Effects of training on sand or hard surfaces on sprint and jump performance of team-sport players: a systematic review with meta-analysis

Training on sand versus hard surfaces

ABSTRACT

We examined the effectiveness of training on sand and compared the effects of sand and hard surface training programs on the sprint and jump performance of team-sport players. PubMed MEDLINE, SPORTDiscus, and Web of Science databases were used in the literature search. A total of 377 records were initially identified and six studies comprising 136 athletes were included in the meta-analysis. Pre- and post-comparisons showed that sand training interventions were effective at improving both jump and sprint capacities. When comparing sand and hard surfaces, no significant differences in favor of any of the interventions were observed. In summary, this review revealed that sand training is an efficient strategy to improve jump and sprint performances in team-sport players. Moreover, sand surfaces produced similar gains to those observed after hard surface training schemes. Strength and conditioning coaches and sport scientists who work with team-sports can use both sand and hard surface training programs as part of their regular training practices, during distinct phases of the season.

Keywords: athletes; muscle power; speed; plyometrics; jump training.

INTRODUCTION

Sprinting speed and muscle power play key roles in numerous team-sports (18, 22, 37, 58). For this reason, practitioners are constantly seeking more efficient training approaches to maximize these physical qualities in team-sport players. Multiple training methods (e.g., plyometrics, resisted sprints, and acceleration drills) have been shown to be effective in improving sprint speed and power production in elite athletes (22, 31, 36, 38). The above mentioned exercises and training sessions are commonly performed on hard surfaces (e.g., concrete, wood, or synthetic floors) (20, 38, 51), with the rationale that more compliant surfaces (e.g., sand) usually "store" the generated muscle energy and, hence, reduce the elastic rebound force (and, as a result, jumping height) (14). Recently, some studies have suggested the use of sand surfaces as an alternative way to enhance neuromuscular performance, since this strategy may potentially increase the activation of the principal muscle groups involved in the target motor-task (43, 50, 56). Furthermore, due to its absorptive characteristics, sand reduces the shocking impact leading to lower stress over joints and muscles when compared to hard surfaces (30, 43). The use of sand-based approaches is very accessible due to the many natural (e.g., beach environment) or artificial (e.g., indoor and outdoor facilities) sand surfaces available, which makes it a practical and cheap alternative for practitioners working at various performance levels.

Research has shown several differences in terms of physical and physiological factors when performing jumping and sprinting activities on sand or hard surfaces (2, 24, 43). For example, it has been observed that movements on sand have a higher energy cost (34, 59), and lead to greater lactate accumulation (49) and higher lower limb muscles activation (43, 50, 56) when compared to harder surfaces (10-12). Due to the high demands of muscle activity, sand surfaces can also work as a natural and effective way to increase movement resistance, inducing critical adaptations in different physiological, mechanical, and neuromuscular factors (e.g., increased muscle-tendon unit stiffness, motor unit recruitment, and neurological drive), especially when athletes are chronically exposed to this training strategy (30, 33, 55). Some authors have advocated that training on sand can elicit positive changes in physical performance, leading to increased muscle contractile capacity and, thus, enhancing force application during explosive movements (30, 33, 55). Moreover, due to the higher shock absorption properties, exercises on sand could result in lower levels of mechanical stress, provoking less exercise-induced muscle damage and reducing the associated risk of injuries (30, 43).

In contrast, as previously mentioned, when performing explosive actions on sand, athletes dissipate a considerable amount of ground reaction forces when landing (2, 24, 30), which affects movement pattern in terms of velocity and specificity (6). Accordingly, Alcaraz et al. (2) reported reduced sprint and angular velocities, and lower stride length and frequency in sand sprinting (compared to sprinting on a synthetic track). Similarly, Giatsis et al. (24) revealed that jumping on sand resulted in lower jump height, take-off velocity, and power output than jumping on a hard floor. Indeed, as sand surfaces reduce the reutilization of elastic energy, they compromise the efficiency of the stretch shortening cycle (SSC) and, consequently, acute speed and power performance (12, 23, 43). Together, these issues might preclude the proper development of some neuromechanical abilities during sand training interventions. Therefore, it is not possible to determine which approach is more effective (i.e., training on firm or sand surfaces) without performing an in-depth examination of the main results of experimental studies through a systematic review and meta-analysis.

