comparison tests. The $\alpha$ level was set at 0.05. Moreover, the intra-class correlation coefficient (ICC) was used to assess the test–retest reliability of all the measurements, and partial eta-squared ($\eta^2$) as well as observed power (OP) were also computed.

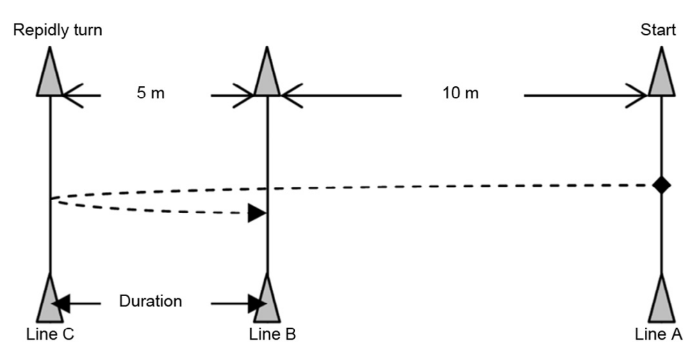


Fig. 2. Procedure for the 505 test.

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## 3. Results

All measurements indicated good reliability; the ICC for the dependent variables was 0.974 (COD ability), 0.982 (SJ), 0.993 (CMJ), and 0.808 (EUR). The performances in the pre-test were not significantly different among the three WBV protocols (agility: $p = 0.126$, $\eta^2 = 0.147$, OP = 0.416; SJ: $p = 0.751$, $\eta^2 = 0.022$, OP = 0.091; CMJ: $p = 0.467$, $\eta^2 = 0.057$, OP = 0.169).

For the jumping tests, no significant interaction was observed between time and protocol factors (SJ: $p = 0.540$, $\eta^2 = 0.046$, OP = 0.144; CMJ: $p = 0.061$, $\eta^2 = 0.194$, OP = 0.551), as shown in Table 1. A primary effect for time factors showed that all of the DFW and SFWs significantly improved jumping height of SJs and CMJs ($p = 0.008$, $\eta^2 = 0.426$, OP = 0.819; $p < 0.001$, $\eta^2 = 0.640$, OP = 0.993, respectively). For the EUR, no significant interaction was observed between the two factors ($p = 0.565$, $\eta^2 = 0.043$, OP = 0.136), and no primary effect for time ($p = 0.671$, $\eta^2 = 0.014$, OP = 0.069) or protocol factors ($p = 0.687$, $\eta^2 = 0.028$, OP = 0.105) was observed (Table 1).

For the COD ability test, a significant interaction was shown between protocol and time factors ($p = 0.007$, $\eta^2 = 0.316$, OP = 0.841). A single primary effect for time factors showed that the DFW significantly enhanced COD ability ($p = 0.001$, $\eta^2 = 0.613$, OP = 0.987), whereas the SFW35Hz and SFW45Hz did not ($p = 0.622$, $\eta^2 = 0.019$, OP = 0.076; $p = 0.870$, $\eta^2 = 0.002$, OP = 0.053, respectively) (Table 1). A single primary effect for protocol factors showed that the DFW had a greater enhancement than the SFWs did ($p < 0.05$).

## 4. Discussion

This study is the first to investigate the efficacy of new dual-plate WBV on muscle power and COD ability in athletes. The results of this study revealed that DFW improved COD ability, and both DFW and SFWs enhanced vertical jumping. Additionally, all vibration protocols did not alter the EUR after WBV exposure.

