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Effect of Instability Resistance Training on Core Muscle Strength among Athletes: A Systematic Review

Jianxin Gao, Borhannudin Bin Abdullah*, Roxana Dev Omar Dev

Department of Sports Studies, Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia

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Abstract Background: Although instability resistance training (IRT) frequently engages as a form of muscle training, little has been reported in the literature about the effect of IRT on core muscle strength. Objectives: This study aims to conduct a systematic review of the impact of IRT on core muscle strength among athletes. Design: This study used the (PRISMA) guidelines and databases such as Web of Science, EBSCOhost (SPORTDiscus), PubMed, and Scopus for the original reference collection. This article collected 149 articles, and only 8 met the analysis criteria. Result: Each article's quality was determined using the PEDro scale, the scoring for 8 articles ranged from 7-9 with a low risk of bias. IRT could significantly improve isometric, isotonic, and isokinetic core muscle strength among Judo athletes, adolescent elite athletes, volleyball players, soccer players, collegiate athletes, and rhythmic gymnasts using unstable surfaces or environments (i.e., Suspension trainer, Swiss ball, Sissel pillows, Indo board with flow cushion, Stability ball, Airex balance pad, Togu power ball, Thera-Band, BOSU ball, Balance disc and so on). Conclusion: Theoretically, this study indicated that IRT is an improvement training method for activating core muscles, enhancing coordination between agonistic and antagonistic muscles, and improving muscle proprioception. In addition, based on emphasizing the integration of other training actions, IRT adopts an unstable form closer to specialized exercises or increasing difficulty to improve training efficiency and effectiveness. Practice has shown that continuous IRT has a positive promoting effect on core muscle strength than traditional training methods. Therefore, this review suggests that IRT should be considered in athletes' daily training routines for core muscle strength.

Keywords Instability Resistance Training, Unstable Surface, Core Strength, Athletes, BOSU and Swiss Ball

1. Introduction

At present, core strength training has attracted the attention of many sports workers and researchers [1,2]. However, traditional resistance training emphasizes the single development of local large muscle groups, neglecting the training of deep small muscle groups and the overall strength in the power chain, making it difficult to meet the current training and competition needs [3,1]. Compared to this, core strength training not only leverages its advantages but also compensates for the shortcomings of single functionality, laying the foundation for the efficient performance of the power chain. The key lies in the increase of "unstable factors", that is, conducting resistance training in an unstable state [4].

Instability Resistance Training (IRT) is the process of creating an "Unstable" platform by altering the stability of the support surface, imbalanced movement symmetry, and the occurrence of unexpected external forces that cause internal or external force imbalances in the body [2].

Unstable surfaces, platforms, and environments can be built with professional equipment, such as Wobble Boards, Swiss balls or BOSU balls, suspended chains, foam rollers, and bands. In addition, unstable training conditions can use snow, water, sand and gravel materials, and so on [5]. In summary, the instability support platform can be built for various materials. This training method can strengthen core muscles and stabilize body posture (balance ability), collectively known as IRT [3, 6, 4]. Research has confirmed that IRT has significant effects on stabilizing the spine and pelvis, improving control and balance, improving the economy and effectiveness of technical movements, and preventing sports injuries [1,7].

Most studies have mentioned the efficiency of IRT for the core muscle strength of athletes [4,8]. However, because this method has a relatively short history, the new training method needs to be systematically sorted out in terms of its structural function and theoretical and practical application. A systematic review of the effectiveness of varying degrees of IRT is still lacking [9,10]. Therefore, the purpose of this study is to conduct a systematic review of the existing articles on the impact of IRT on the core muscle strength of athletes.

2. Materials and Methods

2.1. Databases and Keywords

This article used these databases Web of Science, EBSCOhost (SPORT Discussion), PubMed, Scopus, and Google Scholar, until the end of 2023. The keywords in this study were: (“instability resistance training” OR “instability resistance exercise” OR "unstable surface training" OR “unstable training” OR “unstable surface exercise” OR “unstable exercise”) AND (“core muscle strength” OR “core muscle” OR “core muscular strength” OR “core strength” OR “isotonic core strength” OR “isometric core strength” OR “isokinetic core strength” OR “maximum core strength” OR “agile or speed or rapid core strength” OR “speed core strength” OR “rapid core strength” OR “endurance core strength” OR “core stability”) AND (“player” OR “athlete” OR “sportsman” OR “sportswoman” OR “sportsperson”).

