Effect of Instability Resistance Training on Sports Performance Among Athletes: A Systematic Review

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Abstract

The aim of this investigation is to systematically review the impact of instability resistance training (IRT) on sports performance, providing both theoretical and practical insights for athletes in routine training. Adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, databases such as Web of Science, EBSCOhost (SPORTDiscus), PubMed, and Scopus were employed for the comprehensive collection of original references. A total of 402 articles were gathered, with only 17 meeting the specified analytical criteria. The quality of each article was assessed using the PEDro scale, resulting in scores ranging from 2 to 6 across the 17 articles. IRT exhibited significant efficacy in enhancing sports and athletic performance across disciplines such as Judo, cricket, weightlifting, rifle shooting, sprinting, handball, soccer, and basketball, with the exception of 25 male elite golf players. Theoretically, this study posits that IRT, rooted in functional training, represents an advancement in activating core muscles, fostering coordination between agonistic and antagonistic muscles, and enhancing muscle proprioception – pivotal physiological foundations for augmenting exercise performance. Moreover, by emphasizing the integration of training actions and the role of the "power chain," IRT, adopting an unstable format akin to specialized exercises or increasing difficulty, aims to enhance training efficiency. Empirical evidence demonstrates that continuous IRT positively influences sports performance, with moderate IRT identified as a secure and effective stimulation method. Consequently, this review advocates for the incorporation of IRT into athletes' daily training routines to optimize sports performance.

Keywords: Instability Resistance Training, Unstable Surface, BOSU and Swiss Balls, Sports Performance, Athletes

Introduction

Recently, functional training has garnered significant attention in sports injury prevention, rehabilitation, fitness, and competitive sports. Scholars emphasize that core strength training serves as a crucial component and manifestation of functional training (Han & Wang, 2019). Currently, core strength training has captured the attention of sports professionals and researchers. Conventional resistance training predominantly emphasizes the isolated development of prominent muscle groups, overlooking the cultivation of intrinsic small muscle groups and comprehensive strength within the power chain. This limitation poses challenges in meeting contemporary training and competition requirements. In contrast, core strength training not only capitalizes on its inherent advantages but also addresses the drawbacks of singular functionality, thereby establishing a basis for the effective functioning of the power chain. The crux of this lies in the introduction of "unstable factors," denoting the execution of resistance training under unstable conditions (Xu & Zhen, 2020). Research substantiates the substantial impact of core strength training on stabilizing the spine and pelvis, enhancing control and balance, optimizing technical movement economy and effectiveness, and mitigating sports injuries. Nevertheless, a comprehensive systematic review on the efficacy of Instability IRT for professional athletes in terms of sports performance is currently lacking.

Conventional resistance training, centred on strengthening large muscle groups in a stable environment, lacks efficacy in targeting deep and smaller muscles. This limitation impedes the development of core stability and overall power

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chain strength, rendering it inadequate for contemporary sports training requirements (Borghuis, Hof, & Lemmink, 2008). Hence, there is an emphasis on core muscle training (Cuğ et al., 2012). Core muscle training assumes a vital role in functional training, compensating for deficiencies in traditional single-function strength training methods. Its broad application spans various domains, including training and rehabilitation (Behm & Colado, 2012). Furthermore, the core of functional training lies in introducing "unstable factors and surfaces," which enhances spinal and pelvic stability, refines technical movement stability, and augments posture control and balance capabilities (Borreani et al., 2014; Youdas et al., 2020).

IRT involves inducing instability by modifying the support surface stability, introducing asymmetrical movement, and subjecting the body to unexpected external forces, resulting in internal or external force imbalances (Behm et al., 2010). Professional equipment, including Wobble Boards, Swiss balls, BOSU balls, suspended chains, foam rollers, and bands, can be utilized to construct unstable surfaces, platforms, and environments. Furthermore, unstable training conditions can be created using materials such as snow, water, sand, and gravel (Colado et al., 2020). In summary, diverse materials can be employed to construct instability support platforms, constituting a training method recognized as IRT. This approach effectively enhances core muscle strength and stabilizes body posture, specifically addressing balance ability (Borreani et al., 2014; Xu & Zhen, 2020). Research has substantiated that IRT demonstrates noteworthy impacts in stabilizing the spine and pelvis, refining control and balance, enhancing the efficiency and effectiveness of technical movements, and averting sports injuries (Behm et al., 2011; Slijper & Latash, 2000).

IRT primarily comprises two components: stability training and resistance training. Throughout the training regimen, participants are required to execute predetermined or varied resistance load/exercise tasks, concurrently managing the challenge of posture stability and balance disruption. Muscle hypertrophy and neural adaptation, pertaining to the coordination between nerves and muscles, emerge as pivotal determinants influencing strength and explosive growth (Willardson, 2004). To enhance motor performance via IRT, focus should be directed towards training in muscle functional performance, posture stability, and balance ability mechanisms.

IRT is commonly employed for exercise rehabilitation and physical fitness improvement, primarily by creating unstable conditions utilizing specific instruments. Despite athletes achieving high-strength resistance training in traditional strength training, the acquired capability is challenging to fully exploit during actual exercise due to the destabilizing nature of the activities. Insufficient core strength increases the risk of disrupting the motion chain in unstable situations, inducing compensatory movements in limb muscles under heightened pressure, consequently elevating the risk of injury (Wang et al., 2021). Hence, enhancing adaptability to unstable conditions and trunk stability through IRT methods may prove advantageous for augmenting motor performance.

The majority of studies have underscored the efficacy of IRT in enhancing the sports performance of athletes (Xu & Zhen, 2020). Nevertheless, given the relatively brief history of this approach, there is a need for a systematic examination of its structural function, theoretical underpinnings, and practical applications. A comprehensive systematic review evaluating the effectiveness of different intensities of IRT is currently lacking. Consequently, this study aims to conduct a systematic review of existing literature pertaining to the influence of IRT on the sports performance of professional athletes.

Methods and Materials

The Registration on INPLASY

This study employed the methodology recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to systematically search, screen, and analyse pertinent data within the selected articles. Furthermore, following registration on the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY), the study was assigned the registration number INPLASY2023100048, with a corresponding DOI number of 10.37766/inplasy2023.10.0048, accessible on the platform's website: https://inplasy.com/ (Moher et al., 2009).

Databases and keywords

To acquire relevant literature, this study utilized databases including Web of Science, EBSCOhost (SPORTDiscus), PubMed, Scopus, Google Scholar, and References spanning the period from 2010 to 2023. In each database, keywords were employed to conduct a comprehensive search across all fields. The keywords in this study were: ("Instability resistance or Unstable Surface Training" OR "Unstable Surface Training" OR "Instability Training" OR "Instability Resistance or Unstable Surface Exercise" OR "Instability Exercise" OR "Unstable Surface Exercise" OR "Unstable Training" OR "Unstable Exercise") AND ("Athletic Performance" OR "Performance" OR "Sports Performance").

Eligibility criteria

This study employed the PICOS model, encompassing five components: population, intervention, comparison, outcome, and study design. The inclusion criteria for each component were as follows: 1) The population comprised healthy professional athletes, excluding students and non-professional (amateur) athletes, without differentiation based on age or gender. 2) The intervention involved instability resistance or unstable surface training lasting at least 4 weeks, with each program, cycle, and action incorporating instability intervention and environment in the experimental group. 3) Study designs encompassed single-group trials, two groups, three groups, four groups, or multiple-group trials. 4) Outcomes were required to evaluate the impact of instability resistance or unstable surface training on at least one or more aspects of sports performance among athletes or players. 5) Eligible study designs included single-group trials or randomized controlled trials, as detailed in Table 1.

Table 1

Inclusion and Eligibility Criteria

PICOS	Detailed Information of inclusion and eligibility criteria
Population	Healthy athletes or players, must be professional athletes, not include student and non-professional (amateur) athletes, not distinguishing between age and gender
Intervention	Instability resistance or unstable surface training (not less than 4 weeks), furthermore, each training programs, cycle and action must include instability intervention and environment in experimental group
Comparison	Single-group trials, two groups, three groups and four groups or multiple-group trials
Outcome	Outcome must comprise the impact of instability resistance or unstable surface training on at least one or more whole sports performance among athletes or players
Study Design	Single-group trials or randomized controlled trials

Study Search, Screening and Selection Processes

Initially, the Zotero 6.0 citation management system was employed to eliminate duplicate articles. Subsequently, a two-stage screening process was implemented. In the first stage, the author conducted an initial screening of literature based on title and abstract, followed by a second round of screening on the articles selected in the first round, this time considering the full text. Thirdly, the literature meeting the predetermined criteria underwent evaluation to ascertain its final reliability. Lastly, during the seminar, all authors collectively reached a consensus on the literature to be included in the systematic review.

