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A Scoping Review of the Effects of Wearable Resistance Training on Exercise Performance

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Abstract: *The aim was to analyze the effectiveness of wearable resistance training (WRT) in enhancing athletes' performance, especially in competitive sports. Methods Based on the JBI guidelines, relevant literature from several databases up to August 11, 2024, was searched and analyzed to sort out the application strategies and intervention effects of WRT. Results WRT has been used in various intervention modalities, mainly in athlete populations, involving trunk and lower limb appendages. WRT had a positive effect on sprinting ability, potentially increasing speed by enhancing downward force and horizontal propulsion. Also, WRT improved change-of-direction movement and jumping performance, which may be related to neurological adaptations, muscle coordination, and rapid strength gains. However, the effects were influenced by individual differences, training duration, and load size. Conclusions There is a limited number of WRT studies, particularly a lack of upper limb appendage studies. WRT improves certain motor performances, but the effects are variable. In the future, the combined effects of different attachment sites, load intensities, and training formats in WRT on specific sports need to be further explored to optimize training protocols.*

Keywords: *Wearable Resistance Training, Athletic Performance, Scoping Review*

1. Introduction

It is well known that training methods are essential to improve athletes' performance and skills. At present, although traditional resistance training is widely used to enhance muscle strength, the efficiency of this kind of general strength is not high[1]. In addition, the training in the gym is disconnected from the actual competition environment, which cannot affect the athletes' emotion, attention, perception, etc[2]. Therefore, in order to improve sports performance more effectively, the motion pattern in training should be consistent with the real competition scene as much as possible[3].

Wearable Resistance Training (WRT) is an innovative method of training that helps athletes improve performance such as speed and agility by adding weight to specific parts of the body during exercise. This approach allows athletes to combine resistance training with actual competition scenarios while maintaining a specific motion pattern to optimize power output and athletic performance[4]. Macadam et al.(2019)[5] said WRT enables golfers to perform golf-specific actions with additional loads connected to the body, thereby significantly improving club head speed, consistent with the principles of exercise-specific training. Uthoff et al.(2020)[6] also indicate that forearm load sprinting can be used to develop longer strides by generating greater horizontal propulsion during early acceleration, and to promote changes in step frequency and time of flight through greater vertical load demand during the later stages of acceleration to improve sprinting performance. Considering that the wearable resistance of different parts and loads seems to improve the performance of different sports, WRT may become a better method of transforming non-specific strength gain into sports performance training.

The effects of wearable resistance training (WRT) on athletic performance may exhibit significant variations depending on the targeted body segments and applied loads, while sport-specific demands further complicate its application across disciplines. Internationally, limited systematic reviews have explored the efficacy of WRT. Macadam et al. [7] demonstrated that WRT effectively enhances sports performance, systematically analyzing its kinetic characteristics and biomechanical impacts on gait, running, and jumping across different body segments. Furthermore, Cleary Dolcetti et al. [2] proposed that WRT improves speed and agility without significantly altering movement velocity, range of motion, or sport-specific techniques. However, a paucity of domestic systematic investigations in this field persists, hindering the practical implementation of WRT in competitive sports training. This study aims to comprehensively evaluate the long-term intervention effects of segment-specific WRT with varying loads on athletic performance, thereby providing scientific evidence for performance optimization and

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formulating evidence-based strategies for coaches to design WRT protocols.

2. Materials and methods

2.1 Research questions

After a literature review and group discussion, the questions for this study were identified as: (a) What are the specific components of the WRT intervention (sample size, form of attachment, intensity of attachment, duration)?;(b)What are the effects of WRT based on different body parts on athletic performance?; and(c)How is it specifically applied?

2.2 Literature search

A systematic search was conducted across seven databases, including PubMed, Web of Science, Scopus, Medline, CNKI (China National Knowledge Infrastructure), Wanfang Data, and VIP Database. The search strategy combined subject headings, free-text terms, and Boolean operators (AND/OR). The search timeframe spanned from the inception of each database to August 11, 2024.