2.2. Eligibility Criteria

The PICOS model was used in this study, and there are 5 parts of the population, intervention, comparison, outcome, and study design in this model. Inclusion criteria for the 5 parts are shown in Table 1.

Table 1. Inclusion and eligibility criteria

PICOS	Detailed Information of inclusion and eligibility criteria
Population	Healthy athletes or players, not distinguishing between age and gender
Intervention	Instability resistance (unstable surface) training separately or integrating other training with instability intervention in the experimental group (not less than 4 weeks)
Comparison	Single or multiple-group trials
Outcome	The outcome must comprise the impact of instability resistance training with different types of core muscle strength among athletes and players
Study Design	Single-group or randomized controlled trials

2.3. Study Search, Screening and Selection Processes

Firstly, this article used the Zotero 6.0 citation management system to eliminate duplicate articles. Secondly, the authors conducted a first round of screening on the literature that met the requirements based on the title and abstract and then conducted a second round of screening on the literature that had already been selected in the first round according to the full text. Thirdly, literatures that meet the standards were evaluated to determine the final reliability literature. Finally, at the seminar, all authors reached a consensus on which literature would be selected for this systematic review.

2.4. Data Extraction and PEDro Scale Assessment

Based on reading the entire literature, the authors summarized the content using standardized templates. In addition, this study used the PEDro scale in which reliability has been proven when building system reviews [11]. PEDro scale is a Delphi series of scales specifically developed by Verhagen and colleagues for epidemiology. The PEDro scale includes 11 items to evaluate the quality of the method, with each item scoring only 0 and 1, with 1 representing yes and 0 representing no. If the score of the literature is high, it indicates that the quality of the literature method is better [12,13].

3. Results

3.1. Article Selection

The procedure of identification, screening, and inclusion is shown in Figure 1. In the beginning, a total number of 149 articles were identified through database searching. After a preliminary screening, any duplicate articles were deleted, and there were 145 articles. After the screening of the second phase, they included 1 article not in English, 32 articles for review, conference papers, books, chapters, and magazines, and 1 article without full-text. In the next screening phase, 111 articles were evaluated for full-text. 39 articles were not a training/intervention or RCT relevant study, the participants were not healthy people, students and amateur athletes of 36 articles, 5 articles were not instability and unstable surface training interventions, and 23 articles were not core muscle strength outcome studies. In the end, there were a total of 8 articles for quantitative synthesis that met the criteria shown in Figure 1.