Although many studies (10-12, 30, 56) have suggested the use of conditioning training programs on sand surfaces and reported their main characteristics and benefits, the level of evidence regarding the effectiveness of sand training on the neuromuscular performance of team-sport players is not well-established. Furthermore, it is still not known whether there are significant differences between the chronic adaptations (e.g., interventions $\geq$ 4 weeks) promoted by exercises performed on hard or sand surfaces. Given the popularity of these respective strategies, it is important to determine their efficacy in improving sprint and jump capacities in team-sport players through the analysis of the current body of literature. The purposes of this review were to assess the effectiveness of sand training and compare the effects of sand and hard surface training interventions on the sprint and jump performance of team-sport players.

METHODS

Literature research and data sources

This research was completed in accordance with the Preferred Reported Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (44). The literature search was conducted using the following online databases: PubMed MEDLINE, SPORTDiscus, and Web of Science and included studies published until October 21st, 2020. Keywords were defined based on previous studies and according to the study purposes. The following keywords were used in conjunction with the Boolean operators "AND" and "OR" as part of the search strategy: (training OR plyometric OR plyometrics OR running) AND (sand OR beach) AND (jump OR jumping OR sprint OR sprinting OR "reactive strength index" OR power OR speed OR performance) AND (athletes OR players OR team-sport OR "team sport"). Reference lists from relevant articles were also examined to find other potentially eligible studies.

Eligibility criteria

Randomized peer-reviewed studies published in English, Spanish, or Portuguese were considered for inclusion and no age or sex restrictions were imposed. Studies were included based on these criteria: 1) one group was allocated to a training program performed exclusively on sand; 2) the sample was composed of team-sport athletes (no competitive level restriction); 3) interventions lasted at least 4 weeks; and 4) linear sprint (< 40-m) or vertical jump (VJ) as outcome variables. Regarding the exclusion criteria, studies were not considered for analysis if: 1) no other comparison group was tested; 2) only acute effects were assessed; and 3) no full text was available.

Study selection

The initial search was carried out by two researchers (LAP and TTF). After the removal of duplicates, titles and abstracts were screened and studies not meeting the eligibility criteria were excluded. Subsequently, full texts of the remaining articles were analyzed. Then, in a blind, independent fashion, two reviewers selected the studies for inclusion (LAP and TTF), following the eligibility criteria. If no agreement was obtained, a third researcher (IL) was consulted.

Data extraction and analysis

Mean, standard deviation (SD), and sample size data were extracted from the included manuscripts by two authors (LAP and TTF). All descriptive data needed were presented in the articles so no contact with the authors was necessary to ask for additional information. Any disagreements during the process of data extraction and analysis were resolved by consensus among three authors (LAP, TTF, IL).

The meta-analysis was performed using Review Manager software (RevMan 5.3; Cochrane Collaboration, Oxford, UK). A random-effect meta-analysis was conducted to determine the summary effect of sand training interventions on the linear sprint and VJ performances. Effects between sand and hard surface training interventions and differences between post- and pre-training in the sand group are expressed as standardized mean differences (SMD) and their 95% confidence intervals (CI). Standardized mean differences were used because sprints were assessed over different distances and VJ was obtained through distinct methods. VJ and sprint data were divided into subgroups, according to the jump type or sprint distance considered in each study. For the VJ, subgroups were divided into 1) squat jump (SJ); and 2) countermovement and block jumps (CMJ and BJ). For the SJ, players started from a standing position, bending the knees to about 90^{o}, stopping for 3 s, and then jumping as high as possible, trying to avoid any knee or trunk countermovement (30). The CMJ was performed starting from a standing position; the athletes were required to jump as high as possible with a rapid preparatory downward eccentric action (30). In the BJ, players executed a movement similar to a volleyball blocking, and had to jump as high as possible touching the board with their hands (53). For sprint performance, subgroups were separated into 1) 10-m; and 2) 20- and 30-m distances. The thresholds used to qualitatively interpret SMD were: < 0.2 (trivial), ≥ 0.2 (small), ≥ 0.5 (moderate), and ≥ 0.8 (large) (17). The data analysis was focused on the magnitude of effects obtained.

