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Effects of Complex Functional Strength Training on Balance and Shooting Performance of Rifle Shooters

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Abstract: The purpose of this research was to study the effects of complex functional strength training (whole-body vibration + unstable surface training) on overall shooting performance, including the shooters' stability of hold, time on target, and the body sway. We compared the shooters' performances at three time intervals: (a) pretraining, (b) 6 weeks post-WBV+UST, and (c) 6 weeks detraining. The study participants were eight rifle shooters. Training was c on an unstable surface with vibration frequency of 30 Hz and amplitude of 2 mm. Six weeks after complex training, participants' shooting performance and body sway significantly improved. Specifically, shooting scores and total time improved by 5.50% and 7.34%, respectively, as did the DevTotal values between performances at different times: 10 ms ($p = 0.01$), 20 ms ($p = 0.04$), 30 ms ($p = 0.02$), and 40 ms ($p = 0.02$). The DevY values also showed significant differences between performances at different times: 10 ms ($p < 0.01$), 20 ms ($p < 0.01$), 30 ms ($p < 0.01$), 40 ms ($p < 0.01$), and 50 ms ($p < 0.01$). A 6 week complex training method can effectively improve shooting stability, fluency, and scores.

Keywords: whole-body vibration; unstable surface training; body sway; rifle; overall performance

1. Introduction

During the 10 m air rifle competition, each shooter fires each bullet from the firing line to a 10 point stationary target. In 2017, the competition rules for women were revised such that the number of shots was changed from 40 to 60, similar to that for men [1]. However, such a static sport competition demands highly accurate and stable auxiliary means for athletes to have a good shooting performance. Maintaining stability of movement during the competition has become an important factor in performance [2,3]. In the past, the players' performance was evaluated using the paper target. Currently, a shooting simulator can be used to analyze the shooting players' aiming trajectory, and temporal, spatial, and other indices during the players' movements can be further interpreted [4]. Accurate understanding of movement characteristics and improvement of athletic performance by certain methods have become key points in developing athletic skills.

The International Shooting Sport Federation defines the stages of shooting movements as movement stability, aiming accuracy, and firing fluency. Previous studies have suggested that movement stability is positively associated with shooting performance [5,6]. Additionally, movement and postural stability directly influence athletic performance [6]. Previous studies have reported that balance is an important factor in both daily physical activities and professional sports [7]. Balance is achieved through the integration of the visual, proprioceptive, and vestibular sensory ability systems [8], which are adjusted

according to the situation, tactile sense, stimulation, and information obtained through body shaking assisted by lower limb muscle strength [9]. Elite shooters and gymnasts have found that their dependence on posture control and muscle strength consumption when receiving external stimuli can be reduced through balance [10,11]. The reduction of dependence on posture control and balance ability in the movement process enables better competition performance [12]. Strength and conditioning experts should consider the aspect of sensory nervous system integration in different balance exercises. However, most studies focused only on stability and balance in shooting movements; muzzle trajectory and temporal parameters during the movements were seldom analyzed. The stability of movements is affected by insufficient lower-limb muscle strength. Through training interventions, lower-limb muscle strength can be effectively improved, leading to better athletic performance. For example, effective training methods such as vibration training and unstable surface training (UST) have special auxiliary effects in specific sports.

Whole-body vibration (WBV) has become a routine training mode for athletes and fitness enthusiasts and has been an alternative or supplementary process for muscle and strength training. The sine wave displacement is generated through the frequency set by the vibration platform (VP). VP is mainly divided into two types: the vertical platform, which generates vertical vibration stimulation, and the alternating platform, which takes the horizontal and vertical axes of VP as the vibration center and generates left–right alternating vibration stimulation [12,13]. Previous studies on vibration stimulation reported that the *g*-value produced by VP acceleration stimulates the major end of the muscle spindle (Ia afferent), thus activating and recruiting more α-motor neurons. This state leads to muscle tetanic contraction, which is known as tonic vibration reflex (TVR) [14–16]. WBV can improve muscle strength, movement stability, agility, and overall fitness.