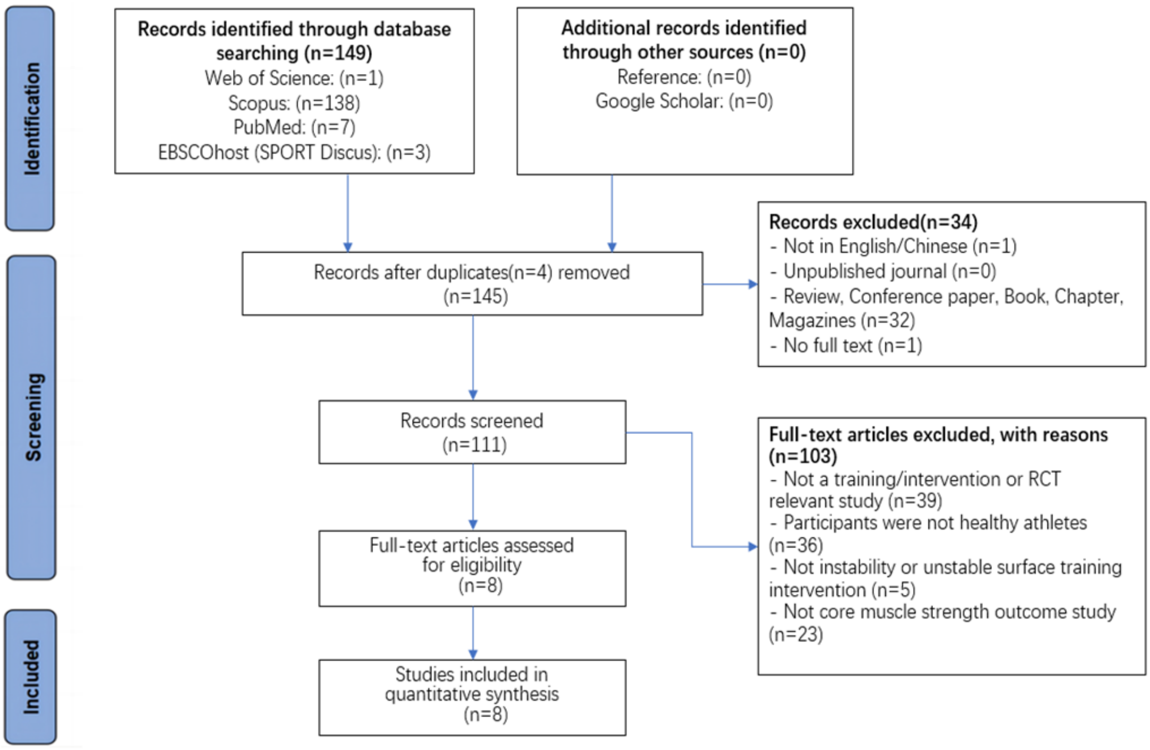

Figure 1. The Identification, Screening and Included Processes for Articles Based on PRISMA

Table 2. Summary of PEDro scale assessment scores

N	Reference	EC	RA	AC	BC	BP	BT	BA	FU	ITA	GC	PMV	Total PEDro Score
1	(Norambuena et al., 2021)	1	0	0	1	1	1	1	1	0	0	1	7
2	(Sever & Zorba, 2018)	0	1	0	1	1	1	1	1	0	1	1	8
3	(Mueller et al., 2022)	1	1	0	1	1	1	1	1	0	1	1	9
4	(Nuhmani, 2021)	1	1	0	1	1	1	1	1	0	1	1	9
5	(Oliver & Brezzo, 2009)	0	0	0	1	1	1	1	1	0	1	1	7
6	(Parkhouse & Ball, 2010)	1	0	0	1	1	1	1	1	0	1	1	8
7	(Prieske et al., 2016)	1	1	0	1	1	1	1	1	0	1	1	9
8	(Cabrejas et al., 2022)	1	1	0	1	1	1	1	1	0	1	1	9

Note: EC, Eligibility Criteria; RA, Random Allocation; AC, Allocation Concealment; BC, Baseline Comparability; BP, Blind Participants; BT, Blind Therapist; BA, Blind Assessor; FU, Follow-Up; ITA, Intention to Treat Analysis; GC, Group Comparison; PMV, Point Measure and Variability. 1 representing yes and 0 representing no.

3.2. Methodological Quality Assessment

Table 2 shows the detailed scores on the PEDro scale of 8 articles in this study, all studies with a score of 7-9. In the 11 items of this scale, the intention was to treat analysis, blinding participants, assessors concealed allocation, and therapists. Since accompanied by professional unstable training and the sports injury of athletes and players in different sports events, it is difficult to get scores rarely for these evaluation-based items of blind participants, assessors, and therapists of the 8 articles. While the authors report that total PEDro scores of 0-3 are considered ‘poor’, 4-5 ‘fair’, 6-8 ‘good’, and 9-10 ‘excellent’ [14], it is important to note that these classifications have not been validated of 8 articles in this study is shown in Table 2.

3.3. Participant Characteristics

In Table 3, there were the characteristics of participants, intervention, and outcomes for the 8 studies as follows. 1) Classification by athletes. Two articles were on soccer players [15, 16]; 1 article on mixed volleyball and soccer players [17]; one article on judo athletes [18]; one article on adolescent elite athletes [19], two articles on collegiate athletes [20,21]; one article on rhythmic gymnast [22]. 2) Participant, gender, and age. The total athletic number of subjects was 261 (96 males, 103 females, and 62 no reported gender). All studies reported the Mean or Standard deviation of the age for different participants. The max-minimum age range of participants was 27-10 respectively as shown in Table 3.

3.4. The Type of Unstable Intervention

Table 3 shows the type of unstable intervention, duration, and frequency for the 8 studies. Some studies refer to instability suspension training [18], core training on Swiss balls [15]; core-specific sensorimotor exercises using unstable surfaces [19]; Dynamic Swiss ball training [20]; Indo board functional balance training for volleyball players [17]; static and dynamic core training with stability ball [21]; core training performed on unstable surface [16]; functional core training with BOSU ball and balance disc [22].

In addition, because there is no control group in the studies, two articles only explored the effect of instability resistance training on athletes’ core muscle strength [18,21]. The remaining studies compared the differences in the effect of instability resistance training between experimental group and control group.

In the type of unstable surface or environment, a common feature is that separating or integrating training with instability intervention used unstable surface or environment (i.e., Suspension trainer, Swiss ball, Sissel pillows, Indo board with flow cushion, Stability ball, Airex balance pad, Togu power ball, Thera-Band, BOSU ball, Balance disc and so on) for each intervention or training activities.