Heterogeneity among studies was assessed using I^2 statistics. *I* values range between 0% and 100% and are considered low, modest, or high for < 25%, 25 ± 50%, and > 50%, respectively. A high heterogeneity means that the included studies exhibit a substantial variability in some outcomes and methodological aspects, which also results in different weights of evidence. Although it is not a premise for a meta-analysis, it is always expected to find lower levels of heterogeneity among the studies considered. Heterogeneity may be assumed when the *P* value of the *I* test is < 0.05 (8). Publication bias was evaluated by estimating the funnel plot asymmetry. Statistical significance was considered for $P < 0.05$ (21).

Risk of bias and quality of the studies

Methodological quality and risk of bias were assessed through the Cochrane risk of bias tool (RoB 2.0) (28) by two authors independently (LAP, EMC), with disagreements being resolved by a third party evaluation (TTF), in accordance with the Cochrane Collaboration Guidelines (29).

The Physiotherapy Evidence Database (PEDro) scale (19) was used to assess the methodological quality of the included studies. The quality of assessments was interpreted as follows: ≤3 poor quality, 4–5 moderate quality, and 6–10 high quality. The analyses were performed by two authors independently (LAP, EMC), with disagreements being resolved by a third-party evaluation (TTF).

RESULTS

Study selection

A total of 374 records were identified through database searching and 3 additional studies were identified through other sources. After title and abstract screening, from the 292 studies that remained after removal of duplicates, 281 studies were excluded. As a result, 11 studies were assessed for eligibility and 6 studies (9, 13, 26, 30, 46, 53) were included in the meta-analysis based on the inclusion and exclusion criteria. Overall, the risk of bias between the analyzed studies was low: 5 demonstrated a low risk of bias (9, 13, 26, 30, 46) and 1 a high risk (53). The quality of the studies, according to the PEDro scale was high (19). The mean score was 6.50 ± 0.84 out of a possible 10 points (Table 1).

From the articles included, 5 presented measures of sprint performance (9, 13, 26, 30, 46) and 5 presented VJ tests (9, 26, 30, 46, 53). A total of 69 players from different team-sports (i.e., netball (9, 13), field hockey (9, 13), handball (26), soccer (30), volleyball (53), and basketball (46)) were enrolled in the sand surface training group and 67 in the hard surface training group.

*****INSERT TABLE 1 HERE*****

Characteristics of the interventions

The characteristics of the training programs of the included studies are exhibited in Table 2. The interventions varied from 4 to 8 weeks of duration and the weekly training frequency consisted of 2 or 3 sessions. The sprint distance assessed in studies varied between 10- and 30-m, all measured through the use of photocells. In addition, distinct methods and tests were used to assess VJ performance. The VJ tests comprised SJ (9, 26, 30), CMJ (9, 26, 30, 46), and BJ (53), which were evaluated via contact mat (30), infrared photocell mat (26), yardstick (9), digital jump meter device (46), and measuring tape (53).

*****INSERT TABLE 2 HERE*****

Main effects and sub-group analysis

Pre- vs. post-training meta-analysis revealed large and significant improvements in SJ (ES = 0.97; $P = 0.04$), CMJ and BJ (ES = 1.27; $P = 0.01$), and all VJ modes (ES = 1.27; $P = 0.0006$) following sand training programs (Figure 1). Large and significant increases were also observed for 10-m sprint (ES = 1.17; $P = 0.02$), >10-m sprint (ES = 0.95; $P < 0.001$), and all sprint distances (ES = 1.02; $P < 0.0001$), when comparing pre- and post-sand training measures (Figure 2).