UST is widely used in rehabilitation therapy and sports training because of its benefits in injury prevention and rehabilitation through Swiss balls, total body resistance exercise (TRX), wave velocity BOSU balls, and other equipment [17]. The effect of UST is similar to that of traditional resistance training [18,19]. Previous studies showed that the human body needs to maintain posture stability through muscle and ankle joint activation when standing on an unstable surface [20,21]. However, the use of training machines vibrating at a frequency of 30 Hz and an amplitude <2 mm combined with unstable surface wave velocity balls has been proven to be effective in improving the stability of the lower limbs [22], facilitating better movement control. Compound training enables the shooter to utilize less muscle strength for aiming, which helps maintain movements for a long time. Maintaining muscle strength and skill are the keys to winning shooting competitions as this is a sport that requires high stability and accuracy.

The use of unstable surfaces has become popular because UST produces lower loads while inducing muscle activation [17,23,24]. However, to the best of our knowledge, few studies have assessed UST on the WBV platform to investigate the changes in balance and proficiency in specific sports. Moreover, research on the influence of long-term use of WBV on shooters is limited. Therefore, this study aimed to explore the effect of WBV+UST for 6 weeks on two performance variables: specific sports performance and balance. It was hypothesized that the two variables defining the shooters' ability would improve after the training.

2. Materials and Methods

2.1. Participants

This research was designed to evaluate the influence of WBV+UST on the shooters' ability. For this purpose, eight athletes (mean age, 20.63 $\pm$ 1.3 years; height, 166.7 $\pm$ 5.46 cm; weight, 66.37 $\pm$ 10.85 kg) from the Taiwan National Air Rifle Team were recruited. To minimize the influence of external factors, the athletes had to meet the following inclusion criteria: (i) had undergone professional shooting training for at least 5 years and (ii) had undergone no previous stimulation-induced muscle activation methods leading to neural adaptations to enhance muscle strength. Furthermore, no participant should have been a

part of other studies involving neuromuscular mechanical stimulation (NEMES) in the last 6 months prior to this research. The study was conducted in accordance with the tenets of the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Fu Jen Catholic University Institutional Review Board (C106085). All participants signed the informed consent forms prior to participation.

2.2. Experimental Design

We studied and compared the UST intervention in shooters on a vibration training platform for 6 weeks and investigated the differences in shooting performance, shooting muzzle kinematics, and static balance.

2.3. Procedures

Before participating in the study, an explanation regarding the study was provided to all participants; however, they were not informed on whether each situation would change. The participants had to take part in two different tests in the shooting range, with a minimum interval of 48 h to minimize fatigue and any potential cumulative neuromuscular effects. One week before the pretest period, the participants were simulated to adapt to the experimental set-up.

Following previous studies, consumption of caffeine-containing foods, such as energy drinks and alcoholic beverages, was limited for 7 days before the test to avoid these affecting the performance of the study participants [25]. In addition, to avoid the difference of the test time point, the test time was set the same for all participants: beginning at 1800 h in the evening [26].

During each test session (from 1800 h), specific shooting tests and center of pressure (COP) tests were measured. Each shooter used a uniform 10 m air rifle (WALTHER, LG400, Carl Walther GmbH, Germany) installed with a shooting trajectory recorder (SCATT USB, SCATT, Scatt ©, Moscow, Russia). A competition was simulated according to the International Shooting Sport Federation's new shooting system, and data on 60 shots were collected. During the shooting process, 4.5 mm air rifle bullets (RWS R-10 Match Heavy, Umarex Sportwaffen GmbH, Fort Smith, AR, USA), conforming to the international competition system were used, and the muzzle trajectory, time, and scores were recorded. Static balance test was conducted by having the participant stand on one foot for 30 s on the force plate. The right foot was used first; then, after a rest period for 30 s, the left foot was used. COP changes during standing were recorded.