As for duration, the duration of the 8 studies was from 5 to 9 weeks. Among these studies, 3 studies’ duration time lasted 6 weeks [19,20,21]; 2 studies lasted for 8 weeks [15,22]; 1 duration time lasted 5 weeks [18]; 1 study lasted 9 weeks [16]; and the remaining studies’ duration time lasted unknown weeks for the entire season [17].

Regarding frequency, the training frequency was 2 to 5 per week. Among these studies, 3 studies’ training frequency was 3 times per week [15,20,22]; 2 studies’ training frequency was 2 times per week [19,21]; 1 training frequency was 2-3 times per week [18]; 1 training frequency was 4 times per week [17]; and the remaining training frequency was 5 times per week [18].

3.5. Outcome

The division of muscle strength can be shown in Table 4 ，according to the muscle contraction theory in the field of sports training [23-26]. Among them, there are three subcategories in the muscle contraction type of the general category: (1) Isometric strength; (2) Isotonic strength; and (3) Isokinetic strength. Therefore, this study systematically summarized and analyzed the results of 8 papers based on the general category and subcategories of muscle strength mentioned above as shown in Table 4.

Table 4. The categories of core muscle strength

General Category	Subcategories	Main Representative test method
Type of muscle contraction	Isometric strength	Abdomen bridge, Back bridge and Lateral(side) bridge
	Isotonic strength	Concentric, eccentric, and plyometric contraction strength:
	Isokinetic strength	Angular velocity, total work, peak torque, average power

Effect of IRT on Isometric Core Muscle Strength

Six studies have explored the effect of the IRT program on isometric strength among 38 soccer players [15], 67 collegiate athletes [20], 26 mixed volleyball and soccer players [17], 12 collegiate athletes [21], 39 soccer players [16], and 32 rhythmic gymnasts respectively [22].

One article showed that significant difference between soccer players in leg raise (dynamic group: 145.5 ± 54.3 vs 168.6 ± 77.3, p<0.05; static group: 128.6 ± 56.1 vs 148.8 ± 63.5, p<0.05), plank (static group: 129.1 ± 48.9 vs 159.9 ± 44.6, p<0.05), and back isometric extension (dynamic group: 112.9 ± 33.5 vs 132.5 ± 42.1, p<0.05; static group: 124.1 ± 50 vs 160.1 ± 44.2, p<0.05) for pre-test and post-test of two experimental groups, and no significant difference between groups for leg raise [15].

Meanwhile, in another study, the research participants were also soccer players. In within-subject comparison to EG (CSTU) and CG (CSTS), the study result showed that it is significant differences in improved of trunk extensor MIF (CSTU: 591.4 ± 67.1 vs 614.0 ± 115.1, p<0.05) and (CSTS: 603.1 ± 98.8 vs 644.0 ± 92.6, p<0.05) after core training performed on an unstable and stable surface [16].

The result of the third study showed a statistically significant difference within-group for collegiate athletes' isometric core strength: side bridge (EG: 57.4 ± 8.4 vs 71.1 ± 6.5, p=0.00; CG: 60.4 ± 6.3 vs 67.8 ± 7.2, p=0.01), prone bridge (EG: 62.9 ± 7.2 vs 75.4 ± 5.8, p=0.02; CG: 60.6 ± 4.6 vs 66.3 ± 5.7, p=0.04) [20].

In another study, Indo-board functional balance training for volleyball and soccer players was implemented. In comparison to the pre-test, the results showed that the post-test prone Quadra-Ped core isometric strength significantly improved for Quadra-ped (right) score (EG: 9.2 vs 10.7, p>0.05; CG: 1.9 vs 2.6, p>0.05) and Quadra-ped (left) score (EG: 3.6 vs 9.3, p>0.05; CG: 2.6 vs 2.1, p>0.05) [17].

The result of the fifth study showed statistically significant difference within-group differences at posttest were noted for 12 collegiate athletes' isometric core strength of two experimental groups, plank (unstable static group: 59.0 ± 4.69 vs 64.0 ± 4.6, p<0.01; unstable dynamic group: 51.76 ± 4.43 vs 63.8 ± 4.04, p<0.01), standing stork (unstable static group: 3.89 ± 0.17 vs 6.55 ± 0.44, p<0.05) [21].