Data Extraction and PEDro scale assessment

Following a thorough examination of the entire literature, the author encapsulated the pertinent information using standardized templates. This included: 1. Article number, 2. Author name and year of publication, 3. Population, 4. Type of Athlete, 5. Gender, age, and type, 6. Instance environment, 7. Sports performance measured index, 8. Frequency & duration, 9. Main outputs related to sports performance. Additionally, the study employed the PEDro scale (Verhagen et al., 1998) whose reliability has been substantiated in the construction of systematic reviews. The PEDro scale, developed by Verhagen and colleagues for epidemiological purposes, comprises 11 items designed to assess methodological quality. Each item is scored as 0 or 1, with 1 denoting "yes" and 0 indicating "no." A higher score for a given literature implies superior methodological quality (Luo et al., 2022; Xiao et al., 2021).

Results

Article Selection

The article identification, screening, and inclusion process are depicted in Figure 1. Initially, a total of 402 articles were identified through database searching. Following the initial removal of duplicate articles, 331 records remained. The Zotero 6.0 citation management system further refined this to 331 articles in the first screening. In the second phase, 3 articles not in English/Chinese, 0 articles from unpublished journals, 12 articles consisting of conference papers, books, chapters, magazines, and 10 articles lacking full-text were excluded. The subsequent screening phase assessed 306 articles for eligibility, resulting in the exclusion of 119 articles not relevant to training/intervention or randomized controlled trials (RCT), 69 articles with participants not meeting the criteria for health, students, or amateur athletes, 52 articles lacking instability or unstable surface intervention, and 49 articles not focused on performance outcomes. Ultimately, 17 relevant articles meeting the selection criteria were included for quantitative synthesis, as illustrated in Figure 1.

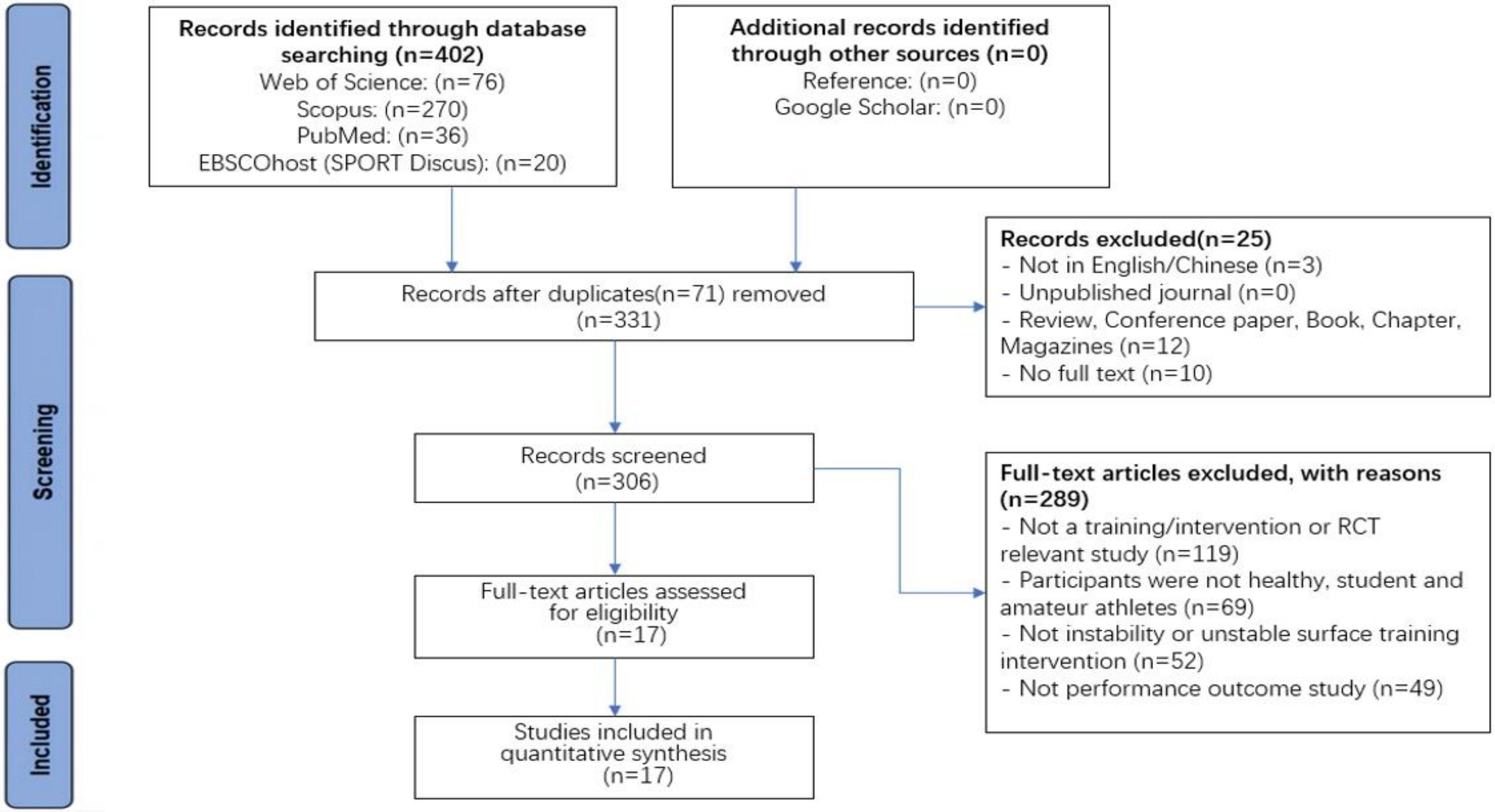

Figure 1. The identification, screening and included processes for articles based on PRISMA

Study Quality Assessment

Table 2 presents the comprehensive scores on the PEDro scale for the 17 articles included in this study, with all studies scoring between 2 and 6. Within the 11 items of the scale, deduction of points was consistently observed across studies for items such as intention-to-treat analysis, blinding of participants, concealed allocation of assessors and therapists. Conversely, points were consistently increased across studies for items including random allocation, eligibility criteria, baseline comparability, follow-up, and point measure and variability. Given the specialized nature of unstable training and the inherent sports injury risks associated with athletes across various sports events, obtaining high scores on evaluation-based items such as blinding of participants, assessors, and therapists proved challenging across the 17 articles. Refer to Table 2 for details.

Table 2

Summary of PEDro scale assessment scores

N	Study	Eligibility Criteria	Random Allocation	Allocation Concealment	Baseline Comparability	Blind Participants	Blind Therapist	Blind Assessor	Follow-Up	Intention to Treat Analysis	Group Comparison	Point Measure and Variability	Total PEDro Score
1	(Norambuena et al., 2021)	0	0	0	0	0	0	0	1	0	0	1	2
2	(Sanghvi, Dabholkar, & Yardi, 2014)	0	1	0	1	0	0	0	1	0	1	1	5
3	(Kang et al., 2013)	0	0	0	1	0	0	0	1	0	1	1	4
4	(Makhlouf et al., 2018)	1	1	0	1	0	0	0	1	0	1	1	6
5	(García Sillero et al., 2022)	1	1	0	1	0	0	0	1	0	1	1	6
6	(Hung et al., 2021)	1	0	0	0	0	0	0	1	0	0	1	3
7	(Negra et al., 2017)	0	1	0	1	0	0	0	1	0	1	1	5
8	(Romero-Franco et al., 2012)	0	1	0	0	0	0	0	1	0	1	1	4
9	(Hammami et al., 2022)	0	1	0	1	0	0	0	1	0	1	1	5
10	(Hammami et al., 2023)	1	0	0	1	0	0	0	1	0	1	1	5
11	(Prieske et al., 2016)	1	1	0	1	0	0	0	1	0	1	1	6
12	(Zemková & Hamar, 2010)	0	0	0	1	0	0	0	1	0	1	1	4
13	(Hammami et al., 2020)	0	0	0	1	0	0	0	1	0	1	1	4
14	(Gidu et al., 2022)	1	0	0	1	0	0	0	1	0	1	1	5
15	(Gaamouri et al., 2023)	1	1	0	1	0	0	0	1	0	1	1	6
16	(Sanchez-Sanchez et al., 2022)	1	1	0	1	0	0	0	1	0	1	1	6
17	(Granacher et al., 2015)	1	1	0	1	0	0	0	1	0	1	1	6