Traditional WBVs are widely used to improve muscle power[4,15] but have a limited efficacy for enhancing COD ability.[3,19,20] The current finding of the SFW on the COD ability indicated using traditional vertical or side-alternating WBVs had no enhancement of COD ability, which is in agreement previous studies.[3,19] Contrary, the DFW of this study enhanced COD ability (about 3%). The discrepancy may be explained by the different methodologies utilized. Compared to the SFW which is similar to traditional vertical WBV, the unique mechanical characteristics of the DFW produce vertical and horizontal directions of movement resulting in activating more muscles of the lower extremities to maintain body position. The COD ability is related to multidirectional motions,[25] which involves overall muscle work of lower extremities. It has been shown that WBV can increase muscular performance by increasing muscle temperature[26] which could increase nerve-conduction rate, muscle conduction velocity, muscle compliance,[27] and induced tonic vibration reflex (TVR) resulting in increased recruitment of motor units.[5] Although no measurement was made on muscle activation and muscle temperature in this study, it has been known that different direction movements induce various muscle activations. Accordingly, the DFW may not only facilitate muscles involved in sagittal plane movement such as knee extensor and flexor but also muscles involved in frontal plane movement such as hip abductor. Accordingly, the DFW inducing various direction of movement may improve muscular performance in the lower extremities resulting in the enhancement of COD ability.

Inducing various directions of movements from the DFW may not solely contribute to COD ability. Traditional side-alternating WBV which also produces various directions of movement to the body did not successfully improve COD ability in past studies using side-alternating WBV at a vibration frequency 15–30 Hz.[3] Previous studies indicate that higher vibration frequency induced higher muscular performance.[8,9] The DFW produces vertical and horizontal vibrations at a high frequency 35 and 45 Hz, compared to side-alternating WBV (30 Hz maximum). This may also be the possible explanation as to why the DFW improved COD ability in this study. Therefore, a dual-plate WBV has a positive effect and can be a good selection or alternative modality to enhance COD ability in athletes.

According to the above mentioned, enhancing COD ability by WBV should combine both conditions: providing movements in various directions and high vibration frequency (>30 Hz). However, it is still a matter of debate as to which type of platform and vibration parameters induces optimal muscular performance. In this study, a new dual-plate WBV machine with dual frequency provides both vertical and horizontal movements to the body with higher vibration frequency (30–50 Hz) and lower amplitude (2 mm). Further studies are required to evaluate or compare the effect of these three vibration types and vibration parameters on electrographic measurement, muscle temperature, and other muscular performances, which provides evidence to explain the improvement.

Table 1
Comparisons of all variables between pre- and post-tests and among the three protocols (mean ± SD).

| Variable | DFW | SFW35Hz | SFW45Hz |
|---|---|---|---|
| Agility (s) | | | |
| Pre | 2.83 ± 0.15 | 2.83 ± 0.12 | 2.78 ± 0.16 |
| Post | 2.73 ± 0.15[a,b] | 2.81 ± 0.17 | 2.78 ± 0.16 |
| SJ (cm) | | | |
| Pre | 43.0 ± 5.9 | 42.9 ± 6.8 | 43.6 ± 6.7 |
| Post | 44.8 ± 5.5[a] | 45.6 ± 5.4[a] | 45.4 ± 5.7[a] |
| CMJ (cm) | | | |
| Pre | 46.3 ± 5.9 | 46.2 ± 6.2 | 47.0 ± 6.7 |
| Post | 48.1 ± 5.8[a] | 49.5 ± 6.1[a] | 48.3 ± 7.0[a] |
| EUR | | | |
| Pre | 1.08 ± 0.05 | 1.08 ± 0.07 | 1.08 ± 0.07 |
| Post | 1.07 ± 0.04 | 1.09 ± 0.04 | 1.06 ± 0.05 |

[a] $p < 0.01$, compared with pre-test.
[b] $p < 0.01$, compared with the SFWs.
Abbreviations: SJ = squat jump; CMJ = countermovement jump; EUR = eccentric utilization ration; DFW = dual-frequency whole-body vibration; SFW = single-frequency whole-body vibration.