A study revealed that the functional core training with BOSU ball and balance disc vs traditional RG training sessions intervention did provide additional benefit to the specific isometric core strength of the Pelvic Tilt right and left test in 45 rhythmic gymnasts for the pre-test and post-test of the experimental and control group. The variables of Pelvic Tilt right (EG: 103.4 vs 138.6, p<0.001; CG: 97.3 vs 118.3, p=0.02), Pelvic Tilt left (EG: 95.5 vs 137.9, p<0.001; CG: 83.0 vs 114.6, p=0.01) were performed using the Pelvic Tilt Test [22].

Effect of IRT on Isotonic Core Muscle Strength

Similar to isometric core muscle strength, six studies have explored the effect of the IRT program on isometric strength among 10 Judo athletes [18], 38 soccer players [15], 67 collegiate athletes [20], 26 mixed volleyball and soccer players [17], 12 collegiate athletes [21], and 32 rhythmic gymnasts respectively [22].

The result of the first study showed statistically significant within-group differences for pre and post-test of the experimental group (no control group) were noted for the isotonic Lumbar extensors core muscles strength (134 ± 43.4 vs 195 ± 46.7, p<0.05, Effects size=1.2) which was conducted as previously study' [27] recommended [18].

One article showed a significant difference between soccer players in the sit-up test for isotonic abdomen muscle strength (dynamic group: 31.23 ± 6.25 vs 37.9 ± 4.3, p<0.05, static group: 28.43 ± 6.16 vs 31.2 ± 5.9, p<0.05) for pre and post-test of the two experimental groups, and also a significant difference between groups for sit-up test [15].

The result of the third study showed a statistically significant difference within-group for collegiate athletes' isotonic core strength: Biering-Sorenson (EG: 63.7 ± 7.9 vs 76.2 ± 5.3, p=0.01; CG: 65.9 ± 6.7 vs 72.8 ± 4.4, p=0.05), Double leg lowering (EG: 29.1 ± 8.5 vs 35.5 ± 6.8, p=0.01; CG: 27 ± 7.82 vs 31.2 ± 5.3, p=0.01) [20].

In another study, Indo-board functional balance training for volleyball and soccer players was implemented. In comparison to the pre-test, the results showed that the post-test participants' core isotonic strength significantly improved for Single-leg squat (right) (EG: 13.6 vs 24.6, p<0.05; except CG: 5.8 vs 7.7, p>0.05), Single-leg squat (left) (EG: 10.3 vs 24.9, p<0.05; except CG: 6.4 vs 6.7, p>0.05), One-Minute Sit-up(EG: 44.2 vs 47.1, p<0.05; CG: 45 vs 47.5, p<0.05) [17].

The result of the fifth study showed a statistically significant difference in participants' core isotonic strength for back extension (unstable static group: 67.00 ± 4.34 vs 77.80 ± 2.64, p<0.05; unstable dynamic group: 65.60 ± 2.16 vs 70.10 ± 1.94, p<0.05) and no statistically significant difference of participants' core isotonic strength for overhead medicine ball throw (unstable static group: 3.48 ± 0.36 vs 3.58 ± 0.26, p>0.05; unstable dynamic group: 3.53 ± 0.22 vs 3.50 ± 0.22, p>0.05), vertical jump (unstable static group: 33.4 ± 1.92 vs 32.7 ± 2.16, p>0.05; unstable dynamic group: 32.9 ± 1.36 vs 34.7 ± 1.35, p>0.05), 20 m sprint (unstable static group: 5.56 ± 0.48 vs 5.50 ± 0.30, p>0.05; unstable dynamic group: 5.51 ± 0.31 vs 5.59 ± 0.41, p>0.05), within-group differences at posttest were noted for 12 collegiate athletes' isometric core strength of two experimental groups [21].

A study revealed that the functional core training with BOSU ball and balance disc vs traditional RG training sessions intervention did provide additional benefit to the specific isotonic core strength of the Bent Knee Fall Out (BKFO) test and no statistically significant difference of Active Straight Leg Raise (ASLR) test in 45 rhythmic gymnasts for the pre-test and post-test of the experimental. The variables of ASLR right (EG: 7.5 vs 6.6, p=0.59; CG: 10.9 vs 9.0, p=0.30), ASLR left (EG: 6.9 vs 6.9, p=0.47; CG: 9.1 vs 9.7, p=0.33), BKFO right (EG: 10.4 vs 7.2, p<0.01; CG: 10.1 vs 9.5, p=0.64), BKFO left (EG: 11.6 vs 8.6, p<0.01; CG: 10.0 vs 9.5, p=0.69) [22].