In each round of training tests, the participants warmed up for 5 min on the treadmill, and the speed during warm-up was set as the participants' preferred walking speed. The vibration scheme consisted of two groups of five rounds of 60 s repetitions. The two groups were separated by an interval (a 60 s passive recovery period and 5 min resting period). In the training process, the shooters stood with their feet apart at a distance equivalent to their pelvic width and performed isometric exercises (knee joint flexion at 60°) and WBV training (frequency = 30 Hz, peak-to-peak displacement = 2 mm) on the unstable surface. UST was performed using a BOSU balance trainer (Fitness Quest, Canton, OH, USA), the area (61 cm × 61 cm) of which was similar to that of the vibration platform (59 × 69 cm). To ensure consistent foot position, the researchers marked the positions of the bilateral heels and big toes on the BOSU. During the test, the participants wore sneakers (Figure 1).

2.4. Dependent Measures

A vibration plate generates linear vibration and can be set with different frequencies. The amplitude is the linear displacement caused by the power plate, frequency is the number of vibrations per second, and duration is the period of intensity of the vibration process. The setting used in this study included an amplitude of 2 mm, a frequency of 30 Hz, and a duration of 60 s. This protocol was developed by referring to other studies that assessed balance and muscle strength [27,28].

Figure 1. Whole-body vibration and unstable surface training setup and procedure.

The shooting trajectory recorder was used to measure the trajectory and time from the start to the end of each shot, and this was used to evaluate overall performance, stability of hold, and time on target chosen to coincide with the 100 Hz fixed sample rate of the aim point measurement software (SCATT Shooting Performance and Analysis System, Zao SCATT, Scatt ©, Moscow, Russia). All the collected data were analyzed using a computer program written in MATLAB (Version R2008a; The MathWorks Inc., Natick, MA, USA) to calculate the shooting score, total time, and horizontal (DevX), vertical (DevY), and total (DevTotal) standard deviations in rings of the aiming point location at 10–50 ms. MATLAB was used to record the 10–50 ms before firing as the evaluation method of the test. Details on the parameters are in Table 1.

Table 1. Variables calculated from the aiming point trajectory.

Component	Variable (Unit)	Description
Overall performance	Shooting score (pts)	Shot score as measured in air rifle shooting: 0–10.9
Stability of hold	DevX (mm) DevY (mm) DevTotal (mm)	Horizontal and vertical standard deviations of the aiming point at 10–50 ms Total standard deviation of the aiming point at 10–50 ms
Time on target	Total time (s)	Total aiming time

Variable abbreviations have been selected according to the SCATT manufacturer abbreviations in order to facilitate the application of results in practice. DevTotal, deviations-total in rings; DevX, deviations-X in rings; DevY, deviations-Y in rings.

The COP used to measure body swing was set at 10,000 cP using Kistler amplifier magnification based on quantized data obtained from a 60 × 90 platform and was subsequently converted to 16 bit digital signals. The COP during standing on one foot was evaluated using BioWare software. The COP test is a multivariable method that evaluates body shaking in different ethnic groups. We used three parameters to analyze the body shaking status [29,30], as described in Table 2.

Table 2. Parameters indicating body sway of single-legged stance calculated from force plate data.

Parameter	Definition
COPxLength	Total COP displacement in the *x*-axis (perpendicular to line of shot)
COPyLength	Total COP distance in the *y*-axis (parallel to line of shot)
COP area	Area described by total COP length.

2.5. Data Analyses

The statistical significance of the data was analyzed in SPSS statistics software (Version 20.0; SPSS Inc., Chicago, IL, USA). Results are expressed as mean ± SD. One-way repeated-measures analysis of variance (RM ANOVA) was used to determine the variance and difference in overall performance (shooting score), stability of hold (DevX, DevY, DevTotal),

time on target (total time), and COP between 6 weeks after WBV+UST and detraining. The power analysis was used to provide the probability of rejecting a null hypothesis when it is false, and the effect size were calculated between variables. The Shapiro–Wilk method was applied to test for normality. The results showed that all the variables were fulfilled the requirement of the normal distribution. The statistical significance level was set at 5%.