*****INSERT FIGURE 1 HERE *****

*****INSERT FIGURE 2 HERE *****

When comparing pre- and post-changes between sand and hard training interventions, trivial and small non-significant effects were detected for SJ (ES = 0.15; $P = 0.50$) and CMJ and BJ (ES = 0.35; $P = 0.42$), and a small and non-significant effect for all VJ (ES = 0.25; $P = 0.32$) was revealed (Figure 3). Moderate and small non-significant effects for 10-m (ES = 0.65; $P = 0.20$) and >10-m (ES = 0.28; $P = 0.15$) sprint performance were observed when comparing sand and hard training surfaces (Figure 5). Meanwhile, a small and significant effect was found in favor of sand training interventions when all sprint distances were simultaneously analyzed (ES = 0.42; P = 0.05; Figure 4).

*****INSERT FIGURE 3 HERE *****

*****INSERT FIGURE 4 HERE *****

DISCUSSION

This systematic review and meta-analysis examined the effectiveness of sand training and compared the effects of sand and hard surface training programs on sprint and jump performance of team-sport players. The results revealed that: 1) sand training interventions were effective in improving both jump and sprint capacities; and 2) the effects of training programs executed on sand were similar to those obtained on firm surfaces. As such, training schemes using sand surfaces seem to be a valuable alternative for enhancing sprint and jump performance in team-sport athletes. This approach elicits distinct adaptations to those observed for hard surfaces. As a consequence, both strategies may be implemented together or separately, depending on training objectives (e.g., lower vs. higher mechanical stress; slower vs. faster SSC actions) and period (e.g., pre-season or competitive phase). Of note, we observed modest to high heterogeneity among the studies included in the meta-analysis (I^2 values ranging from 45% to 81%; $P < 0.05$); thus, the results of this review should be interpreted with caution.

Meaningful and large improvements were detected in VJ and sprint performances in the majority of studies included in the meta-analysis when comparing pre- and post-assessments (Figures 1 and 2). Although sand surfaces increase shock absorption and compromise force application during explosive actions (2, 23, 24, 34) (which may hamper VJ and sprint performances), we confirmed that this training strategy is effective for inducing positive changes in sprint and jump capacities. For instance, Ozen et al. (46) showed significant increases in VJ and 30-m sprint performance after a 6-week sand plyometric training in young basketball players. Likewise, a 7-week sand plyometric intervention induced large and significant improvements in VJ and sprint performances over a range of distances (i.e., 5-, 10-, and 20-m) in junior male handball players (26). Therefore, despite increasing compliance (and shock absorption) and compromising the optimal storage and utilization of elastic energy (23, 43), training on sand was found to be effective for increasing both jump and sprint performances. Based on this, it is possible to infer that this training strategy is (among other things) able to promote positive changes in motor unit recruitment during explosive muscle actions (5, 6) such as maximal jumps and sprints (12, 25, 55). However, this is speculative and further studies are needed to explore and elucidate these mechanisms.

When comparing the changes induced by both sand and hard training surfaces, similar effects were found (Figures 3 and 4). As mentioned earlier, performing explosive actions on firm surfaces may increase the capacity of muscles to store and utilize elastic energy through the SSC (32, 45). This is especially important during sprinting and jumping tasks, where athletes have to use the elastic energy stored over the eccentric phases to generate fast and forceful concentric actions (30, 32, 43, 45). Thus, the adaptations provided by firm surfaces may be more related to improved efficiency in storing and reusing elastic energy during explosive actions (5, 6). Conversely, during sand training sessions, a considerable amount of elastic energy is dissipated, increasing the energy cost and level of muscle activation (12, 25, 42). As such, the compliant nature of sand could serve as a practical way to increase overload during workouts (36, 55), without the need to use additional resistance or supplementary equipment (e.g., elastic bands) (36, 39, 52). These assumptions are supported by previous studies that have already shown significant increases in muscle activation and jumping ability after plyometric training on sand (25, 42, 55). From these results, it is plausible to suggest that both training strategies are capable of enhancing sprint and jump performance via two distinct - and possibly complementary - mechanisms.