Effect of IRT on Isokinetic Core Muscle Strength

There was only one study that examined the effect of core-specific sensorimotor exercises using unstable surfaces for isokinetic core muscle strength of 24 adolescent elite athletes (16±1 years) [19]. In this experimental study, three indicators were evaluated for trunk rotation test and trunk extension test: 1) Isokinetic concentric core strength, 2) Isokinetic eccentric core strength, and 3) Sudden trunk loading of core strength.

In this study, the analysis result showed that no significant difference within group of the experimental group and the control group for trunk rotation test and trunk extension test in the following variables. Trunk rotation test of isokinetic concentric core strength (RG: 69 vs 71, p>0.05; SMT: 64 vs 68, p>0.05; CG: 70 vs 66, p>0.05), isokinetic eccentric core strength (RG: 69 vs 72, p>0.05; SMT: 67 vs 67, p>0.05; CG: 68 vs 68, p>0.05), and sudden trunk loading of core strength (RG: 168 vs 164, p>0.05; SMT: 160 vs 155, p>0.05; CG: 144 vs 163, p>0.05). Trunk extension test of isokinetic concentric core strength (RG: 183 vs 177, p>0.05; SMT: 181 vs 173, p>0.05; CG: 208 vs 201, p>0.05), isokinetic eccentric core strength (RG: 253 vs 251, p>0.05; SMT: 217 vs 220, p>0.05; CG: 264 vs 250, p>0.05), and sudden trunk loading of core strength (RG: 315 vs 330, p>0.05; SMT: 276 vs 270, p>0.05; CG: 337 vs 329, p>0.05) [19].

Table 3. Participant, intervention and main outcome for the 8 studies

N	Study	Subjects	Intervention							Main outcome related to core muscle strength
			Type of athlete	Gender	Age	Type	Instability environment	Core muscle strength measured index	Frequency & duration	
1	(Norambuena et al., 2021)	10	Judo athletes	Mixed: 8 Female 2 Male	15.4±2.8 y	EG: Instability suspension training CG: No control group	1) Suspension trainer (TRX®, USA)	1) Sorensen muscle endurance test	5 times/ Week, 5 weeks	EG: Lumbar extensors muscles↑
2	(Sever & Zorba, 2018)	38	Soccer player	Unknown	EG (Static): 18.2±1.8 EG(Dynamic): 17.3±0.6 CG: 17.7±1.3	EG (Static): Core training EG (Dynamic): Core training on Swiss ball CG: Soccer training sessions	1) Swiss ball	2) Isometric type: leg raise, plank, back isometric extension test; 3) Isotonic type: sit-up and push-up test	3 times/ Week, 8 weeks	EG (Static): leg raise↔, back isometric extension↑, sit-up↑, push-up↑ EG (Dynamic): leg raise↑, back isometric extension↑, plank↑, sit-up↑, push-up↑
3	(Mueller et al., 2022)	24	Adolescent elite athlete	Mixed	16±1 y	EG (RT): Trunk strength exercises using strength training machines EG (SMT): Core-specific sensorimotor exercises using unstable surfaces CG: Ergometer based endurance training	1) Swiss ball 2) Sissel pillows	1) Trunk rotation test; 2) Trunk extension test	2 times/ Week, 6 weeks	EG (RT): isokinetic concentric↔, isokinetic eccentric↔, sudden trunk loading (STL) ↔ EG (SMT): isokinetic concentric↔, isokinetic eccentric↔, sudden trunk loading (STL) ↔
4	(Nuhmani, 2021)	67	Collegiate athlete	Mixed: 18 Female 49 Male	24.32±3.53 y	EG: Dynamic Swiss ball training CG: Floor exercises	1) Swiss ball	1) Biering-Sorenson trunk extension test 2) Side bridge test 3) Prone bridge test 4) Double leg lowering test	3 times/ Week, 6 weeks	EG: Biering-Sorenson↑, Side bridge↑, Prone bridge test↑, Double leg lowering↑ CG: Biering-Sorenson↔, Side bridge↑, Prone bridge test↑, Double leg lowering↑
5	(Oliver & Brezzo, 2009)	26	Mixed: Volleyball and Soccer player	Female	Volleyball: 19.9±1.8 y Soccer player: 18.5±0.5 y	EG: Indo board functional balance training for volleyball player CG: No intervention for soccer player	1) The Indo Board with Flow cushion	2) Single-Leg Squat test 3) Prone Quadra-Ped Core Test 4) One-Minute Sit-up Test:	4 times/ Week, Unknown weeks (entire season)	EG (Volleyball player): Single-leg squat (right)↑, Single-leg squat (left)↑, One-Minute Sit-up↑,Quadra-ped (right) ↔, Quadra-ped (right) ↔ CG (Soccer player): Single-leg squat (right) ↔, Single-leg squat (left) ↔, One-Minute Sit-up↑,Quadra-ped (right) ↔, Quadra-ped (right) ↔