2.3 Study selection: article inclusion/exclusion criteria

Inclusion Criteria: (a) Chinese or English literature; (b) Literature on the effect of WRT on speed, agility, and other athletic performance; (c) literature on WRT program; (d) literature on healthy subjects; (e) literature on chronic interventions with portable weights. Exclusion criteria: (a) literature with duplicated article content; (b) literature where the full text is not available; (c) subjects in non-healthy populations; (d) literature where the intervention protocol is an acute intervention or cross-sectional study; (e) literature testing a warm-up protocol in the form of multiple repetitions; and (f) literature where the evaluation indexes do not match or where the evaluation of metabolic energy supply capacity is the main objective.

2.4 Literature screening and data extraction

The retrieved literature citations were first imported into EndNote X9 to remove duplicates. Subsequently, two professionally trained researchers independently conducted preliminary screening by reviewing titles and abstracts based on the predefined inclusion and exclusion criteria. Full-text articles were then assessed for secondary screening to determine the final selection.

3. Results

3.1 Literature search results

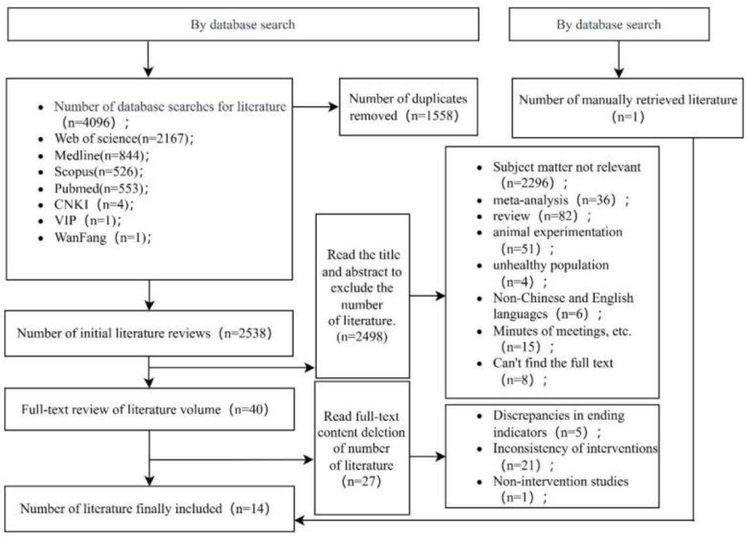

Figure 1 Flowchart of literature screening

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A total of 4,096 articles were retrieved from databases, with 1 additional article identified through manual search. After applying the predefined inclusion and exclusion criteria and screening all literature using EndNote X9 software, 14 articles were ultimately included for full-text analysis (see Figure 1).

3.2 Basic characteristics of included literature

The 14 included studies were published between 2010 and 2024. All selected literature consisted of longitudinal intervention studies, with intervention durations ranging from 8 days to 9 weeks. The basic characteristics of the included studies are summarized in Table 1.