Whereas for jump performance these two respective mechanisms (i.e., SSC and muscle contractile capacity) appear to play crucial and balanced roles, the same does not hold true for short sprints (e.g., 10- and 20-m). During these all-out efforts, players need to effectively accelerate their bodies forward to quickly achieve higher velocities. In the initial phases of sprint actions there is higher participation of concentric strength, while in the later phases (e.g., >20-m), the utilization of elastic energy has a greater contribution to the development of sprint velocity (27, 40, 41). Therefore, the moderate but non-significant significant advantage observed for sand training interventions on 10-m sprint might be related to the fact that this training strategy is more efficient for improving short sprint actions, in which the contribution of muscle contractile capacities appear to be more pronounced (7). This result may have important implications for team-sport athletes, since most of the high-intensity actions performed during matches occur at distances shorter than 20-m (15, 54, 57). Nonetheless, the low number of studies available and the small sample sizes encountered precluded more definitive conclusions.

Strength and conditioning coaches and sport scientists should be aware of the differences between sand and hard training interventions when programming training routines. As previously mentioned, while hard surfaces promote higher stimulus to the SSC, sand training can provoke greater adaptations in muscle contractile properties (32, 43). From a practical standpoint, sand training may be more indicated in the initial phases of the season (e.g., “strength-oriented phase”), while hard training schemes can be applied closer to or even during the competitive period (e.g., “power-oriented phase”) (16, 35). As both strategies are easily implemented, low and moderate volume sessions can be planned prior to sport-specific activities, even as warm-up strategies. Importantly, irrespective of training protocol, athletes should be required to perform the movements with maximal effort and at maximal intended velocity (5). A critical point to consider is related to the kinematic differences between motor-tasks executed on hard or sand surfaces (2, 50). According to previous studies, the changes in sprint velocity and stride length when running on sand are similar to those observed when performing resisted sprints using loads inferior to 20% of the athletes' body mass (2, 47), which was demonstrated to yield positive changes in sprint performance (1, 48). Hence, it could be speculated that sand training programs can promote similar gains in physical performance to those observed after resisted sprint training with light loads (i.e., < 20% body mass) (1, 47). Another potential advantage of using sand in comparison to hard surfaces is that its unstable characteristics may increase trunk (core) activation, thus promoting greater stability and balance for the lumbopelvic complex during explosive sport activities (3, 4). Future studies comparing the effects of speed and plyometric training programs executed on sand or firm surfaces in team-sport athletes are needed to confirm or refute these hypotheses.

The main limitations of this study are that: 1) high heterogeneity among the studies included in the meta-analysis was noted, which may be related to the distinct number and characteristics of the athletes involved in these investigations; 2) one of the studies that assessed VJ presented a high risk of bias; 3) only 5 studies for each specific outcome (jump and sprint data) were included in the final analysis; 4) the specific characteristics of surfaces (i.e., surfaces' density and mechanical properties) used during training interventions were not considered. Furthermore, the limited body of evidence on this topic and small sample sizes in these respective investigations preclude more robust conclusions at this time. Nevertheless, this review provides relevant information regarding the use of a practical, safe, and popular training strategy (i.e., training on sand). In summary, we verified that sand training programs are able to induce positive changes in neuromuscular performance in team-sport players and that both training surfaces are equally effective to improve sprint and jump capacities. These findings are of interest to coaches and researchers, particularly considering that training on sand has been reported to result in lower levels of mechanical stress and exercise-induced muscle damage (30, 43). Finally, it is essential to emphasize that, when programming and prescribing training sessions for athletes, the choice of training surface must take into account the stimuli, purpose of the session, time of the season, and main characteristics of the respective sport.

CONCLUSIONS

Training on sand surfaces is effective for improving sprint and jump capacities in team-sport players. To produce these positive effects in players already familiarized with these surfaces, sand training interventions should last between four and eight weeks, with a frequency of two to three sessions per week. These data support the utilization of sand training programs in athletic settings, although the limited number of studies on this topic precludes more general evidence-based recommendations. Practitioners should be aware that sand training programs may be a suitable and alternative strategy to be incorporated into their weekly routines, in conjunction with more traditional training practices, such as plyometric exercises on harder surfaces.