3. Results

Table 3 shows the shooting performance test results. Table 4 shows the COP results. In addition, trends of improvement after complex training are provided in Figures 2–4.

Table 3. Descriptive statistics of the shooting test.

	Pretest	6 Week WBV+UST	Detraining	ES (Pretest–6-Week WBV+UST)	ES (Pretest—Detraining)	ES (6 Week WBV+UST—Detraining)
Shooting score (pts)	9.845 ± 0.151	10.051 ± 0.156 **	9.673 ± 0.505	1.34	0.46	1.01
Total time (s)	5.506 ± 0.050	5.390 ± 0.113 *	5.445 ± 0.201	1.33	0.42	0.34
10 ms-DevTotal (mm)	2.500 ± 0.348	2.058 ± 0.358 *	2.706 ± 0.585	1.25	0.43	1.34
20 ms-DevTotal (mm)	2.360 ± 0.400	2.015 ± 0.353 *	2.636 ± 0.608	0.91	0.54	1.25
30 ms-DevTotal (mm)	2.341 ± 0.408	1.912 ± 0.532 *	2.537 ± 0.588	0.90	0.39	1.11
40 ms-DevTotal (mm)	2.376 ± 0.422	1.893 ± 0.498 *	2.511 ± 0.568	1.05	0.27	1.16
50 ms-DevTotal (mm)	2.413 ± 0.400	2.050 ± 0.457	2.558 ± 0.612	0.85	0.28	0.94
10 ms-DevX (mm)	0.626 ± 0.126	0.654 ± 0.177	0.693 ± 0.210	0.18	0.39	0.20
20 ms-DevX (mm)	0.626 ± 0.125	0.655 ± 0.178	0.700 ± 0.213	0.19	0.42	0.23
30 ms-DevX (mm)	0.631 ± 0.126	0.655 ± 0.178	0.701 ± 0.214	0.15	0.40	0.23
40 ms-DevX (mm)	0.633 ± 0.127	0.656 ± 0.177	0.704 ± 0.212	0.15	0.41	0.25
50 ms-DevX (mm)	0.659 ± 0.180	0.635 ± 0.129	0.706 ± 0.210	0.15	0.24	0.41
10 ms-DevY (mm)	0.749 ± 0.114	0.549 ± 0.051 **	0.769 ± 0.272	2.26	0.10	1.12
20 ms-DevY (mm)	0.754 ± 0.116	0.550 ± 0.052 **	0.770 ± 0.272	2.26	0.08	1.12
30 ms-DevY (mm)	0.756 ± 0.116	0.550 ± 0.052 **	0.773 ± 0.273	2.29	0.08	1.13
40 ms-DevY (mm)	0.756 ± 0.116	0.557 ± 0.051 **	0.775 ± 0.279	2.22	0.09	1.09
50 ms-DevY (mm)	0.760 ± 0.114	0.556 ± 0.052 **	0.780 ± 0.272	2.30	0.10	1.14

* $p < 0.05$, ** $p < 0.01$.

Table 4. Descriptive statistics of center of pressure.

		Pretest	6 Week WBV+UST	Detraining	ES (Pretest—6-Week WBV+UST)	ES (Pretest—Detraining)	ES (6 Week WBV+UST—Detraining)
Right leg	x-Length (mm)	3.04 ± 0.57	2.85 ± 0.25	4.09 ± 1.10	0.43	1.20	1.55
	y-Length (mm)	2.19 ± 0.38	2.11 ± 0.35	2.52 ± 0.38	0.22	0.87	1.12
	area (mm^2)	5.29 ± 1.69	4.72 ± 0.88	6.59 ± 1.33	0.42	0.85	1.66
Left leg	x-Length (mm)	3.04 ± 0.60 *	2.85 ± 0.54	3.74 ± 0.86	0.33	0.94	1.24
	y-Length (mm)	2.19 ± 0.38	2.10 ± 0.35	2.52 ± 0.41	0.24	0.83	1.10
	area (mm^2)	5.29 ± 1.69	4.00 ± 0.67	5.41 ± 1.12	1.00	0.08	1.53

