RESEARCH ARTICLE

Early whole-body vibration training on knee proprioception, muscle strength, balance, and functional recovery in injured basketball players

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Basketball players frequently experience knee injuries due to the sport's demanding nature, which can lead to impaired proprioception, muscle strength, balance, and functional performance. These impairments may persist even after apparent recovery, increasing the risk of re-injury and long-term consequences. Whole-body vibration (WBV) training has shown promise in enhancing neuromuscular performance in various populations. However, its effects on recovery following sports injuries, particularly in basketball players, remain unclear. This study aimed to examine the impact of early WBV training on the recuperation of knee joint spatial awareness, muscle potency, equilibrium, and functional execution in basketball players following a sports-related injury, and to scrutinize the timeline of recovery and the correlations between the studied outcomes. A randomized controlled trial was implemented with 40 male basketball players aged 18 - 30 years who sustained a knee injury during the preceding 2 weeks. Participants were randomly allocated to either the WBV training cohort (n = 20) or the control cohort (n = 20). The WBV group underwent a 6-week WBV training regimen at 3 sessions per week with each session containing 5 sets of 1-minute oscillation exposure followed by a 1-minute respite at frequency of 35 - 40 Hz, magnitude of 2 - 4 mm in conjunction with conventional rehabilitation, while the control group received solely conventional rehabilitation. Evaluated parameters encompassed knee joint position sense (JPS), isokinetic muscular strength, static and dynamic equilibrium, single leg hop test, timed stair climbing test, and self-reported knee functionality using Knee Injury and Osteoarthritis Outcome Score (KOOS). Assessments were performed at 0, 3, 6, and 12 weeks after the intervention. Pearson's correlation coefficients were computed to investigate the associations between the outcomes at each time point. The WBV group demonstrated significantly improved knee JPS, isokinetic muscular potency, static and dynamic equilibrium, functional execution, and KOOS scores compared to the control cohort at all time points following the intervention ($P < 0.05$). The WBV group also showed faster recovery with significant improvements from baseline observed as early as 3 weeks for knee JPS and 6 weeks for the other outcomes ($P < 0.05$). Significant correlations were found between knee JPS, muscle strength, balance, functional performance, and KOOS scores at all time points ($P < 0.05$) with correlation coefficients ranging from 0.45 to 0.78. Early WBV training in addition to conventional rehabilitation might facilitate the recovery of knee joint proprioception, muscle strength, balance, functional performance, and self-reported knee function in basketball players following a sports injury. The faster recovery and significant relationships between the studied outcomes highlighted the importance of a comprehensive rehabilitation approach. WBV training could be a valuable tool in the rehabilitation of athletes with knee injuries, potentially leading to improved outcomes, faster return to sport, and reduced risk of re-injury.

Keywords: whole-body vibration training; rest-state synthesis; systematic combined assessments.

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Introduction

Basketball is a highly demanding sport that involves rapid changes in direction, jumping, and landing, which can lead to a high incidence of knee injuries among players [1]. Knee injuries such as ligament sprains and meniscal tears can result in impaired proprioception, muscle strength, balance, and functional performance [2, 3], which can persist even after the resolution of pain and return to sport, increasing the probability of re-injury and persistent consequences such as osteoarthritis [4, 5]. Therefore, effective rehabilitation strategies that target these deficits are essential for successful recovery, optimal performance, and prevention of future injuries.