REFERENCES

1. Alcaraz, PE, Carlos-Vivas, J, Oponjuru, BO, and Martinez-Rodriguez, A. The Effectiveness of Resisted Sled Training (RST) for Sprint Performance: A Systematic Review and Meta-analysis. *Sports Med* 48:2143-2165, 2018.
2. Alcaraz, PE, Palao, JM, Elvira, JLL, and Linthorne, NP. Effects of a sand running surface on the kinematics of sprinting at maximum velocity. *Biology of Sport* 28:95-100, 2011.
3. Behm, DG and Anderson, KG. The role of instability with resistance training. *J Strength Cond Res* 20:716-722, 2006.
4. Behm, DG, Drinkwater, EJ, Willardson, JM, and Cowley, PM. The role of instability rehabilitative resistance training for the core musculature. *Strength Cond J* 33:72-81, 2011.
5. Behm, DG and Sale, DG. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol (1985)* 74:359-368, 1993.
6. Behm, DG and Sale, DG. Velocity specificity of resistance training. *Sports Med* 15:374-388, 1993.
7. Behm, DG, Young, JD, Whitten, JHD, Reid, JC, Quigley, PJ, Low, J, Li, Y, Lima, CD, Hodgson, DD, Chaouachi, A, Prieske, O, and Granacher, U. Effectiveness of Traditional Strength vs. Power Training on Muscle Strength, Power and Speed with Youth: A Systematic Review and Meta-Analysis. *Front Physiol* 8:423, 2017.
8. Benoist d'Azy, C, Pereira, B, Chiambaretta, F, and Dutheil, F. Oxidative and Anti-Oxidative Stress Markers in Chronic Glaucoma: A Systematic Review and Meta-Analysis. *PLoS One* 11:e0166915, 2016.

9. Binnie, MJ, Dawson, B, Arnot, MA, Pinnington, H, Landers, G, and Peeling, P. Effect of sand versus grass training surfaces during an 8-week pre-season conditioning programme in team sport athletes. *J Sports Sci* 32:1001-1012, 2014.

10. Binnie, MJ, Dawson, B, Pinnington, H, Landers, G, and Peeling, P. Effect of training surface on acute physiological responses after interval training. *J Strength Cond Res* 27:1047-1056, 2013.

11. Binnie, MJ, Dawson, B, Pinnington, H, Landers, G, and Peeling, P. Part 2: effect of training surface on acute physiological responses after sport-specific training. *J Strength Cond Res* 27:1057-1066, 2013.

12. Binnie, MJ, Dawson, B, Pinnington, H, Landers, G, and Peeling, P. Sand training: a review of current research and practical applications. *J Sports Sci* 32:8-15, 2014.

13. Binnie, MJ, Peeling, P, Pinnington, H, Landers, G, and Dawson, B. Effect of surface-specific training on 20-m sprint performance on sand and grass surfaces. *J Strength Cond Res* 27:3515-3520, 2013.

14. Bishop, D. A comparison between land and sand-based tests for beach volleyball assessment. *J Sports Med Phys Fitness* 43:418-423, 2003.

15. Bradley, PS, Sheldon, W, Wooster, B, Olsen, P, Boanas, P, and Krustrup, P. High-intensity running in English FA Premier League soccer matches. *J Sports Sci* 27:159-168, 2009.

16. Chelly, MS, Fathloun, M, Cherif, N, Ben Amar, M, Tabka, Z, and Van Praagh, E. Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. *J Strength Cond Res* 23:2241-2249, 2009.

17. Cohen, J. *Statistical power analysis for the behavioral sciences.* Hillsdale (NJ): Lawrence Erlbaum Associates, 1988.

18. Cormie, P, McGuigan, MR, and Newton, RU. Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. *Sports Med* 41:125-146, 2011.

19. de Morton, NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother* 55:129-133, 2009.

20. de Villarreal, ES, Kellis, E, Kraemer, WJ, and Izquierdo, M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *J Strength Cond Res* 23:495-506, 2009.