x-Length, COPxLength; y-Length, COPyLength; ES, effect size; * $p < 0.05$.
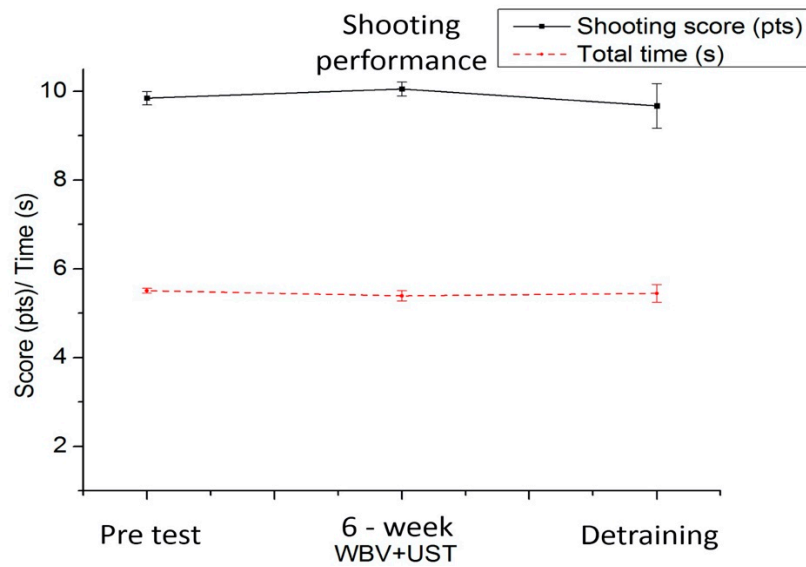
Figure 2. The difference phase during score and time of the shooting performance.
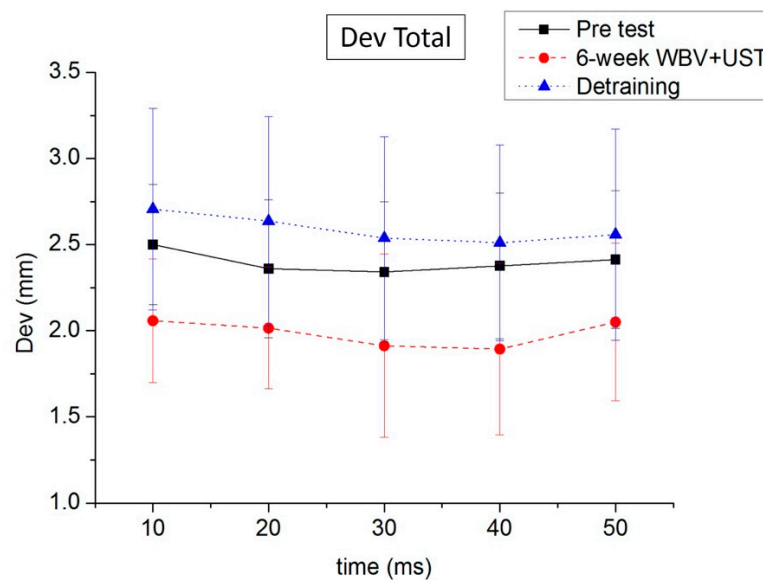

Figure 3. The difference phase during 10–50 ms-DevTotal of the shooting performance.

For the shooting score, the one-way RM ANOVA showed a significant difference between testing times (F = 23.730, $p < 0.01$, power = 0.985). The shooting scores during the 6 week WBV+UST ($p < 0.01$, 6.25%) greatly improved, relative to those of the pretest. Post hoc testing indicated that the 6 week WBV+UST led to improvements after the pretest performances (Table 3). For the total time, the one-way RM ANOVA showed a significant difference between testing times (F = 5.909, $p < 0.05$, power = 0.553). The shooting score after the 6 week WBV+UST (2.00%) greatly improved, relative to the pretest performance (Table 3 and Figure 2).