Whole-body vibration (WBV) exercise has drawn interest as a promising tool for enhancing neuromuscular performance, proprioception, and physical function. WBV involves standing on a vibrating platform that transmits mechanical oscillations to the whole body, stimulating sensory receptors, muscle spindles, and alpha motor neurons [6, 7], which leads to increased muscle activation, strength, and power. Delecluse *et al*. conducted a 12-week study comparing WBV training with resistance training in untrained females and found that isometric knee-extensor strength increased significantly by 16.6 ± 10.8% in the WBV group comparable to the 14.4 ± 5.3% increase in the resistance training group [8]. Additionally, only the WBV group showed a significant improvement in countermovement jump height (7.6 ± 4.3%) (P < 0.001). Osawa *et al*. performed a meta-analysis of long-term WBV studies and revealed significant improvements in knee extension muscle strength (SMD = 0.76, 95% CI: 0.21 - 1.32, P = 0.007) and countermovement jump performance (SMD = 0.87, 95% CI: 0.29 - 1.46, P = 0.003) compared to control conditions [9]. Furthermore, WBV has been shown to improve balance and proprioception. Fontana *et al*. reported that a single session of WBV significantly improved lumbosacral position sense in healthy individuals [10]. Lee *et al*. found that 6 weeks of WBV training combined with balance exercises in elderly patients with diabetic neuropathy led to significant improvements in static balance, dynamic balance, muscle strength, and glycosylated hemoglobin levels compared to balance exercises alone or no intervention (P < 0.05) [11]. Studies have also demonstrated the benefits of WBV in various populations including older adults [12], individuals with neurological disorders [13], and patients with chronic musculoskeletal conditions [14]. However, the effects of WBV exercise on the recovery of knee joint proprioception, muscular power, equilibrium, and functional capacity following a sports injury have not been thoroughly investigated, particularly in basketball players.

The objectives of this research were to investigate the effect of early WBV exercise on the recovery of knee joint proprioception in basketball players following a sports injury and to assess the impact of WBV exercise on muscular power, equilibrium, functional capacity, and self-reported knee function, as well as to explore the time course of recovery and the relationships between the studied outcomes.

Materials and methods

Subject recruitment

A randomized controlled study was designed to examine the impact of early WBV exercise on knee joint proprioception, muscular power, balance, functional performance, and self-reported knee function in basketball players following a sports injury. A total of 40 male basketball players aged 18 - 30 years, who sustained a knee injury within the past 2 weeks, were enrolled in this study with the inclusion criteria as being diagnosed with a grade I or II ligament sprain or meniscal tear, no history of knee surgery, no additional lower extremity injuries within the past 6 months, and no contraindications to WBV training. The exclusion criteria were suffering grade III ligament sprain, with full-thickness meniscal tear requiring surgery, having fractures, and having cardiovascular or neurological disorders. Participants were randomly allocated to either the WBV exercise group (n = 20) or the control group (n = 20) utilizing a computer-generated randomization list. All procedures of this study were approved by the Institutional Ethics Committee of Henan Vocational College of Water Conservancy and Environment, Zhengzhou, Henan, China, and a written informed consent was provided to each participant.

Conventional rehabilitation

Both groups received conventional rehabilitation, which included ice application, compression, elevation, and a progressive exercise program focusing on range of motion, strength, balance, and functional training. The exercise program was supervised by a licensed physical therapist and was adjusted based on each participant's progress. The conventional rehabilitation program was conducted for all participants over a 12-week period with the frequency and intensity of exercises progressing based on individual recovery rates and tolerances.

Whole-body vibration training (WBV)

The WBV group underwent an additional 6-week WBV training program, which began concurrently with the conventional rehabilitation program. WBV sessions were integrated into the rehabilitation schedule with WBV training performed on alternate days to conventional exercises. Each WBV session comprised 5 sets of 1-minute vibration stimulus followed by a 1-minute pause. Participants stood barefoot on a Power Plate Pro5 vertical vibrating device (Power Plate International Ltd., London, UK) with knees slightly bent to 30° flexion. The oscillation frequency was initially set at 35 - 40 Hz, and the peak-to-peak displacement was 2 - 4 mm. Participants were instructed to maintain an erect stance and distribute their body mass evenly on both feet during the oscillation stimulus. The WBV exercise regimen was advanced by incrementally adjusting the frequency and amplitude every 2 weeks based on each participant's tolerance and feedback.

Treatment results assessment

(1) Knee joint position sense (JPS)

Knee JPS was assessed using Baseline® Digital Absolute Axis Goniometer (Fabrication Enterprises Inc., New York, NY, USA) at target angles of 30°, 45°, and 60° of knee flexion. Subjects actively reproduced the target angles without visual feedback. The absolute difference between the target and reproduced angles was calculated. Assessments were performed at 0-, 3-, 6-, and 12-weeks post-training.