21. Egger, M, Davey Smith, G, Schneider, M, and Minder, C. Bias in meta-analysis detected by a simple, graphical test. *BMJ* 315:629-634, 1997.

22. Freitas, TT, Calleja-Gonzalez, J, Carlos-Vivas, J, Marin-Cascales, E, and Alcaraz, PE. Short-term optimal load training vs a modified complex training in semi-professional basketball players. *J Sports Sci* 37:434-442, 2019.

23. Giatsis, G, Kollias, I, Panoutsakopoulos, V, and Papaiakovou, G. Biomechanical differences in elite beach-volleyball players in vertical squat jump on rigid and sand surface. *Sports Biomech* 3:145-158, 2004.

24. Giatsis, G, Panoutsakopoulos, V, and Kollias, IA. Biomechanical differences of arm swing countermovement jumps on sand and rigid surface performed by elite beach volleyball players. *J Sports Sci* 36:997-1008, 2018.

25. Häkkinen, K, Komi, PV, and Alén, M. Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. *Acta Physiol Scand* 125:587-600, 1985.

26. Hammami, M, Bragazzi, NL, Hermassi, S, Gaamouri, N, Aouadi, R, Shephard, RJ, and Chelly, MS. The effect of a sand surface on physical performance

responses of junior male handball players to plyometric training. *BMC Sports Sci Med Rehabil* 12:26, 2020.

27. Higashihara, A, Nagano, Y, Ono, T, and Fukubayashi, T. Differences in hamstring activation characteristics between the acceleration and maximum-speed phases of sprinting. *J Sports Sci* 36:1313-1318, 2018.

28. Higgins, JP, Altman, DG, Gøtzsche, PC, Jüni, P, Moher, D, Oxman, AD, Savovic, J, Schulz, KF, Weeks, L, and Sterne, JA. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 343:d5928, 2011.

29. Higgins, JPT, Thomas, J, Chandler, J, Cumpston, M, Li, T, Page, MJ, and Welch, VA. *Cochrane handbook for systematic reviews of interventions*. Chichester (UK): John Wiley & Sons, 2019.

30. Impellizzeri, FM, Rampinini, E, Castagna, C, Martino, F, Fiorini, S, and Wisloff, U. Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *Br J Sports Med* 42:42-46, 2008.

31. Jeffreys, I. Movement training for field sports: Soccer. *Strength Cond J* 30:19-27, 2008.

32. Komi, PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *J Biomech* 33:1197-1206, 2000.

33. Krentz, JR and Farthing, JP. Neural and morphological changes in response to a 20-day intense eccentric training protocol. *Eur J Appl Physiol* 110:333-340, 2010.

34. Lejeune, TM, Willems, PA, and Heglund, NC. Mechanics and energetics of human locomotion on sand. *J Exp Biol* 201:2071-2080, 1998.

35. Loturco, I, Bishop, C, Freitas, TT, Pereira, LA, and Jeffreys, I. Vertical Force Production in Soccer: Mechanical Aspects and Applied Training Strategies. *Strength Cond J* 42:6-15, 2020.

36. Loturco, I, Kobal, R, Kitamura, K, Abad, CCC, Faust, B, Almeida, L, and Pereira, LA. Mixed training methods: effects of combining resisted sprints or plyometrics with optimum power loads on sprint and agility performance in professional soccer players. *Front Physiol* 8:1034, 2017.

37. Loturco, I, Pereira, LA, Abad, CC, Tabares, F, Moraes, JE, Kobal, R, Kitamura, K, and Nakamura, FY. Bar velocities capable of optimising the muscle power in strength-power exercises. *J Sports Sci* 35:734-741, 2017.

38. Loturco, I, Pereira, LA, Cal Abad, CC, D'Angelo, RA, Fernandes, V, Kitamura, K, Kobal, R, and Nakamura, FY. Vertical and horizontal jump tests are strongly associated with competitive performance in 100-m dash events. *J Strength Cond Res* 29:1966-1971, 2015.