Participant Characteristics

In Table 3, the characteristics of participants, intervention, and outcomes for the 17 studies are detailed as follows. 1) Categorized by athletes, six articles focused on soccer players (Gidu et al., 2022; Granacher et al., 2015; Makhlouf et al., 2018; Negra et al., 2017; Prieske et al., 2016; Sanchez-Sanchez et al., 2022); 3 articles on handball players (Gaamouri et al., 2023; Hammami et al., 2020; Hammami et al., 2022); 2 articles on weightlifters (Hammami et al., 2023; Kang et al., 2013); one article on judo athletes (Norambuena et al., 2021); one article on cricketers (Sanghvi et al., 2014); one article on golf player (García Sillero et al., 2022); one article on rifle shooter (Hung et al., 2021); one article on sprinters (Romero-Franco et al., 2012); one article on basketball players (Zemková & Hamar, 2010). 2) Participant, gender, and age. The total athletic number of subjects was 613 (529 males, 76 females, and 8 no reported gender). The majority of studies provided information on the mean or standard deviation of participants' ages, with only 24 participants among the total of 613 not having reported their average age (Sanghvi et al., 2014). The participants' age range spanned from a minimum of 10 to a maximum of 25 years, as indicated in Table 3.

Table 3

Participant, intervention and main outcome for the 17 studies

N	Study	Participant	Intervention							Main outcome related to sports performance
			Type Of athlete	Gender	Age	Type	Instability environment	Sports performance Measured index	Frequency & duration	
1	(Norambuena et al., 2021)	10	Judo athletes	Mixed: 8 F, 2 M	15.4 ± 2.8 y	EG: Instability Suspension training CG: No control group	Suspension trainer, TRX®, USA	1) Single-leg horizontal jumping, 2) Sorensen test, 3) Sit-and-reach, 4) Y balance, 5) Prone instability and Handgrip strength tests	5 times/ Week, 5 weeks	Single-leg horizontal jumping↑, Sorensen test↑, Sit-and-reach↑, Y balance↑
2	(Sanghvi et al., 2014)	24	Cricketer	Male	18-25y Average age: Un-known	EG: Instability core training CG: Stable core muscle training	Swiss ball / Stability trainers	1) **Abdominis muscle** 2) **Functional performance tests.** a) Standing Stork Test; b) Speed-Single Sprint Test; c) Run Three 505 Agility Test; d) Vertical Jump Height Test	Unknown times/ Week, 6 weeks	1) Abdominis muscle at rest↑,on contraction↑ 2) Functional performance tests. a) Standing Stork Test↔, b) Speed-Single Sprint Test (17.7m) ↔, c) Speed-Agility: Run Three 505 Agility Test ↔, d) Vertical Jump Height Test↔
3	(Kang et al., 2013)	32	Weight lifter	Male	MS: 14y HS: 17y	EG 1 (MS): Instability Balance training program EG 2 (HS): Instability Balance training program CG 1 (MS): No training CG 2 (HS): No training	Swiss ball	1)Sit-ups, 2) Push-ups, 3) Handgrip power, 4) Vertical jump, 5) Side step, 6) Body reaction time, 7) One-leg standing time with closed eyes, 8) Flexibility in the sagittal plane, 9) Sit and reach, 10) Back hyperextension in the prone position	Unknown times/ Week, 8 weeks	One-leg standing time with eyes closed↑ Back hyperextension↑, Left arm external rotation↑, Push-ups↑
4	(Makhlouf et al., 2018)	57	Soccer player	Male	BTP:11.06±0.75y ATP:11.29±0.85y CG:10.98±0.80y	EG 1 (BPT): Instability balance training program EG 2 (APT): Stable agility-plyometric training CG: Regular soccer training	1)Swiss ball, 2) An inflated disk, 3) A foam surface progressing to a BOSU ball or inflated disk, 4) Elastic band straps	1) **Strength, power:** Hand grip strength, MVIC back extensor, MVIC knee extensor, CMJ, RSI, Triple hop. 2)**Agility:** ICODT, ICODT with and without ball, Agility 4*9m. 3) **Speed:** 10 m sprint, 30 m sprint. 4)**Balance:** Standing Stork Test, YBT CS.	2 times/ Week, 8 weeks	CMJ↑, Hand grip MVIC (maximum voluntary isometric contraction)↑, ICODT (Illinois change of direction test) without ball↑, Agility (4 m*9 m) ↑, Standing stork balance↑, Y-balance↑, 10 and 30-m sprint↑
5	(García Sillero et al., 2022)	25	Golf athletes	Male	19.20 ± 1.77 y	EG: Unstable surface Training CG: Stable surface training	Elastic bands, BOSU or stability ball	1) CHS: club head speed 2) CARRY: carry distance	4 times/ Week, 8 weeks	CHS: club head speed ↔ CARRY: carry distance ↔
6	(Hung et al., 2021)	8	Rifle shooter	Un-known	20.63 ± 1.3 y	EG: Complex functional strength training (vibration and unstable surface) CG: No control group	BOSU trainer, USA	1)Shooting score, 2) Total time, 3) Dev Total 10-50ms, 4) Dev X 10-50ms, 5) Dev Y 10-50ms	Unknown times/ Week, 6 weeks	Shooting score↑, Total time↓, Dev Total 10-40ms↓, Dev Total 50ms↔, Dev X 10-50ms↔, Dev Y 10-50ms↓
7	(Negra et al., 2017)	37	Soccer player	Male	PTS: 12.1 ± 0.5 y PTC: 12.2 ± 0.6 y	EG: Unstable performed combined plyometric training (PTC) CG: Stable performed plyometric training (PTS)	Airex balance pad / Thera-Band stability trainer	1) **Muscle power**: CMJ, SLJ, 2) **Muscle strength**: RSI, 3) **Speed**: 20-m, 4) **Agility**: MICODT, 5) **Static balance**: SSBT, 6) **Dynamic balance**: USBT	3-5 times/ Week, 8 weeks	USBT ↑ of the PTC group
8	(Romero-Franco et al., 2012)	33	Sprinters athletes	Male	21.82 ± 4.84 y	EG: Proprioceptive training program on BOSU and Swiss ball CG: A shorter duration training program	BOSU and Swiss ball	1)Stability Test with Eyes Open and Closed 2)Postural Stability, 3)Gravity Center Control	3 times/ Week, 6 weeks	XEO↑, Position of the gravity center in the posterior direction (Back) ↑, Position of the gravity center in the right direction ↑