Table 3 Continued

6	(Parkhouse & Ball, 2010)	12	Collegiate athlete	Mixed: 6 Female 6 Male	Male: 21.2±3.3 y Female: 20.6±1.7 y	EG: Static core training with stability ball EG: Dynamic core training with stability ball CG: No control group	1) Stability ball	1) 3 core tests (plank; double leg lowering; back extensions), 2) 1 static test (standing stork), 3) 3 dynamic tests (overhead medicine ball throw; vertical jump; 20 m sprint)	2 times/ Week, 6 weeks	EG (Static): Plank↑, Double leg lowering↑, Back extensions↑, Double leg lowering↑, Standing stork↑, Overhead medicine ball throw↔, Vertical jump↔, 20 m sprint↔ EG (Dynamic): Plank↑, Double leg lowering↑, Back extensions↑, Double leg lowering↑, Standing stork↔, Overhead medicine ball throw↔, Vertical jump↔, 20 m sprint↔
7	(Prieske et al., 2016)	39	Soccer player	Male	17±1 y	EG (CSTU): Core training performed on unstable surface CG (CSTS): Core training performed on stable surface	1) Airex ® Balance Pad 2) Togu © Power Ball 3) Thera-Band ® Stability Trainer	1) Maximal isometric force of the trunk flexors and extensors 2) Electrode placement for the assessment of muscle activity of m. rectus abdominis and m. erector spinae lumbalis	2-3 times/ Week, 9 weeks	EG (CSTU): Trunk extensor MIF↑ CG (CSTS): Trunk extensor MIF↑
8	(Cabrejas et al., 2022)	45	Rhythmic gymnast	Female	10.5±1.8 y	EG: Functional Core Training with BOSU ball and balance disc CG: Traditional RG training sessions	1) BOSU ball 2) Balance disc	1) Active Straight Leg Raise (ASLR) test 2) Bent Knee Fall Out (BKFO) Test 3) Pelvic Tilt Test	3 times/ Week, 8 weeks	EG: ASLR right and left↔, BKFO right and left↑, Pelvic Tilt right and left↑ CG: ASLR right and left↔, BKFO right and left↔, Pelvic Tilt right and left↑

Note: ↑ significant within-group improvement from pretest to post-test; ↔ non-significant within-group change from pretest to post-test; CG: control group; EG: experimental group.

4. Discussion

4.1. Effect of IRT on Isometric Core Muscle Strength

Five studies empirically showed that instability resistance (unstable surface) training separately or integrating other training interventions significantly improves young soccer players' leg raise, plank, and back isometric extension [15], and trunk extensor MIF [16], collegiate athletes' side bridge, prone bridge [20], volleyball and soccer players' Quadra-ped (right and left) score [17], collegiate athletes' plank, standing stork [21], rhythmic gymnasts' Pelvic Tilt right and left [22] for experimental and control groups. Only one study showed that core training performed on unstable and stable surfaces could not significantly improve young volleyball and soccer players' Quadra-ped (right and left) scores of Prone Quadra-Ped core isometric strength [17].

The reasonable explanation for the results in which IRT intervention could significantly improve the core isometric strength within-group and not significant difference for both EG and CG of the five studies are as follows [28]. The first reason may be that only a small portion of the training actions in the intervention used an unstable surface or environment and a small amount of unstable intervention resulted in no significant difference in isometric core muscle strength between the EG and CG groups [29-31]. In addition, there was no significant difference for both EG and CG for some indicators of evaluating isometric core muscle strength, such as leg raise and standing stork. The reason that may be to complete this leg raises and standing stork, the athlete not only needs the muscle strength of the core area but also the muscle strength of the upper or lower limbs to work together to complete it [32,33]. Therefore, the influence of muscle strength in other parts of the athlete's body is an undeniable factor that leads to this result. Moreover, the reasonable explanation for the results which Indo board functional balance training could not significantly improve the mixed volleyball and soccer players' Quadra-ped (right and left) score of core isometric strength within-group for both EG and CG of the only one study may be that the training cycle of 4 weeks is relatively short [34,35].