On the shooting performance test, we recorded the trajectory values of the rifle under the 10–50 ms-DevTotal and 10–50 ms-DevY categories. For the 10–50 ms-DevTotal values, the one-way RM ANOVA showed a significant difference between performances at different times: 10 ms (F = 10.610, $p = 0.01$, power = 0.979), 20 ms (F = 6.292, $p = 0.04$, power = 0.579), 30 ms (F = 9.811, $p = 0.02$, power = 0.766), and 40 ms (F = 9.025, $p = 0.02$, power = 0.732). Furthermore, the 10 ms-DevTotal values after the 6 week WBV+UST ($p = 0.04$, 17.68%) greatly improved compared with that of the pretest performance. Post hoc testing indicated that the 6 week WBV+UST led to improvements after the pretest

performances (Table 3 and Figure 3). For the 10–50 ms-DevY, the one-way RM ANOVA showed a significant difference between performances at different times: 10 ms (F = 29.887, $p < 0.01$, power = 0.996), 20 ms (F = 31.337, $p < 0.01$, power = 0.997), 30 ms (F = 30.624, $p < 0.01$, power = 0.997), 40 ms (F = 31.285, $p < 0.01$, power = 0.997), and 50 ms (F = 33.699, $p < 0.01$, power = 0.998). Furthermore, the 10–50 ms-DevY after the 6 week WBV+UST greatly improved, relative to the pretest performance (10 ms ($p < 0.01$, 26.70%), 20 ms ($p < 0.01$, 27.10%), 30 ms ($p < 0.01$, 27.25%), 40 ms ($p < 0.01$, 26.32%), and 50 ms ($p < 0.01$, 26.84%)). Post hoc testing indicated that the 6 week WBV+UST led to improvements after the pretest performances (Table 3 and Figure 4).
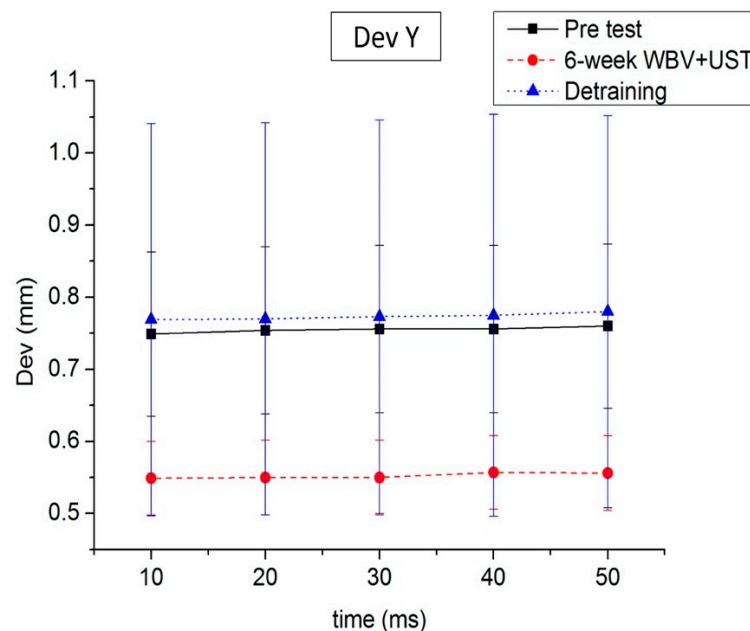

Figure 4. The difference phase during 10–50 ms-DevY of the shooting performance.

For COP, the one-way RM ANOVA showed no significant difference between testing times. The time score performances of the shooters at each of the separate testing intervals did not significantly improve compared to those in the pretest performance (Table 4).