9	(Hammami et al., 2022)	42	Handball player	Male	EG: 16.4 ± 0.4 y CG: 16.2 ± 0.4 y	EG(JSTG): Sand surface supplemental jump and sprint training CG: Standard in-season regimen	On sand	1)**Jumps** (squat, counter-movement, and 5 jump tests), 2) **Sprint times** (5 m, 10 m and 20 m), 3)**Agility** (modified T and modified Illinois tests), 4) **Repeated sprint T-test**, 5) **Balance** (standing stork and Y balance tests)	3 times/ Week, 7 weeks	Sprint times over all distances↓, T-Half and Illinois-tests ↓, Jumping squat↓, Counter-movement jumping↓, 5-jump test↔ Repeated sprint scores (BT, MT and TT) ↑, The decrement (DEC) ↔, Y balance test for the right leg and left leg↑, Stork balance (right leg) ↑
10	(Hammami et al., 2023)	32	Weight lifter	Male	10.94 ± 0.47 y	EG (IRT1): Instability resistance training, 2 sets x 8, 20% (1RM) EG (IRT2): Instability resistance training, 2 sets x 4, 40% 1RM	1)Balance beam and balance Pad 2)Stability Trainer, Togu Aero Step	1)1RM; 2) SLH dominant and non-dominant; 3)3 H; 4) CoP SA, 5) Lateral displacement of the center of pressure oscillation; 6) CoP Y; 7) CoP V	5 times/ Week, 8 weeks	Within group: all the assessed variables↑, lower inter-limb asymmetry ↔; Between group: squat 1RM↑, SLH ↑, 3H↑, CoP SA↑
11	(Prieske et al., 2016)	39	Soccer player CSTU 19 CSTS 20	Male	CSTU: 16.6 ± 1.0y CSTS: 16.6 ± 1.1y	EG (CSTU): Untable core training CG (CSTS): Stable core training	1)Balance Pad, AG, Sins, Switzerland, Airex® 2)Stability Trainer, Germany, Thera-band® 3)Swiss ball, Germany, Togu®	1)**Trunk muscle strength/activity:** Trunk flexor and extensor, 2) **Athletic performance:** CMJ, 0–10-m time, 10–20-m time, 0–20-m time, T test, Kicking performance	2-3 times/ Week, 9 weeks	Trunk extensor ↑, 10–20-m sprint time↑, Kicking performance↑
12	(Zemková & Hamar, 2010)	34	Basketball player	Female	EG: 20.9± 2.4 y CG: 21.2 ± 2.8 y	EG: Combined agility-balance wobble boards training CG: Combined agility-balance stable training	Wobble boards	1) Eyes open and closed Bipedal stance, 2) multi-choice reaction and agility task, 3) Step initiation, 4)50% of 1max jump height, 5) Drop jump from the height of 45 cm, 6) Countermovement and squat jumps, 7)10-s jumping test	4-5 times/ Week, 6 weeks	Bipedal stance on wobble board with eyes open and closed↓, Simple and Multi-choice agility task↓, Step initiation↑, Estimation of 50% of 1max jump height↓, Drop jump from the height of 45 cm↓
13	(Hammami et al., 2020)	31	Handball player PS:11, P:10 C:10	Male	PS: 16.2 ± 0.6, P: 16.4 ± 0.5 C: 16.5 ± 0.4	EG:(PS) plyometrics training on sand surface; EG:(P) Standard plyometrics training on a stable surface; CG: (C) A standard in season regimen	On sand surface	1)**Sprint:** 5 m, 10 m, 20 m, 2) **Change of direction:** T-Half, Illinois-MT, 3) **Jump tests:** SJ, CMJ, 5JT, 4) **Repeated sprint T-test:** Best, Mean, Fatigue and Total, 5) **Y Balance Test:** 6) **Stork Balance Test**	6-7 times/ Week, 7 weeks	Sprint speed: PS: ↑, P: ↔, C: ↔ Change of direction scores: PS: ↑, P: ↔, C: ↔ Repeated sprint T-test: PS: ↑, P: ↑, C: ↔ Y Balance Test: PS: ↑, P: ↔, C: ↔ Stork Balance Test: PS: ↑, P: ↑, C: ↔
14	(Gidu et al., 2022)	96	Soccer player	Male	EG: 14.2 ± 0.4 y CG: 14.0 ± 0.0 y	EG: Proprioceptive training (PT) on Bosu ball CG: No training	Balance trainer/ Bosu ball	1) Balance performances, 2) Jump performances, 3) Agility and dribbling performances	4 times/ Week, 8 weeks	Single-leg forward jump with the right leg↑, Agility right and left side test↑, Short dribbling test↑
15	(Gaamouri et al., 2023)	34	Handball players	Female	15.8 ± 0.2 y	EG: Strength training program use Elastic band CG: Performed regular handball training	Elastic band, USA	1)Change of direction, 2) Jump, 3) Repeated sprint ability, 4)1RM, 5) Upper/Lower limb	2 times/ Week, 10 weeks	COD performance↑, Squat and countermovement jump↑, Best, mean, and total RSA scores↑, 1RM bench press ↑, Half squat ↑, Upper limb force-velocity performance ↑
16	(Sanchez-Sanchez et al., 2022)	55	soccer players	Male	uRT: 18.0±0.4 y sRT: 17.9±0.6 y	EG: An unstable resistance training (uRT) CG: stable resistance training group (sRT)	BOSU ball (which diameter is 68cm and high is 25cm)	1)**Hop tests:** Hop D and non-D, 2) **Repeated sprint ability:** RSA, Illinois changes of direction speed test (COD), 3) **YoYo Intermittent Recovery Test**	2 times/ Week, 10 weeks	Hop non-D↑, RSA best and mean↑
17	(Granacher et al., 2015)	24	soccer players	Male	15 ± 1 y	EG: Unstable plyometric training (IPT) CG: Stable plyometric training (SPT)	1)Balance beam, pad, Airex® 2)Stability trainer, Thera-Band® 3)Togu® Aero Step	1)**Jump:** CMJ height, DJ height, DJ performance index, MB5 distance, 2)**Sprint:** 0–10 m, 10–20 m, 20–30 m, 0–30 m, 3)**Agility:** Figure-8 run time,4) **Balance:** CoP_{tot}, ml oscillations, ap oscillations	2 times/ Week, 8 weeks	CMJ height ↑, DJ height↑, DJ performance↑, 0-10-m sprint time↑, agility and balance↑. Group *Time interaction for CMJ height↑ of the SPT group.

The Type of Unstable Intervention

Table 3 delineates the heterogeneous nature of interventions characterized by instability, encompassing details on intervention types, durations, and frequencies across the 17 studies. Within this context, certain investigations specifically allude to instability suspension training as a distinct modality (Norambuena et al., 2021), core muscle training with instability on an unsteady surface is under consideration (Prieske et al., 2016; Sanghvi et al., 2014); instability balance training program (Kang et al., 2013; Makhlouf et al., 2018); complex functional strength training with body vibration on unstable surface training (Hung et al., 2021); unstable surface training (García Sillero et al., 2022); performed combined plyometric training on include sand surface (Hammami et al., 2020; Negra et al., 2017); proprioceptive training program on BOSU and Swiss ball (Gidu et al., 2022; Romero-Franco et al., 2012); supplemental short jump and sprint training on sand surface (Hammami et al., 2022), instability resistance or unstable surface training programs (Hammami et al., 2023; Sanchez-Sanchez et al., 2022); combined agility and balance training on wobble boards (Zemková & Hamar, 2010); elastic band strength training or unstable surface for upper and lower body (Gaamouri et al., 2023); plyometric training on highly unstable surfaces (Granacher et al., 2015). Moreover, given the absence of a control group within the studies, three articles exclusively examined the impact of instability resistance or training on an unstable surface on the athletic performance of participants (Hammami et al., 2023; Hung et al., 2021; Norambuena et al., 2021). The remaining studies contrasted IRT with conventional stable training modalities, such as normal and routine seasonal training. Notably, all interventions shared a common characteristic, utilizing an unstable surface or instability resistance during training. Various tools, including Suspension trainers, Swiss balls, Stability trainers, BOSU balls, Inflated disks, Elastic band straps, Balance pads, Balance beams, Sand surfaces, Foam surfaces, Wobble boards, and similar equipment, were employed in these interventions.

Regarding the duration of the 17 studies, the timeframe ranged from 5 to 10 weeks. Notably, within this set, seven studies maintained a duration of 8 weeks (García Sillero et al., 2022; Gidu et al., 2022; Granacher et al., 2015; Hammami et al., 2023; Kang et al., 2013; Makhlouf et al., 2018; Negra et al., 2017); 4 studies lasted for 6 weeks (Hung et al., 2021; Romero-Franco et al., 2012; Sanghvi et al., 2014; Zemková & Hamar, 2010); 2 studies' duration time lasted 10 weeks (Gaamouri et al., 2023; Sanchez-Sanchez et al., 2022); 2 studies lasted 7 weeks (Hammami et al., 2020; Hammami et al., 2022); and the remaining studies' duration time lasted 5 weeks and 9 weeks (Prieske et al., 2016).

Regarding frequency, only 3 studies did not give the instability resistance or unstable surface training frequency, (García Sillero et al., 2022; Kang et al., 2013). The remaining 14 studies' frequency times was 2 to 7 per week (Hammami et al., 2022; Hammami et al., 2023; Hung et al., 2021; Makhlouf et al., 2018; Negra et al., 2017; Norambuena et al., 2021; Prieske et al., 2016; Romero-Franco et al., 2012; Zemková & Hamar, 2010), (Gaamouri et al., 2023; Gidu et al., 2022; Granacher et al., 2015; Hammami et al., 2020; Sanchez-Sanchez et al., 2022).