4.2. Effect of IRT on Isotonic Core Muscle Strength

Three studies empirically showed that instability resistance (unstable surface) training separately or integrating other training interventions could significantly improve Judo athletes' isotonic Lumbar extensors core muscle strength [18], volleyball and soccer players' Single-leg squat (right and left) [17], rhythmic gymnasts' Bent Knee Fall Out (BKFO) [22] for experimental group and no significant improvement for control group. Three studies empirically showed that instability resistance (unstable surface) training separately or integrating other training interventions could significantly improve young soccer players' isotonic core muscle strength of sit-up test [15], collegiate athletes' Biering-Sorenson [20], collegiate athletes' back extension [21] for both experimental and control groups. Only two studies showed that core training performed on unstable and stable surfaces could not significantly improve young collegiate athletes' core isotonic strength of vertical jump, overhead medicine ball throw, and 20 m sprint [21], rhythmic gymnasts' Active Straight Leg Raise (ASLR) [22].

The reasonable explanation for IRT's significant improvement for the experimental group is that IRT has had a better exercise effect than traditional resistance training for core isotonic strength of Judo athletes, volleyball, and soccer players [36,38]. About IRT could significantly improve young soccer players' isotonic core muscle strength in sit-up tests, collegiate athletes' Biering-Sorenson, and back extension for both experimental and control groups [39, 40]. The reason may be that only a small portion of the training actions in the intervention for unstable surfaces or environments and this low intensity of unstable intervention resulted in significant differences in isotonic core muscle strength in both the EG and CG groups. In addition, there was no significant difference for both EG and CG for some indicators of evaluating isotonic core muscle strength, such as vertical jump, overhead medicine ball throw, 20m sprint, and Active Straight Leg Raise (ASLR) [37,41]. The reason is that to complete vertical jump, overhead medicine ball throw, 20m sprint, and Active Straight Leg Raise (ASLR), the athlete not only needs the muscle strength of the core area to perform contraction work but also the muscle strength of the upper or lower limbs to perform contraction work (For example, the biceps brachii, triceps brachii, quadriceps femoris muscle and gluteus maximus) even working together to complete the action above [42].

4.3. Effect of IRT on Isokinetic Core Muscle Strength

Only the article examined that core-specific sensorimotor exercises using unstable surfaces could help 24 adolescent elite athletes (16±1 years) improve their isokinetic core muscle strength. This study examined that using core-specific sensorimotor exercises intervention did not increase significant difference for any Trunk rotation test and Trunk extension test of isokinetic concentric core strength, isokinetic eccentric core strength, and sudden trunk loading of isokinetic core strength [19].

Perhaps the main reason for this result is that young athletes of different genders. In addition, this study did not analyze the basic level of athletes, which may have an impact on the covariates of the experimental results [43]. Therefore, it can be said that covariance variance mathematical statistical analysis should be conducted on athletes at different baseline levels to eliminate the influence of covariates on the experimental results.

5. Limitations

This review provided evidence and materials to examine the effect of IRT on core muscle strength among Judo athletes, adolescent elite athletes, volleyball players, soccer players, collegiate athletes, and rhythmic gymnasts. There are still some limitations as follows:

1) Lack of participants in isokinetic core muscle strength for existing literature.
2) The existing studies focus on the unstable surface of the environment or IRT mostly using Swiss and BOSU balls. Therefore, future studies should develop other unstable training environments, such as water, snow, sand surfaces, elastic bands, and suspension instability methods and environments.
3) In the existing articles, most of the unstable training interventions are combined with other training methods, and there are not many pure single IRT intervention methods in the literature. Future studies should develop other single IRT interventions for athletes in different events.

6. Conclusions

This systematic review of IRT on core muscle strength among athletes provided evidence and materials that unstable surface training could improve some sports performance of Judo athletes, adolescent elite athletes, volleyball players, soccer players, collegiate athletes, and rhythmic gymnasts. IRT refers to a training method that conducts resistance training under constructed unstable support conditions, which is closer to specialized exercises and increases core muscle strength significantly. Therefore, this review suggests that IRT should be considered in athletes' daily training routines for core muscle strength.

Author Contributions

Jianxin Gao: Conceptualization, Methodology, Software, Writing-Reviewing and Editing; Borhannudin Bin Abdullah and Roxana Dev Omar Dev: Validation, Formal analysis, Supervision, Data Curation.

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