Agility includes both decision-making and COD ability components.[17] One vibration-related study investigated the effect of acute side-alternating WBV in reactive agility, but their finding indicated no positive effect.[28] Although it has limited ecological validity as the COD ability test (505 test) is used as a measurement for rugby players, the current study found that COD ability significantly improved after the DFW exposure. This finding suggested that the DFW might contribute to increased reactive agility as COD ability is a critical component in agility.[29]

Muscle power of lower extremities is related to the COD ability.[21] An interesting finding from this study was that the DFW enhanced COD ability compared to the SFW, but the DFW did not have significantly greater improvement in muscle power than the SFWs, as indicated by vertical jumping height and EUR. Previous studies indicated that the ability of vertical jumps has limited ability to predict the COD ability[30] and reactive agility,[31] as these involve single leg and a combination of horizontal, lateral, and vertical movements.[25] In this study, muscle power as measured by SJ and CMJ which are bilateral vertical jumps may have a limited ability to predict the COD ability. Accordingly, it should be considered adding other directions with unilateral measurements in muscle power such as single-leg horizontal and lateral jumps to evaluate the efficacy on COD ability in the further agility-related study.

All DFW and SFWs enhanced SJ (increased 4.1%–6.3%) and CMJ (increased 2.8%–7.1%) but not EUR. Improvements in vertical jumping performance with the three WBV protocols in this study were similar to previous studies that used a 1- to 5-min identical-frequency WBV, with frequencies between 26 Hz and 50 Hz, resulting in a 2.5%–8.1% improvement in vertical jumping.[3,4,15] The EUR, defined as the efficiency of SSC, is a critical ability in numerous field-based sports, which require superior muscle power, particularly in rugby.[16] McGuigan et al.[16] indicated that the EUR values in rugby union are higher in the pre-season period than in the off-season period, which represents the greater reliance on SSC by rugby players. Vibration may stimulate muscle spindles, inducing TVR to increase the sensitivity of the stretch-reflex loop, and resulting in the improvement of neuron excitability and motor units recruitment,[5] which is associated with SSC performance, such as CMJs. However, in this study, the EUR values after three different WBV protocols remained the same.

In previous studies, the acute effect of WBV on stretch reflex remained equivocal. It has been documented that a stretch-reflex loop (its amplitude, onset latency, or electromechanical delay) can be improved (vibration frequency of 26 Hz and an amplitude of 12 mm),[32] remain the same with (vibration frequency of 26 Hz and an amplitude of 6 mm),[33] or diminished (vibration frequency of 22 Hz and an amplitude of 4 mm)[34] after a session of acute side-alternating WBV. It appears that using different vibration parameters (i.e., frequency and amplitude) resulted in different results. In addition, vibration type used in previous studies was a side-alternating WBV relatively low frequency (<30 Hz) and a relatively high amplitude (>2 mm, peak-to-peak), which were different from the parameters used in this study. However, a similar study using a vertical WBV at a higher vibration frequency (45 Hz) and a lower amplitude (0.69 mm) showed no immediate change in stretch reflex,[35] suggesting WBV with higher frequency between 30 Hz and 45 Hz and lower amplitude of 2 mm unlikely to enhance the SSC efficiency.

## 5. Conclusion

This study indicated that the dual-frequency WBV that was applied independently to the dominant leg at frequency of 35 Hz and to the non-dominant leg at frequency of 45 Hz significantly enhanced COD ability. Dual-plate WBV with dual frequencies or single frequency had positive effects on vertical jumping performances without altering the EUR. Superior COD ability and muscle power are required for competition or training in field-based sports, such as rugby and football, as well as in other sports that require an ability to change direction, such as table tennis and baseball. Using a 4-min dual-frequency WBV session with appropriate frequencies of 35 Hz and 45 Hz could be a feasible warm-up protocol to improve COD ability as well as vertical jump height in athletes; therefore, the novel dual-frequency WBV could be a potential training or warm-up method. Future studies can investigate optimal vibration parameters and long-term dual-plate WBV training effects on agility enhancement and sports performance.

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## Authors' Contributions

C. Liu and T. Y. Shiang designed research; W. W. Yang and W. H. Chen carried out research; L. W. Chou, W. W. Yang and W. H. Chen analyzed the data and performed the statistical analysis; W. W. Yang, L. W. Chou and C. Liu wrote the paper. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

## Competing Interests

None of the authors declare competing financial interests.

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