Outcome

Table 4 illustrates the categorization of sports events. Drawing upon the established "event group theory" in sports training, which classifies sports events into four overarching categories, the first pertains to physical ability leading, while the remaining three encompass skill-leading categories. These skill-leading categories include skill and psychological ability leading, as well as skill and tactical ability leading general categories. Within the category of physical ability leading in sports events, three subcategories exist: (1) Fast strength sports, encompassing activities like short jumping, short throwing, and weightlifting; (2) Speed sports, which involve short-distance running, swimming, speed skating, and cycling; (3) Endurance sports, including medium/super long-distance running, race walking, skating, swimming, cross-country skiing, road cycling, boating, and canoeing. The skill-leading general category encompasses Aesthetic sports, featuring representative events such as rhythmic gymnastics, diving, figure swimming, figure skating, martial arts routines, freestyle skiing, dance, and gymnastics. The skill and psychological ability leading general category includes Accuracy sports, with representative events like Crossbow archery, golf, and shooting. Furthermore, the skill and tactical ability leading general category consist of four subcategories: (1) Net/Court sports, including table tennis, badminton, tennis, and volleyball; (2) Invasion sports, comprising soccer, basketball, water polo, football, ice hockey, hockey handball, etc.; (3) Combat sports, featuring boxing, fencing, Judo, Muay Thai, martial arts, karate, etc.; and (4) Attack and defence alternate sports, with representative events like baseball, softball, and cricket (Metzger & Benzaken, 2006; Mitchell, Haskell, & Raven, 1994; Shultana, Moharram, & Neehal, 2020; Tian, 2006). Hence, this investigation systematically compiled and examined the outcomes of 17 studies, aligning with the general category and subcategories of sports events delineated earlier, as presented in Table 4.

Table 4

The General and Subcategories of Sports and Main Representative Sports Events

General Category	Subcategories	Main Representative Sports Events
Physical ability leading	Fast strength event	Short jumping, short throwing and weightlifting
	Speed event	Short distance running (include 100m, 200m, 400m); Short distance swimming (include 50m, 100m); Speed skating (include 500m); Cycling (include 200m, 1000m)
	Endurance event	Medium/super long-distance running, race walking, skating; Medium/super long-distance swimming, cross-country/Nordic skiing; Medium/super long-distance road cycling, boating, canoeing
Skill leading	Aesthetic event	Rhythmic gymnastics, diving, figure swimming, figure skating, martial arts routines, freestyle skiing, dance, gymnastics, etc.
Skill and psychological ability leading	Accuracy event	Crossbow archery, golf and shooting
Skill and tactical ability leading	Net/Court event	Table tennis, badminton, tennis, volleyball
	Invasion event	Soccer, basketball, water polo, football, ice hockey, hockey handball etc.
	Combat event	Boxing, fencing, Judo, Muay Thai, martial arts, karate, etc.
	Attack and defense alternate event	Baseball, softball, cricket

Effect of IRT on fast strength sports

Two studies have explored the effect of IRT program on sports performance of fast strength sports among 32 male adolescent weightlifters aged 14-17 years and 32 young weightlifters aged 10.94 ± 0.47 years (Hammami et al., 2023; Kang et al., 2013). An article indicated the utilization of push-ups in both pre-test and post-test assessments for the MS group (36.55±2.68 vs 36.89±2.26, p<0.05), one-leg standing time with eyes closed between the HS and MS group (22.12±3.40 vs 38.44±7.63, p<0.05), and upper body back extension between the HS and MS group (58.81±2.76 vs 58.38±2.16, p<0.05) could significantly improve after doing IRT. Furthermore, solely the external rotation value of the left arm was assessed within the HS group (-5.625±1.33 vs -1.63±0.84, p<0.05) (Kang et al., 2013). Simultaneously, in an alternate investigation, 32 young weightlifters constituted the research cohort. Through within-subject comparisons within both experimental groups (IRT1 and IRT2), the study revealed noteworthy enhancements in all assessed variables. However, non-significant variations were observed only in lower inter-limb asymmetry. Additionally, significant differences were noted in the comparison between the two experimental groups (IRT1 and IRT2), particularly in the improvement of squat 1RM (45.94±3.66 vs 40.75±5.00, p<0.05), SLH with the dominant leg (182.19±15.81 vs 167.81±17.41, p<0.05), 3H (516.25±42.56 vs 469.69±64.56, p<0.05), CoP SA (548.21±164.47 vs 692.80±216.02, p<0.05) (Hammami et al., 2023).

Effect of IRT on speed sports

A solitary study, involving a cohort of 33 sprinters individuals, exclusively investigated the impact of unstable proprioceptive training programs utilizing BOSU and Swiss ball on sports performance within the domain of speed sports (21.82 ± 4.84 years) (Romero-Franco et al., 2012). In this experimental investigation, three parameters underwent evaluation: 1) Stability Test with Eyes Open and Closed, 2) Postural Stability, and 3) Gravity Centre Control. The analysis revealed a significant disparity between the experimental and control groups in specific variables, including XEO (mean position centre of pressure in the medial-lateral plane with eyes open) (-0.78 ± 4.31 vs 2.30 ± 2.75, p=0.010), the position of the gravity centre in the posterior direction (Back) (69.75 ± 18.20 vs 54.71 ± 17.68, p=0.026), and the position of the gravity centre in the right direction (Right) (63.31 ± 17.15 vs 49.71 ± 23.87, p=0.041) (Romero-Franco et al., 2012).

Effect of IRT on accuracy sports

Two investigations have examined the impact of IRT on sports performance in two precision sports events within a cohort of 25 male adult golf athletes (García Sillero et al., 2022) and 8 (unknown gander) adult rifle shooters (Hung et al., 2021) average age of about 20 years. A study unveiled that the prescribed destabilizing training intervention, involving stable versus unstable surfaces, failed to yield additional benefits to the stroke-specific sports performance of elite golfers in both pre- and post-tests conducted on the experimental (UST) and control (SST) groups. The variables of CHS-Post (109.60 ± 5.66 vs 106.27 ± 5.01, p=0.135, Cohen's d= 0.62), CARRY-Post (243.73 ± 14.26 vs 235.89 ± 16.85, p=0.220, Cohen's d= 0.50) were performed using the Trackman Golf® system (García Sillero et al., 2022). Concurrently, in an alternative study, a regimen of unstable complex functional strength training, incorporating whole-body vibration alongside unstable surface training, was administered to a cohort of eight rifle shooters. Relative to the pre-test measurements, the outcomes indicated a noteworthy enhancement in shooting performance and reduced body sway in the post-test, with shooting scores and total time demonstrating a substantial improvement of 5.50% (9.845 ± 0.151 vs 10.051 ± 0.156, p<0.01), and 7.34% (5.506 ± 0.050 vs 5.390 ± 0.113, p<0.05) respectively, as did the Dev Total values between performances at different times: 10ms (2.500 ± 0.348 vs 2.058 ± 0.358, p=0.01), 20ms (2.360 ± 0.400 vs 2.015 ± 0.353, p=0.04), 30ms (2.341 ± 0.408 vs 1.912 ± 0.532, p=0.02), and 40ms (2.376 ± 0.422 vs 1.893 ± 0.498, p=0.02). The DevY values also showed significant differences between performances at different times: 10ms (0.749 ± 0.114 vs 0.549 ± 0.051, p<0.01), 20ms (0.754 ± 0.116 vs 0.550 ± 0.052, p<0.01), 30ms (0.756 ± 0.116 vs 0.550 ± 0.052, p<0.01), 40ms (0.756 ± 0.116 vs 0.557 ± 0.051, p<0.01), and 50ms (0.760 ± 0.114 vs 0.556 ± 0.052, p<0.01) (Hung et al., 2021).