4. Discussion

This study aimed to investigate the effect of combined training (WBV+BOSU) on shooting performance and movement stability. Post-training, every parameter is affected. No previous study has conducted UST on WBV; hence, its possible benefits to shooters were uncertain. According to the results of this study, WBV+UST could effectively improve the shooting score by 6.25%. The training also shortened the shooting movement time by 2.00%, reducing fatigue. With the shortened time and improved score, maximum benefit can be obtained. Additionally, after the 6 week WBV+UST, the overall movement control 10 ms before firing improved by 17.68%, as measured using DevTotal, and the vertical stability of hold (DevY) improved by 26.70%, 27.10%, 27.25%, 26.32%, and 26.84% in 10, 20, 30, 40, and 50 ms, respectively, with the stimulation of a vertical sine wave. It can, thus, be seen that WBV+UST is a feasible auxiliary training method for shooting.

This study also aimed to explore the influence of the 6 week training on the important factors of elite air rifle players in shooting and identify the best training method to improve their performance. Among air rifle shooting skills, stability maintenance, accurate aiming, smooth firing, and firing time have been confirmed as the most relevant factors influencing air rifle shooting scores. The degree of gun stability is a condition that is essential to movement in shooting skills. Our study results showed that the 10–40 ms-DevTotal and 10–50 ms-DevY values significantly improved, which was consistent with the results of the

previous studies. Based on this, the influence score was determined, which revealed that muzzle movement contributed to 54% of the shooting score [11].

Shooting demonstrated a static, relatively subtle movement. The results showed that the 6 week WBV+UST training reduced the muzzle trajectory and shooting time, indicating improvements of body stability and shooting performance. Further, all the parameters recovered to the initial condition after the 6 week detraining period, confirming the strong evidence of positive effects of WBV+UST.

The results of this study emphasize the importance of gun-holding stability in achieving excellent shooting skills. DevTotal values showed significant improvement, specifically the improved stability of posture control 10 ms before firing due to training. However, the ability of elite athletes to reduce posture swing in the forward and backward directions in the last second before firing is related to gun-holding stability. Therefore, maintaining posture control is important as this indirectly influences performance score. Previous studies have investigated the association between stability and shooting score in novice rifle shooters, and the results were consistent with those of the present study [6]. Therefore, when designing training programs for improving the abilities of novice and elite athletes, stability maintenance should be considered.

To the best of our knowledge, this is the first study to investigate the effect of WBV+UST on professional sports proficiency and balance. We speculated that UST by standing on a vibration platform is an effective method to improve lower limb stability. In this study, vertical sinusoidal oscillations at 30 Hz were adapted, similar to those in previous studies. Some studies also showed that squatting on the left and right electric balance plates can improve the activation method of the lower limb muscles, as evaluated through surface electromyography (EMG). EMG was not used to evaluate muscle activation in this study; thus, the conclusion cannot be extrapolated for a more detailed explanation.

The absence of a time limit in shooting competitions has prompted studies to investigate aiming time or firing fluency. This study showed improvements in the players' total time. The longer the shooting time, the more the players experience fatigue. It can be deduced that reduced total time has a positive effect on the score. This study confirmed that time affects shooting score, as proper timing improves the shooters' fluency [6]. Ihalainen et al. [11] found that aiming time is significantly associated with firing fluency and score, and these parameters are very important for enhancing shooting performance.

5. Conclusions

The results of this study showed that the WBV+UST method can effectively improve shooting performance. Significant differences were found in shooting tests, specifically in stability, fluency, and scores. In general, the use of WBV+UST may improve athletic performance. This information is pertinent for activities requiring body stability maintenance, such as archery, gymnastics, and ballet. Additionally, the vertical interference generated by WBV may improve movement stability. While we showed that riflers benefitted from acute WBV+UST, no conclusions were made regarding the settings that should be used for optimal results. Further studies are recommended to determine the ideal intensity for WBV+UST. One of the main study limitations is associated with the small sample size. Such studies, however, are difficult to conduct and need to be biomechanically assessed and prospectively followed over a prolonged period of time.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Fu Jen Catholic University Institutional Review Board (No.C106085).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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