Table 1 Basic characteristics of literature inclusion

Study n	Subject characteristics				WRT intervention		
	Age (years)	Gender	Level	Size	loading position	Intensity	Duration
1 Feser, Bayne, et al. (2021)	22.6±2.94	male	College football players	22	Calf (both legs)	1%BM	6 weeks
2 Clark et al. (2010)	19.7±0.92	male	College Hockey Players	20	trunk	≈18.5%BM	7 weeks
3 Feser, Korfist, et al. (2021)	16.6±0.50	undescribed	High School Rugby Player	19	Calf (both legs)	1%BM	9 weeks
4 Marriner et al. (2017)	23.1 ±2.3	male	Young men with 5-6 years of strength training experience	16	Trunk and lower limbs	12.0%BM	5 weeks
5 Simpson et al. (2020)	21 ±2	women	Trained and healthy women	19	trunk	8% BM	3 weeks
6 (Bustos et al. (2020)	15-18	male	National-level football players	31	Calf (both legs)	200-600g	8 weeks
7 Rey et al. (2017)	2 3.7±4.5	male	amateur footballer	19	trunk	18.9% ±2.1%BM	6 weeks
8 Khlifa et al. (2010)	23.11 ± 0.32	male	Division I professional league basketball players	27	trunk	10-11 % MB	10 weeks
9 Barr et al. (2015)	22.4±2.7	male	National-level rugby player	15	trunk	12%BM	8 days
10 Turki et al. (2020)	18±0.88	male	footballer	15	trunk	5%BM/10%BM/15%BM	3 weeks
11 A. Uthoff et al. (2022)	17.1±0.76	undescribed	National-level football players	28	Calf (both legs)	200-600g	8 weeks
12 Brown et al. (2024)	27.6 ±5.0	undescribed	Semi-professional footballer	26	Calf (both legs)	200g	9 weeks
13(Markovic et al. (2013)	23.7±1.7	undescribed	Physical education students	60	trunk	30 percent BM	8 weeks
14 Rantalainen et al. (2012)	32±6	male	General male	17	trunk	An average of about 5.6 % of BM	3 weeks

3.2.1 Intervention population and sample size

The included studies involved participants with diverse training backgrounds and skill levels. Among them, 10 studies focused on athletes [8–10,13–15,17–19], 1 study selected 16 trained young males [11], and 1 study recruited 19 trained healthy females as participants [12]. Additionally, 1 study targeted 60 sports - related undergraduate students [20], and 1 study involved 17 untrained males [21].The athlete population included national - level athletes: national football athletes (31 and 28 participants, respectively) [13,18] and 15 national rugby athletes [16]. College athletes were also studied, including 22 college rugby athletes [8] and 20 college hockey athletes [9]. Furthermore, 19 high school rugby athletes participated in one study [10]. Other participants included amateur football athletes (19 and 15 participants, respectively) [14,17], 26 semi - professional football athletes [19], and 27 professional basketball athletes from a firsttier league [15].

3.2.2 Attachment forms, intensity, and intervention duration

The attachment forms, intensity, and intervention duration varied across studies. Specifically:Trunk attachment was reported in 8 studies [9,12,14–17,20,21], with intensities ranging from 5% BM to 30% BM and intervention durations spanning 8 days to 10 weeks. Notably, Turki et al. [17] compared three intensities (5%, 10%, and 15% BM) to identify the most effective load.Lower limb (bilateral) attachment was used in 5 studies [8,10,13,18,19], with intensities of 1% BM or 200g to 600g and durations of 6 to 9 weeks.One study combined trunk and lower limb attachments at 12% BM intensity over 5 weeks [11].

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3.3 Main research protocols and results of the included studies

Among them, 2 studies [12, 21] adopted daily activities as the intervention mode, and 3 studies [13, 17, 18] used warm - up exercises as the intervention protocol. The rest all employed their respective specific comprehensive training as the intervention protocol. The descriptions of the effects of each WRT attachment intervention on athletic performance vary.

3.3.1 Effects of WRT based on different body parts on athletic performance

The descriptions of the effects of trunk-loaded WRT on athletic performance varied across studies. Specifically, four studies [14,15,17,20] reported that trunk-loaded WRT significantly improved performance in sprinting, jumping, or repeated change-of-direction movements. Notably, one study [11] that combined trunk and lower limb loading also reported that 12% BM WRT training had significant positive effects on athletes' strength and jumping ability, while also improving technical aspects of the power clean. Rantalainen et al. [21] found that wearing a weighted vest slightly improved agility in young males, though the effect was not statistically significant. Barr et al. [16] suggested that athletes' responses to trunk-loaded WRT interventions showed both positive and negative aspects, with potentially limited effects on improving sprint speed. Two studies [9,12] indicated that compared to conventional training, using lower-load weighted vests did not significantly enhance athletes' long jump and sprint performance.