Effect of IRT on invasion sports

The sports of soccer, basketball, and handball are classified under the invasion sports subcategory. Within the scope of the 17 articles subjected to quantitative analysis in this investigation, six articles specifically focused on soccer players (Gidu et al., 2022; Granacher et al., 2015; Makhlouf et al., 2018; Negra et al., 2017; Prieske et al., 2016; Sanchez-Sanchez et al., 2022); 3 articles on handball players (Gaamouri et al., 2023; Hammami et al., 2020; Hammami et al., 2022); one article on basketball players (Zemková & Hamar, 2010) investigated the impact of instability resistance or training on unstable surfaces on sports performance within the domain of invasion sports. Six studies delved into the influence of IRT on comprehensive sports performance in the context of soccer, an invasion sport. The participants in these investigations comprised 57 young males approximately around the age of 10 (Makhlouf et al., 2018), 37 young males around the age of 12 (Negra et al., 2017), 39 young males around the age of 16 (Prieske et al., 2016), 96 young males around the age of 14 (Gidu et al., 2022), 55 young males around the age of 18 (Sanchez-Sanchez et al., 2022), and 24 young males around the age of 15 (Granacher et al., 2015) soccer player respectively. The result of the first study showed a statistically significant difference time * group interactions: CMJ (19.6 ± 6.0 vs 18.9 ± 3.8 vs 16.2 ± 3.1, p=0.022, Cohen's d=0.78), hand grip MVIC force (25.8 ± 2.7 vs 23.6 ± 3.4 vs 22.1 ± 3.4, p=0.002, Cohen's d=1.03), ICODT without a ball (17.69 ± 0.8 vs 17.43 ± 0.6 vs 18.28 ± 1.0, p=0.045, Cohen's d=0.70), agility (4 m × 9 m) (10.03 ± 0.3 vs 9.97 ± 0.4 vs 10.36 ± 0.5, p=0.007, Cohen's d=0.90), standing stork balance(9.68 ± 3.8 vs 13.61 ± 9.2 vs 4.47 ± 1.7, p=0.001, Cohen's d=1.13), Y-balance (81.7 ± 5.2 vs 78.7 ± 4.9 vs 73.3 ± 7.7, p=0.001, Cohen's d= 1.32), 10m sprint (2.12 ± 0.1 vs 2.12 ± 0.1 vs 2.22 ± 0.2, p=0.044, Cohen's d= 0.7), 30m sprint (5.33 ± 0.2 vs 5.27 ± 0.2 vs 5.51 ±0.4, p=0.049, Cohen's d= 0.69) (Makhlouf et al., 2018). The findings of the second study indicated that statistically significant differences between groups were observed solely for the USBT at the post-test assessment (4.1 ± 0.3 vs 5.7 ± 2.8, p<0.001, Cohen's d= 1.49) (Negra et al., 2017). The outcomes of the third study demonstrated statistically significant main effects between groups in the post-test comparison for trunk extensor Maximal Isometric Strength (MIF) (644.0 ± 92.6 vs 644.0 ± 115.1, P=0.02, d = 0.86), 10–20-m sprint time (1.22 ± 0.04 vs 1.25 ± 0.02, P<0.001, d =2.56), and kicking performance (107.5 ± 6.1 vs 103.4 ± 6.3, P=0.003, d = 1.28). No significant Group × test interactions were observed for any variable (Prieske et al., 2016). The outcomes of the fourth study revealed statistically significant within-group differences for the experimental group, observed at both pre-test and post-test assessments following the intervention on a foam surface, specifically in relation to the Single-leg stance (3.665 ±2.938 vs 1.561 ± 2.956, P=0.002, d = 0.713), Double-leg stance (2.427 ± 1.942 vs 1.139 ± 0.251, P<0.001, d = 0.696), Tandem stance (1.389 ± 1.499 vs 0.611 ± 0.965, P<0.001, d = 0.617), Total BESS score (Both surfaces firm + foam) (10.198 ± 8.987 vs 4.370 ± 7.453, P<0.001, d = 0.705), Single-leg forward jump (Right leg) (159.166 ± 4.793 vs 163.083 ± 4.493, P<0.001, d = 0.693), Single-leg forward jump (Left leg) (157.500 ± 7.811 vs 159.916 ± 7.175, P<0.001, d = 0.322), Single-leg lateral jump (Right leg) (127.500 ± 5.780 vs 130.437 ± 5.297, P=0.017, d = 0.529), Single-leg lateral jump (Left leg) (125.125 ± 6.159 vs 127.916 ± 6.327, P=0.003, d = 0.447), Single-leg vertical jump (Right leg) (19.650 ± 2.996 vs 21.002 ± 2.266, P=0.001, d = 0.584), Single-leg vertical jump (Left leg) (19.450 ± 1.467 vs 20.414 ± 2.151, P=0.002, d = 0.523), Double-leg CMJ (35.716 ± 2.801 vs 37.491 ± 2.563, P<0.001, d = 0.661), Agility right side (8.445 ± 0.426 vs 8.043 ± 0.449, P<0.001, d = 0.747), Agility left side (8.655 ± 0.415 vs 8.335 ± 0.548, P<0.001, d = 0.685), Short dribbling test (13.575 ± 0.514 vs 13.302 ± 0.548, P<0.001, d = 0.513) (Gidu et al., 2022). Concurrently, an additional study demonstrated that the experimental group engaging in instability resistance or training on unstable surfaces exhibited significant superiority in the Illinois Change of Direction Speed Test (COD) (17.07 ± 0.96 vs 16.51 ± 0.75, P=0.02) performance in the uRT (experimental group) compared with the sRT (control group) (Sanchez-Sanchez et al., 2022). Furthermore, a comparable positive influence of instability resistance or training on unstable surfaces was evident in the sixth study. The findings indicated that, following participation in instability resistance or unstable surface training, there was a notable improvement in one aspect of sports performance, specifically in terms of the CMJ height (41.10±4.78 vs 30.24±2.52, P=0.005, effect size=0.66) was significantly improved for training group*time interaction in favour of the SPT group (experimental group) (Granacher et al., 2015).

Conversely, three articles pertained to sports performance in handball players, encompassing a total of 73 young male participants and 34 female participants (Gaamouri et al., 2023; Hammami et al., 2020; Hammami et al., 2022). In a particular study, following supplementary jump and sprint training on a sand surface, a notable disparity was evident in all handball sports performance parameters (excluding the 5-jump score). This was observed through the ANOVA group * time interaction, particularly in the acceleration of sprint times across various distances, notably for 5m (0.99 ± 0.10 vs 1.13 ± 0.03, P=0.002, d = 0.735), 10 m (1.78 ± 0.17 vs 1.98 ± 0.11, P=0.012, d = 0.577), 20 m (3.30 ± 0.13 vs 3.50 ± 0.16, P=0.012, d = 0.573), Agility tests T-Half (6.28 ± 0.35 vs 6.84 ± 0.29, P=0.001, d = 0.859), Illinois-MT (12.5 ± 0.5 vs 13.0 ± 0.3, P=0.004, d = 0.670), Vertical jump SJ (34.7 ± 4.5 vs 29.5 ± 2.4, P=0.001, d = 0.813), CMJ (33.5 ± 5.3 vs 30.9 ± 3.5, P=0.004, d = 0.663), but no significant change in the 5-jump score (10.9 ± 0.9 vs 10.5 ± 1.1, P=0.228, d = 0.270). Moreover, there were improved significantly in three of the four repeated sprint scores (BT (10.3 ± 0.7 vs 11.1 ± 0.7, P=0.012, d = 0.577), MT (10.7 ± 0.7 vs 11.7 ± 0.8, P=0.042, d = 0.463) and TT (74.7 ± 5.2 vs82.1 ± 5.4, P=0.043, d = 0.458)). The Y test showed significant differences in two of three scores for the right leg RL/R (96.4 ± 11.4 vs 83.0 ± 6.8, P=0.009, d = 0.593), RL/L(124.1 ± 8.3 vs 105.1 ± 6.0, P<0.001, d = 1.207), and one of the three scores for the left leg (120.0 ± 7.7 vs 108.0 ± 9.0, P=0.003, d = 0.681), and the stork test performance was also enhanced for right leg (6.99 ± 3.93 vs 3.95 ± 1.70, P=0.040, d = 0.468) (Hammami et al., 2022). Concurrently, alternative studies indicated that the implementation of plyometric training on both sand and stable surfaces yielded enhancements in sports performance across the three groups. The data analysis revealed a noteworthy distinction, with the experimental and control groups demonstrating significant increases in sprint speed, particularly for the PS group in comparison to P and C, 5m (0.99 ± 0.12 vs 1.14 ± 0.08 vs 1.21 ± 0.04, p=0.001, Cohen's d=1.12), 10 m (1.68 ± 0.23 vs 2.01 ± 0.11 vs 2.14 ± 0.10, p=0.001, Cohen's d=1.50), 20 m (3.14 ± 0.11 vs 3.40 ± 0.12 vs 3.54 ± 0.18, p=0.005, Cohen's d=0.90). Change of direction scores was also improved for PS relative to P and C, T-Half (6.37 ± 0.25 vs 6.74 ± 0.28 vs 7.14 ± 0.30, p=0.001, Cohen's d=1.24), Illinois-MT (11.9 ± 0.4 vs 12.4 ± 0.5 vs 13.0 ± 0.2, p=0.001, Cohen's d=1.35). Both PS and P increased vertical jump performance squat jump (36.6 ± 3.3 vs 35.6 ± 2.5 vs 29.5 ± 2.7, p=0.001, Cohen's d=1.13), counter-movement jump (40.3 ± 5.3 vs 39.0 ± 3.1 vs 31.8 ± 3.1, p=0.002, Cohen's d=0.98). Repeated sprint T-test the best and mean, fatigue index, and total time scores improved in PS and P compared to C, with the best times of the PS group significant difference to the P group (p < 0.05). Both group PS and P improved their Y balance test (p < 0.05). The stork balance test was also enhanced in both experimental groups (PS > P) (Hammami et al., 2020). Moreover, the third study assessed the impact of elastic band training on change of direction, jumping ability, power, strength, and repeated sprint ability performance in adolescent female handball players. A statistically significant difference was found in the group*time interaction for COD performance (p<0.001, d=1.00), squat and countermovement jump (p=0.002, d≥0.83), best, mean, and total RSA scores (all p < 0.001, d = 0.92-1.66), 1-RM bench press (p=0.02, d=0.59) and half squat (p=0.009, d=0.67), all indices of upper limb force-velocity performance (p≤0.025, d=0.56-1.66), and 3 of 4 indices of lower limb force velocity performance (p≤0.004, d= 0.75-0.92) (Gaamouri et al., 2023).