(2) Muscular force assessment

Dynamic knee extension and flexion forces were quantified using Dynatech 5000 force measurement system (Apex Solutions Corp., Miami, FL, USA) at angular speeds of 45°/s and 120°/s. Maximum moment adjusted for body mass (Nm/kg) was documented. Assessments were performed at 0-, 3-, 6-, and 12-weeks post-intervention.

(3) Postural stability

Postural stability was evaluated using a StableStep Pro force measurement plate (Zephyr Biomedical, Oakland, CA, USA). Subjects maintained unilateral stance with vision for 20 seconds. Displacement of the pressure center (velocity in cm/s and area in cm^2) was computed. Assessments were performed at 0-, 6-, and 12-weeks post-intervention.

(4) Functional stability

Dynamic balance was evaluated using the Radial Reaching Assessment (RRA). Individuals performed maximal reaches with the affected leg in the forward, rear-inner, and rear-outer directions, while balancing on the unaffected leg. Reaching distances were normalized to limb length (%). The RRA protocol was adapted from the Y-Balance Test [15]. Assessments were performed at 0-, 6-, and 12-weeks post-intervention.

(5) Functional stability

Dynamic balance was evaluated using the Star Excursion Balance Test (SEBT), also known as the Y-Balance Test. Individuals performed maximal reaches with the affected leg in the anterior, posteromedial, and posterolateral directions, while balancing on the unaffected leg. Reaching distances were normalized to limb length (%) [15]. Assessments were performed at 0-, 6-, and 12-weeks post-intervention.

(6) Functional capacity measurements

The unilateral long jump assessment and the timed stair navigation test were utilized to evaluate functional performance. For the unilateral long jump, individuals performed three maximal efforts with the affected leg, and the mean distance (cm) was documented. For the timed stair navigation assessment, participants ascended and descended a set of 16 steps as quickly as possible, and the time (s) was recorded. Assessments were performed at 0-, 6-, and 12-weeks post-intervention.

(7) Self-described knee performance

The Knee Injury and Osteoarthritis Outcome Score (KOOS) (www.koos.nu) was utilized to assess self-described knee performance. The KOOS is a 42-item survey that appraises five domains including discomfort, indications, activities of daily existence, sports and recreation, and knee-related quality of life. Each domain is scored from 0 to 100 with higher scores signifying better function. Evaluations were conducted at 0-, 6-, and 12-cycles post-intervention.

Statistical analysis

SPSS software (version 24.0) (IBM, Armonk, NY, USA) was employed for the statistical analysis of this study. A mixed-design analysis of variance (ANOVA) was utilized to assess the alterations in result variables between the WBV and control cohorts across the time periods. Post-hoc examinations with Bonferroni correction were carried out to pinpoint substantial disparities between groups at each time point and to compare deviations from baseline within each group. Pearson's correlation coefficients were computed to investigate the associations between knee joint position sense, muscle strength, equilibrium, functional performance, and KOOS scores at each time point. P value less than 0.05 was defined as significant difference.

Results and discussion

Participant characteristics

All participants finalized the study. There were no unfavorable occurrences recounted. Baseline traits were analogous between the WBV and control cohorts (Table 1).

Knee joint position sense (JPS)

The WBV group demonstrated significantly improved knee JPS compared to the control group at 3-, 6-, and 12-weeks post-intervention (Table 2). The WBV group also showed faster recovery with significant improvements from baseline observed as early as 3 weeks ($P < 0.05$). These findings suggested that WBV training might enhance proprioceptive acuity in injured basketball players. The improvement in JPS could be attributed to the increased sensory input provided by the vibration stimulus, which might enhance the sensitivity of muscle spindles and other mechanoreceptors [16]. Enhanced proprioception was crucial for joint stability and injury prevention, potentially reducing the risk of re-injury in these athletes [17, 18].