When examining the effects of incorporating WRT (possibly referring to weight training or resistance training) into lower limb loading training, Feser et al. [8,10] found that moderate WRT intervention during sprint training helped maintain athletes' sprint performance and mechanical efficiency. Conversely, Brown et al. [19] demonstrated that after 9 weeks of WRT intervention, athletes showed improved sprinting ability, evidenced by increased sprint distances. However, two other studies [13,18] noted that while adding WRT intervention to warm-up training could enhance athletic performance, the improvement effect was not statistically significant.

3.3.2 Specific application effects of WRT

Rantalainen et al. [21] conducted a 3 - week torso - attached training with a 5.6% BM load on ordinary men, resulting in a 1.3% increase in running speed. Similarly, Simpson et al. [12] applied an 8% BM load on women with training experience for 3 weeks. As a result, their 25 - meter sprint and change - of - direction abilities improved, although the countermovement jump ability slightly declined.In addition, Clark et al. [9] applied a 18.5% BM torso load on college field hockey players, which improved their sprint speed from 18.3 m to 59.4 m. Rey et al. [14] carried out a 7 - week torso - load training with 18.9% BM on amateur football players. Their 10 - meter and 30 - meter sprint results increased by 9.42% and 6.04% respectively, and the countermovement jump height increased by 0.31%.Moreover, Barr et al. [16] pointed out in their study that after 8 days of torso - weighted training with 12% BM for national - level rugby players, although the sprint results remained unchanged, the ground - contact time at maximum speed significantly shortened, and the flight time significantly prolonged. Khlifa et al. [15] adopted a combined intervention of torso - attached (10 - 11% BM) WRT and plyometric training. The results showed that the athletes' squat jump ability and countermovement jump ability increased by 9.9% and 12.2% respectively. Turki et al. [17] 's study showed that after football players performed warm - up activities with torso - attached loads of 5%, 10%, and 15% BM respectively, their repeated change - of - direction movement ability significantly improved within 3 weeks. Finally, Markovic et al. [20] conducted an 8 - week torso - attached 30% jump training on physical education majors. Their one - repetition maximum (1RM) of squat, countermovement jump ability, and squat jump ability significantly improved, with the improvement ranges being 8.4%, 7.2%, and 13.1% respectively.

In the studies on the training effects of lower - limb loaded WRT on rugby and football players, Feser et al. [8, 10] conducted a 6 - to 8 - week comprehensive training and sprint - running training with a 1% BM calf load on college and high - school rugby players. The results showed that the 10 - meter, 20 - meter, and 30 - meter sprint results all decreased, with the decline ranging from 0.2% to 5.0%. In particular, the 5 - meter sprint result of high - school athletes significantly decreased by 7.2%, although their maximum sprint speed increased.Uthoff et al. [18] conducted an 8 - week warm - up training with a calf load of 200 g to 600 g on national - level football players, but found that this training did not bring significant improvement. Bustos et al. [13] conducted an 8 - week warm - up training on national - level football players under the same load and intensity conditions. The results showed that the 10 - meter and 20 - meter sprint performance and countermovement jump ability improved, with the improvement ranging from 0.33% to 1.99%, but the improvement was not significant compared with the control group. It is worth noting that there were differences in the warm - up strategies between these two studies, and plyometric training was added in one of the studies.Brown et al. [19] conducted a 9 - week WRT

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intervention on semi - professional football players, which was a football - specific training with a 200 - g calf load. After 9 weeks, compared with the control group, the athletes' sprint distance and mechanical work performance significantly improved, although no obvious differences were observed within the group before and after the intervention.

4. Discussion

4.1 Limited and uneven distribution of WRT chronic intervention studies

The 14 included studies exhibited an uneven distribution in terms of publication timeline, subject populations, and loading locations. While the number of publications has increased annually with more recent publications, the majority of intervention studies focused on football (soccer) players. Most loading protocols targeted the torso, with fewer examining calf loading, and a complete absence of studies investigating upper limb WRT applications for athletic performance enhancement.