Additionally, only one study focused on combined agility-balance training using wobble boards among basketball players. Participants were divided into two groups: one underwent combined agility-balance training on wobble boards, while the other received the same training on a stable surface. In contrast, there was a substantial difference in test index between post-test among participants of experimental and control groups who received combined agility-balance training on different surface for Bipedal stance on wobble board with eyes open and closed (p<0.05), Simple agility task (p<0.05), multi-choice agility task (p<0.01), Step initiation (p<0.05), Estimation of 50% of 1max jump height (p<0.05), Drop jump from the height of 45 cm (p<0.05) (Zemková & Hamar, 2010).

Effect of IRT on combat sports

Among 2 male and 8 female Judo athletes aged 15.4 ± 2.8 years, only one study examined the effect of the suspension training program with a TRX® suspension trainer on sports performance in a combat sport (Norambuena et al., 2021). The results indicated that suspension training program with TRX® suspension trainer had a significant improvements effect were observed in the single-leg horizontal jumping test (right leg: 137 ± 23.3 vs 164 ± 22.0 cm, p<.05; left leg: 131 ± 24.1 vs 169 ± 26.5 cm, p<.05), Sorensen muscle endurance test (134 ± 43.4 vs 195 ± 46.7 s, p<.05), sit-and-reach flexibility test (42.1 ± 8.2 vs 46.2 ± 7.5 cm, p<.05), Y balance test for leg (right leg: 91.3 ± 6.6 vs 101 ± 7.6%, p<.05; left leg: 91.2 ± 4.8 vs 103 ± 6.6%, p<.05) and Y balance test for arm (right arm: 80.9 ± 9.2 vs 89.3 ± 8.4, p<.01; left arm: 81.4 ± 8.6 vs 90.0 ± 9.6%, p<.01) when compared to the control group (Norambuena et al., 2021).

Effect of IRT on Attack and Defence Alternate Sports

A study examined the impact of both stable and unstable surface training on skill performance in attack and defence alternate sports, involving 24 male cricketers aged 18-25 years (Sanghvi et al., 2014). This study found significant differences in the Transversus Abdominis muscle assessment, speed single sprint test, vertical jump height, and standing stork test within the experimental group's post-training performance compared to pre-tests. Although stable and unstable surface training induced greater hypertrophy in the Transversus Abdominis muscle in the experimental group compared to the control group, no statistically significant differences were noted between groups in functional performance measures such as the speed-single sprint test, vertical jump height, and standing stork test in male cricketers (Sanghvi et al., 2014).

Discussion

Effect of IRT on Fast Strength Sports

Two empirical studies provided evidence that an instability balance training program had a significant positive impact on various aspects of performance among young weightlifters. These improvements included enhanced push-up ability, increased duration of one-leg standing with eyes closed, improved back extension of the upper body, and increased external rotation of the left arm (Kang et al., 2013), squat 1RM, SLH with the dominant leg, 3H, CoP SA (Hammami et al., 2023). Weightlifting comprises two key components: the snatch and clean and jerk. These lifts demand a combination of fast strength, power, and balance maintenance (Riemann et al., 2020). Muscle strength is an important physical fitness, it is of great significance for the posture, stability, and balance of athletes to perform well in competitions (Horvat et al., 2003; Latash et al., 2010).

The results of the two studies may be reasonably explained by the fact that IRT programs, by offering an unstable environment more extensively than stable conditions or surfaces, effectively stressed the neuromuscular and balance systems. This induced appropriate neuromuscular and balance adaptations in weightlifters (Amar et al., 2021; Anderson & Behm, 2005). Additionally, it resulted in heightened stimulation of athletes' deep and small muscles, particularly the agonist and antagonist muscles crucial for joint flexion and extension (Colado et al., 2020; Faigenbaum, 2000).

Effect of IRT on speed sports

A study demonstrated that an unstable proprioceptive training program using BOSU and Swiss ball significantly enhanced variables such as XEO , the position of the gravity centre in the posterior direction (Back), and the position of the gravity centre in the right direction (Right) for young sprinters in the domain of speed sports (Romero-Franco et al., 2012). This study confirmed the efficacy of unstable proprioceptive training using specific BOSU and Swiss balls in enhancing postural stability and gravity centre control, both with eyes open and closed. While these findings are specific to the young population of sprinters in speed sports, prior research has established that proprioceptive training with BOSU and Swiss balls leads to core stability and balance improvements. Additionally, the use of an unstable training surface and environment has been associated with sports injury prevention, particularly for sprinters (Griffin, 2003; Matsusaka et al., 2001).

Conversely, in pertinent investigations assessing the efficacy of proprioception exercises, notable improvements have been observed in athletes' core and trunk stability and balance across various sports events (Gioftsidou et al., 2006; Tayshete et al., 2020). This form of proprioceptive training is typically integrated into unstable training regimens employing unstable platforms or environments. Moreover, the enhanced core and trunk stability and balance abilities achieved through proprioceptive training on unstable surfaces serve as a foundational element for athletes, including sprinters, enabling them to generate and sustain higher-intensity strength output (Luo et al., 2022; Stanton, Reaburn, & Humphries, 2004).

Effect of IRT on Accuracy Sports

Two studies investigated the efficacy of Instability Resistance Training (IRT) in enhancing sports performance, specifically among male adult golf athletes and rifle shooters. Another study explored the impact of utilizing unstable surfaces in the proposed intervention, revealing no significant additional benefits for stroke skill performance in elite golfers, as measured by club head speed (CHS) and carry distance (CARRY) (García Sillero et al., 2022). This outcome may be attributed to potential disparities between the data, training experience, and skill levels within the sample of male adult golf athletes in the study. The high-performance status of elite athletes often encounters a "Plateau Phenomenon" in sports training, where marginal improvements become inconspicuous and challenging to distinguish (Doherty, Nobbs, & Noakes, 2003). Enhancing sports performance across multiple factors necessitates more than just a brief period of IRT, as notable improvements require an extended timeframe (Sung et al., 2016). As a result, neither club head speed nor carry distance exhibited improvement.

In accordance with a different study, the goal for rifle shooters is to enhance sports performance in shooting stability, fluency, and scores by employing unstable complex functional muscle strength training (Hung et al., 2021). As per the findings of this study, a 6-week regimen of unstable complex functional muscle strength training on an unstable surface led to notable enhancements in shooting accuracy performance and reduced body sway. Whole body vibration training (WBV) has become a prevalent daily training method among athletes and coaches, establishing unstable whole-body vibration training as a crucial approach for enhancing athlete muscle strength (Marín & Rhea, 2010; Paillard & Noé, 2006). UST, representing unstable training, employs unstable environments utilizing Swiss balls, BOSU balls, and equipment such as TRX for body resistance exercises. This form of unstable training holds significant advantages in injury prevention and rehabilitation, making it extensively utilized in the realms of rehabilitation treatment and exercise training (Ammar, Chtourou, & Souissi, 2017). In shooting competitions, securing victory hinges on shooters sustaining the endurance of their full-body muscle strength and technical stability, crucial in a sport demanding high accuracy and stability. The study reveals that combining whole-body vibration with unstable surfaces allows rifle shooters to optimize aim with less muscle exertion, enhancing shooting posture endurance. This underscores the significance of incorporating composite instability training to boost shooting stability, fluency, and scores for rifle shooters.