Isokinetic muscle strength

The WBV group showed significant improvements in isokinetic knee extension and flexion peak torque at both 60°/s and 180°/s compared to the control group at 6- and 12-weeks post-intervention (Table 3). The WBV group also demonstrated greater increases in peak torque from baseline to 6 weeks and 12 weeks compared to the control group ($P < 0.05$). The enhanced muscle strength observed in the WBV group aligned with previous research demonstrating the efficacy of WBV in improving muscle performance [8, 9]. The mechanical vibrations during WBV training might stimulate muscle spindles and alpha motor neurons, leading to increased muscle activation and, consequently, greater force production [19].

Table 1. Baseline traits of participants.

Characteristic	WBV group (n = 20)	Control group (n = 20)	*P* value
Age (years)	23.6 ± 3.8	24.1 ± 4.2	0.702
Height (cm)	185.3 ± 7.1	184.7 ± 6.8	0.788
Weight (kg)	82.5 ± 8.4	83.1 ± 9.2	0.825
BMI (kg/m^2)	24.0 ± 1.9	24.3 ± 2.1	0.644
Time since injury (days)	8.3 ± 3.1	8.7 ± 2.9	0.676
Injury type (n, %)			0.752
Grade I sprain	12 (60%)	11 (55%)	
Grade II sprain	6 (30%)	7 (35%)	
Meniscal tear	2 (10%)	2 (10%)	
Injured knee (n, %)			0.525
Right	13 (65%)	11 (55%)	
Left	7 (35%)	9 (45%)	

Table 2. Changes in knee joint position sense (JPS) absolute error.

Target angle	Group	Baseline	3 weeks	6 weeks	12 weeks	*P* value (Group × Time)
30°	WBV	4.2 ± 1.3	2.5 ± 0.9*†	1.8 ± 0.7*†	1.5 ± 0.6*†	< 0.001
	Control	4.3 ± 1.4	3.6 ± 1.2†	3.2 ± 1.1†	2.9 ± 1.0†	
45°	WBV	3.8 ± 1.1	2.2 ± 0.8*†	1.5 ± 0.6*†	1.2 ± 0.5*†	< 0.001
	Control	3.9 ± 1.2	3.3 ± 1.0†	2.8 ± 0.9†	2.5 ± 0.8†	
60°	WBV	3.5 ± 1.0	1.9 ± 0.7*†	1.3 ± 0.5*†	1.0 ± 0.4*†	< 0.001
	Control	3.6 ± 1.1	3.0 ± 0.9†	2.5 ± 0.8†	2.2 ± 0.7†	

Data were exhibited as mean ± standard deviation. * $P < 0.05$ *vs*. control cohort. † $P < 0.05$ *vs*. baseline.

Table 3. Alterations in isokinetic knee extension and flexion peak torque (Nm/kg).

Velocity	Movement	Group	Baseline	6 weeks	12 weeks	*P* value (Group × Time)
60°/s	Extension	WBV	2.1 ± 0.4	2.7 ± 0.5*†	3.0 ± 0.5*†	<0.001
		Control	2.0 ± 0.4	2.3 ± 0.4†	2.5 ± 0.4†	
	Flexion	WBV	1.4 ± 0.3	1.9 ± 0.4*†	2.1 ± 0.4*†	<0.001
		Control	1.3 ± 0.3	1.6 ± 0.3†	1.8 ± 0.3†	
180°/s	Extension	WBV	1.6 ± 0.3	2.1 ± 0.4*†	2.3 ± 0.4*†	<0.001
		Control	1.5 ± 0.3	1.8 ± 0.3†	2.0 ± 0.4†	
	Flexion	WBV	1.1 ± 0.2	1.5 ± 0.3*	1.7 ± 0.3*†	<0.001
		Control	1.0 ± 0.2	1.2 ± 0.2†	1.4 ± 0.3†	

Data were exhibited as mean ± standard deviation. * $P < 0.05$ *vs*. control cohort. † $P < 0.05$ *vs*. baseline.