4.2 Mechanistic analysis of WRT chronic intervention effects on sprint performance

Research indicates that an athlete's ability to proficiently achieve faster acceleration during sprinting primarily depends on two factors: the capacity to generate greater ground reaction forces and the efficiency of converting these forces into horizontal propulsion [22,23]. This technical capability is typically quantified through the force-application technique index (DRF), with superior DRF levels demonstrating strong correlations with maximum sprint velocity, 100m average speed, and 4-second sprint distance performance [24,25].

Two studies [8,10] demonstrated that WRT effectively enhances athletes' ability to maintain theoretical maximum horizontal force (F0) while significantly improving DRF. Feser et al. reported particularly notable improvements (Δ=15.8%/ES=16.8), suggesting WRT may enhance technical capacity for horizontal force application, potentially benefiting sprint performance. However, despite these positive DRF improvements, both studies observed less-than-expected sprint performance gains, possibly attributable to high athlete absenteeism and insufficient training frequency.Furthermore, research has established that significant stride length increases correlate strongly with leg spring stiffness [26]. This stiffness enhancement presumably occurs through increased muscular and tendinous stiffness in the lower extremities, which may subsequently improve running economy [27]. In other words, training adaptations can enhance structural properties of athletes' lower limbs, optimizing energy utilization efficiency during running.Four studies [9,14,16,21] reported WRT-induced improvements in sprint performance. Clark et al. [9] observed significant average velocity increases during 18.3-59.4m sprint segments following seven weeks of torso-loaded WRT, accompanied by increased stride frequency, reduced average ground contact time, and decreased flight time. Barr et al. [16] similarly noted significant ground contact time reductions during acceleration phases (ES=1.06), though these biomechanical changes didn't translate to statistically significant sprint performance improvements. Collectively, these findings suggest WRT may enhance sprint performance through combined mechanisms of increased stride length and frequency, coupled with reduced ground contact time.

4.3 Mechanism analysis of chronic WRT intervention on power, jumping ability, and change-of-direction performance

Explosive power and jumping performance are closely related to muscle strength and speed. The key to improving muscle strength, speed, and agility lies in enhancing the adaptability and mobilization efficiency of the nervous system, which involves both intramuscular and intermuscular coordination.

Intramuscular coordination includes optimizing motor unit recruitment within muscles, increasing motor unit firing frequency, and improving reflex activity.Intermuscular coordination focuses on enhancing synergistic work among different muscle groups, particularly the coordinated contraction and relaxation of antagonistic muscles. These factors are crucial for improving muscle strength and reaction speed [28].

Marriner et al. [11] found that five weeks of loaded power clean training not only significantly increased athletes' CMJ height and 1RM)strength but also improved their power output. Additionally, Brown et al. [19] demonstrated that after nine weeks of calf-loaded training, athletes exhibited improved mechanical work output, albeit with a modest effect size (ES = 0.32).In summary, WRT provides effective neuromuscular stimulation during sprint and agility training by enhancing nervous system

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adaptability and muscle recruitment efficiency. Through specific loading and movement patterns, WRT optimizes the neuromuscular system, thereby contributing to improved athletic performance.

5. Conclusion

WRT generally has a positive effect on improving athletic performance (e.g., speed, jumping ability, and agility). However, such effects are not always pronounced. Currently, longitudinal studies are relatively limited, and the research subjects are also restricted in scope, which may constrain the generalizability of the findings. Furthermore, the effectiveness of WRT may be influenced by multiple factors, including load positions, load intensity, training protocols, and specific conditions of the trainees. To gain a deeper understanding of the effects of WRT and identify optimal training strategies for different sports demands, future studies should explore variations in load positions, load intensity, and combinations with other exercise modalities based on intrinsic mechanisms. Such comprehensive research would help optimize WRT interventions to enhance specific athletic performance outcomes.

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