Effect of IRT on Invasion Sports

Six studies showed that IRT would improve soccer players' sports performance in terms of particular 1) Strength, power: Hand grip strength, MVIC back extensor, MVIC knee extensor, CMJ, RSI, Triple hop. 2)Agility: ICODT, ICODT with and without ball, Agility 4*9m. 3) Speed: 10 m sprint, 30 m sprint. 4)Balance: Standing Stork Test, YBT CS (Makhlouf et al., 2018); USBT (Negra et al., 2017); trunk extensor MIF (maximal isometric strength), 10–20m sprint time, and kicking performance (Prieske et al., 2016); Single-leg stance, Double-leg stance, Tandem stance, Total BESS score, Single-leg forward, lateral and vertical jump (Right and Left leg), Double-leg CMJ, Agility left and right side, , Short dribbling test (Gidu et al., 2022); Illinois change of direction speed test (Sanchez-Sanchez et al., 2022); CMJ (Granacher et al., 2015). Unstable resistance training involves implementing resistance exercises within artificially induced unstable support conditions, resembling specialized exercises and intensifying training challenges. While the unstable support surface may result in a reduction in muscle output power, including strength, explosive power, and speed, it concurrently promotes muscle activation. Prolonged engagement in unstable resistance training exhibits a positive influence on enhancing sports performance (Bedoya, Miltenberger, & Lopez, 2015). In contemporary research, incorporating a moderate level of unstable resistance training emerges as a secure and efficacious stimulation technique for soccer players. This approach places emphasis on integrating training movements and optimizing the function of the "Power Chain." Unstable resistance training contributes to heightened activation of core muscles, improved coordination between agonistic and antagonistic muscles, and enhanced muscle proprioception. These physiological enhancements constitute crucial mechanisms for augmenting motor performance (Asadi et al., 2017).

Three studies provided evidence that IRT could improve handball players' sports performance for Sprint times, Agility tests T-Half, Illinois-MT, Vertical jump SJ, CMJ, Repeated sprint, Y test (Hammami et al., 2022), sprint speed, Change of direction, T-Half, Illinois-MT, vertical jump, Repeated sprint, Y balance test (Hammami et al., 2020), COD performance, squat and countermovement jump, RSA scores, 1-RM bench press, upper limb force-velocity (Gaamouri et al., 2023). Furthermore, a solitary investigation identified positive outcomes in basketball players through combined agility-balance training on wobble boards. The beneficial effects encompassed performance in tasks involving eyes open and closed, simple agility, multi-choice agility, step initiation, estimation of 50% of 1max jump height, and drop jump from a height of 45 cm (Zemková & Hamar, 2010). Research findings for handball and basketball players indicate that training focused on posture stability and balance can enhance motor performance. The analysis suggests that this improvement may stem from the reduction of posture swaying during the power generation phase of sports techniques. This reduction benefits muscle power generation and enhances power transmission efficiency, ultimately contributing to improved sports performance. This is particularly relevant as technical movements in sports often align with an inverted pendulum system model (Kean, Behm, & Young, 2006). During muscle exertion, irrespective of absolute strength and individual muscle differences, an individual's posture stability and balance significantly impact the efficiency of work between muscles and the recruitment of sports units. Consequently, athletes with comparable fundamental qualities often display notable performance variations in executing intricate technical movements during training competitions (Behm et al., 2005).

Effect of IRT on combat sports

A study investigated the efficacy of a suspension training program in enhancing physical performance among youth Judo athletes (Norambuena et al., 2021). Judo, a sport demanding elevated physical fitness in youth, underscores the pivotal influence of balance, neuromuscular control, flexibility, and stability on athletes' competitive performance (Demorest et al., 2016). The advantages of suspension training have been substantiated to be associated with heightened mechanical sensory stimulation in the human body (Myer et al., 2006).

This form of unstable movement mirrors a closed power chain, augmenting joint load in flexion, extension, and rotation. The perception of joint movement significantly contributes to stabilizing muscle contraction. The closed power chain is integral to the training of judo athletes, who consistently employ robust closed power chains to enhance athletic performance (Harris et al., 2017). Ultimately, athletes attained a distinctive enhancement in performance that encompasses neural perception, joint activity, and muscle contraction following interventions in unstable training.

Effect of IRT on attack and defence alternate sports

A singular empirical study demonstrated a significant enhancement in Transversus Abdominis muscle assessment, Speed Single Sprint Test, Vertical Jump Height, and Standing Stork Test among male cricketers following Instability IRT in the experimental group, as compared in pre- and post-test assessments (Sanghvi et al., 2014). Several studies indicate a potential correlation between trunk stability and core muscle strength with the impact on sprint performance and vertical jump height (Brumitt, 2010)(Watson et al., 2017).

Yet, an alternative study suggests that the inherent heightened instability of an unstable platform and body interface could present a more substantial challenge to the neuromuscular system. This heightened challenge may exceed the existing threshold, potentially inducing a positive training adaptation and yielding statistically greater improvements (Stanton et al., 2004). This shift may be ascribed to heightened trunk stability, optimizing leg muscle force production through an enhanced neural drive on an unstable surface platform among male cricketers.

Limitations

This review furnishes empirical evidence and resources for scrutinizing the impact of Instability IRT on sports performance within the domains of Judo, cricket, weightlifting, rifle shooting, sprinting, handball, soccer, and basketball. However, certain limitations merit consideration:

1) Insufficiency of participant representation within the extant literature is noted in the realms of endurance sports, aesthetic sports, and net/court sports.

2) Present investigations predominantly centre on contrasting traditional stable training with Instability IRT, primarily employing Swiss balls and BOSU balls. Subsequent research endeavours should explore novel unstable training environments, including but not limited to water, snow, and gravel surfaces, for comprehensive comparative analyses.

3) Within the extant literature, the term "sports performance" encapsulates a broad conceptual framework encompassing both the physical fitness and athletic prowess exhibited across various sports events. The salience of specific performance in the context of this study is comparatively diminished.

4) The seventeen literature sources analysed and deliberated upon in this article are exclusively English-language publications. Consequently, the research scope of this review does not encompass articles in languages other than English.

Conclusion

This systematic review, focusing on the impact of Instability IRT on athletes' sports performance, has yielded evidence and information suggesting that training on unstable surfaces can significantly enhance the performance of athletes engaged in judo, cricket, weightlifting, rifle shooting, sprinting, handball, soccer, and basketball, with potential benefits noted across various sports (with the exception of specific stroke performance in elite golf players). IRT, denoting a training methodology involving resistance training in conditions of deliberately induced instability, closely simulates specialized exercises and heightens training complexity. Despite a discernible reduction in muscle output power, characterized by diminished strength, explosive power, and speed on unstable support surfaces, this training approach proves advantageous for activating athletes' muscles. Continuous engagement in unstable resistance training exhibits a positive and facilitative influence on overall sports performance. Presently, a moderated application of unstable resistance training is identified as a secure and effective method of stimulation.

Practical application

Distinct from conventional stability training approaches, instability resistance training represents a distinctive and efficacious method. This modality employs unstable surfaces and settings to cultivate limb balance, thereby engendering the fortification of joint stability. Throughout the training regimen, synchronous muscle contraction serves to abbreviate muscle response time, concurrently augmenting control over limb muscles and joint stiffness to ensure a steadfast body posture. An integral physiological mechanism underlying unstable surface training lies in the heightened activation of muscles associated with agonist and antagonist roles in posture control coordination and balance stability. This training paradigm holds promise for optimizing sports performance across a broad spectrum of athletes. Consequently, by emphasizing the amalgamation of training movements and the functionality of the "power chain," unstable resistance training emerges as a pivotal method for augmenting athletes' muscle activation, refining coordination between agonist and antagonist muscles, enhancing muscle proprioception, and optimizing physiological mechanisms. Furthermore, this training modality proves instrumental in elevating athletes' performance across diverse sporting disciplines. Drawing on the insights gleaned from the aforementioned 17 studies, this review advocates for the systematic incorporation of Instability Resistance Training (IRT) into the regular training regimens of athletes participating in various sports events. It is imperative to underscore that an optimal training frequency and duration are recommended at 6-8 weeks, with sessions occurring 3-5 times per week.

Data Availability Statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors. All authors have read and agreed to the published version of the manuscript.

Author Contributions

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

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