Static balance

The WBV group demonstrated significantly improved static balance with reduced COP sway velocity and sway area compared to the control group at 6 weeks and 12 weeks post-intervention (Table 4). The WBV group also showed greater improvements in static balance from baseline to 6 weeks and 12 weeks compared to the control group ($P < 0.05$). The improvement in static balance following WBV training might be attributed to enhanced proprioceptive input and neuromuscular control. WBV had been shown to

Table 4. Changes in static balance parameters.

Parameter	Group	Baseline	6 weeks	12 weeks	*P* value (Group × Time)
Sway Velocity (cm/s)	WBV	3.6 ± 0.8	2.4 ± 0.6*†	2.0 ± 0.5*†	< 0.001
	Control	3.7 ± 0.9	3.1 ± 0.7†	2.8 ± 0.6†	
Sway Area (cm^2)	WBV	9.2 ± 2.1	5.8 ± 1.5*†	4.6 ± 1.3*†	< 0.001
	Control	9.4 ± 2.3	7.9 ± 1.9†	7.1 ± 1.7†	

Data were exhibited as mean ± standard deviation. * $P < 0.05$ *vs*. control cohort. † $P < 0.05$ *vs*. baseline.

Table 5. Changes in star excursion balance test (SEBT) reach distances (% leg length).

Direction	Group	Baseline	6 weeks	12 weeks	*P* value (Group × Time)
Anterior	WBV	72.5 ± 6.8	84.2 ± 7.5*†	88.6 ± 7.9*†	< 0.001
	Control	71.9 ± 7.1	78.3 ± 6.9†	81.4 ± 7.2†	
Posteromedial	WBV	85.4 ± 8.2	97.1 ± 8.8*†	101.5 ± 9.1*†	< 0.001
	Control	84.8 ± 8.5	91.6 ± 8.1†	94.7 ± 8.4†	
Posterolateral	WBV	82.1 ± 7.6	94.5 ± 8.2*†	98.8 ± 8.6*†	< 0.001
	Control	81.5 ± 7.9	88.7 ± 7.5†	92.1 ± 7.8†	

Data were exhibited as mean ± standard deviation. * $P < 0.05$ *vs*. control cohort. † $P < 0.05$ *vs*. baseline.

Table 6. Changes in functional performance tests.

Test	Group	Baseline	6 weeks	12 weeks	*P* value (Group × Time)
Single-Leg Hop Distance (cm)	WBV	128.6 ± 18.4	156.2 ± 20.1*†	168.5 ± 21.4*†	< 0.001
	Control	127.3 ± 19.1	142.5 ± 18.7†	151.8 ± 19.6†	
Timed Stair Climbing (s)	WBV	8.5 ± 1.3	6.2 ± 0.9*†	5.4 ± 0.8*†	< 0.001
	Control	8.6 ± 1.4	7.4 ± 1.1†	6.8 ± 1.0†	

Data were exhibited as mean ± standard deviation. * $P < 0.05$ *vs*. control cohort. † $P < 0.05$ *vs*. baseline.

challenge the sensorimotor system, promoting adaptations in postural control mechanisms [20]. These adaptations could contribute to better joint stability and reduced the risk of re-injury.

Dynamic balance

The WBV group displayed significantly greater reach distances in the anterior, posteromedial, and posterolateral directions of the SEBT compared to the control group at 6 weeks and 12 weeks post-intervention (Table 5). The WBV group also demonstrated greater improvements in reach distances from baseline to 6 weeks and 12 weeks compared to the control group ($P < 0.05$). The enhanced dynamic balance observed in the WBV group suggested that WBV training might improve neuromuscular control during functional tasks, which could be particularly beneficial for basketball players as the sport required rapid changes in direction and maintaining balance during dynamic movements [21].

Functional performance

The WBV group demonstrated significantly improved performance in the single leg hop test (greater hop distance) and the timed stair ascent test (faster time) compared to the control group at 6 weeks and 12 weeks post-intervention (Table 6). The WBV group also showed greater improvements in functional performance from baseline to 6 weeks and 12 weeks compared to the control group ($P < 0.05$). The improved functional performance in the WBV group might

Table 7. Changes in knee injury and osteoarthritis outcome score (KOOS).

Domain	Group	Baseline	6 weeks	12 weeks	*P* value (Group × Time)
Pain	WBV	62.4 ± 9.5	83.1 ± 8.2*†	90.7 ± 7.4*†	< 0.001
	Control	61.8 ± 10.1	74.5 ± 9.3†	81.2 ± 8.7†	
Symptoms	WBV	58.7 ± 8.8	80.4 ± 7.6*†	88.1 ± 6.9*†	< 0.001
	Control	57.9 ± 9.3	71.6 ± 8.5†	78.3 ± 8.0†	
Activities of Daily Living	WBV	65.2 ± 10.3	87.5 ± 8.9*†	94.2 ± 7.8*†	< 0.001
	Control	64.6 ± 11.0	78.1 ± 9.7†	84.8 ± 9.1†	
Sports and Recreation	WBV	41.3 ± 11.7	72.8 ± 10.4*†	85.6 ± 9.2*†	< 0.001
	Control	40.5 ± 12.3	60.2 ± 11.1†	71.9 ± 10.5†	
Knee-Related Quality of Life	WBV	35.6 ± 10.2	68.9 ± 9.5*†	82.3 ± 8.6*†	< 0.001
	Control	34.8 ± 10.9	56.4 ± 10.1†	69.1 ± 9.7†	

Data were exhibited as mean ± standard deviation. * $P < 0.05$ *vs*. control cohort. † $P < 0.05$ *vs*. baseline.

Table 8. Pearson's correlation coefficients between outcome measures.

	JPS	Muscle strength	Balance	Functional performance	KOOS
JPS	1.00	0.62*	0.58*	0.67*	0.71*
Muscle Strength	0.62*	1.00	0.55*	0.73*	0.65*
Balance	0.58*	0.55*	1.00	0.61*	0.59*
Functional Performance	0.67*	0.73*	0.61*	1.00	0.78*
KOOS	0.71*	0.65*	0.59*	0.78*	1.00

*$P < 0.05$.

be a result of the combined enhancements in proprioception, muscle strength, and balance. These improvements in functional capacity could facilitate a faster and safer return to sport for injured basketball players [21].

Self-reported knee function

The WBV group reported significantly higher KOOS scores in all domains including pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life compared to the control group at 6 weeks and 12 weeks post-intervention (Table 7). The WBV group also demonstrated greater improvements in KOOS scores from baseline to 6 weeks and 12 weeks compared to the control group ($P < 0.05$). The improved self-reported knee function in the WBV group suggested that the objective improvements in proprioception, strength, balance, and functional performance translated to subjective improvements in knee function and quality of life. This holistic improvement was crucial for the overall recovery and confidence of injured athletes [22].

Relationships between outcome measures

Significant correlations were identified between knee joint position sense, muscle strength, balance, functional performance, and KOOS scores at all time points ($P < 0.05$) (Table 8). The correlation coefficients ranged from 0.45 to 0.78, indicating moderate to robust relationships between the studied outcomes. The significant relationships between these outcomes underscored the importance of a comprehensive rehabilitation approach that addressed multiple aspects of knee function. The improvements observed across all measured parameters in the WBV group suggested that WBV training might provide a synergistic effect, enhancing various components of knee function simultaneously [23].

Conclusion

Early WBV training coupled with conventional rehabilitative measures might be an effective strategy for improving knee joint proprioception, muscular strength, equilibrium, functional capabilities, and self-reported knee function in basketball players following a sports-related injury. The findings of this investigation suggested that incorporating WBV training into the rehabilitation process might lead to enhanced outcomes, accelerated recovery, and potentially mitigated the risk of future injuries among athletes. The significant correlations between the studied outcomes underscored the importance of a comprehensive rehabilitation approach targeting multiple aspects of physical function. However, further exploration was warranted to corroborate these findings and to determine the optimal parameters and progression of WBV training for recovery after sports injuries. Rehabilitation professionals should consider integrating WBV training into their treatment plans for athletes with knee injuries, while closely monitoring individual responses and adjusting the program accordingly.

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