39. Loturco, I, Pereira, LA, Reis, VP, Zanetti, V, Bishop, C, and McGuigan, MR. Traditional free-weight versus variable resistance training applied to elite young soccer players during a short preseason: Effects on strength, speed, and power performance. *J Strength Cond Res* In Press, 2020.

40. Mann, RA and Hagy, J. Biomechanics of walking, running, and sprinting. *Am J Sports Med* 8:345-350, 1980.

41. Mero, A, Komi, PV, and Gregor, RJ. Biomechanics of sprint running. A review. *Sports Med* 13:376-392, 1992.

42. Mirzaei, B, Norasteh, AA, and Asadi, A. Neuromuscular adaptations to plyometric training: depth jump vs. countermovement jump on sand. *Sport Sci Health* 9:145-149, 2013.

43. Miyama, M and Nosaka, K. Influence of surface on muscle damage and soreness induced by consecutive drop jumps. *J Strength Cond Res* 18:206-211, 2004.

44. Moher, D, Shamseer, L, Clarke, M, Ghersi, D, Liberati, A, Petticrew, M, Shekelle, P, and Stewart, LA. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev* 4:1, 2015.

45. Nicol, C, Avela, J, and Komi, PV. The stretch-shortening cycle : a model to study naturally occurring neuromuscular fatigue. *Sports Med* 36:977-999, 2006.

46. Ozen, G, Atar, O, and Koc, H. The Effects of A 6-Week Plyometric Training Programme on Sand Versus Wooden Parquet Surfaces on the Physical Performance Parameters of Well-Trained Young Basketball Players. *Montenegrin J Sports Sci Med* 9:27-32, 2020.

47. Pareja-Blanco, F, Pereira, LA, Freitas, TT, Alcaraz, PE, Reis, VP, Guerriero, A, Arruda, AFS, Zabaloy, S, Sáez De Villarreal, E, and Loturco, I. Acute Effects of Progressive Sled Loading on Resisted Sprint Performance and Kinematics. *J Strength Cond Res*, 2020.

48. Pareja-Blanco, F, Sáez de Villarreal, E, Bachero-Mena, B, Mora-Custodio, R, Asián-Clemente, JA, Loturco, I, and Rodríguez-Rosell, D. Effects of Unloaded Sprint and Heavy Sled Training on Sprint Performance in Physically Active Women. *Int J Sports Physiol Perform*:1-7, 2020.

49. Pinnington, HC and Dawson, B. The energy cost of running on grass compared to soft dry beach sand. *J Sci Med Sport* 4:416-430, 2001.

50. Pinnington, HC, Lloyd, DG, Besier, TF, and Dawson, B. Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. *Eur J Appl Physiol* 94:242-253, 2005.

51. Ramirez-Campillo, R, Alvarez, C, Garcia-Pinillos, F, Garcia-Ramos, A, Loturco, I, Chaabene, H, and Granacher, U. Effects of Combined Surfaces vs. Single-

Surface Plyometric Training on Soccer Players' Physical Fitness. *J Strength Cond Res* In Press, 2019.

52. Riviere, M, Louit, L, Strokosch, A, and Seitz, LB. Variable Resistance Training Promotes Greater Strength and Power Adaptations Than Traditional Resistance Training in Elite Youth Rugby League Players. *J Strength Cond Res* 31:947-955, 2017.

53. Sharma, R and Chaubey, D. Effect of Sand Training on Jumping Abilities of Junior Volleyball Players. *J Educ Prac* 4:101-106, 2013.

54. Taylor, JB, Wright, AA, Dischiavi, SL, Townsend, MA, and Marmon, AR. Activity Demands During Multi-Directional Team Sports: A Systematic Review. *Sports Med* 47:2533-2551, 2017.

55. Tillin, NA, Pain, MT, and Folland, JP. Short-term training for explosive strength causes neural and mechanical adaptations. *Exp Physiol* 97:630-641, 2012.

56. Trajković, N, Sporiš, G, and Krističević, T. Does training on sand during off-season improves physical performance in indoor volleyball players? *Acta Kinesiologica* 10:107, 2016.

57. Varley, MC and Aughey, RJ. Acceleration profiles in elite Australian soccer. *Int J Sports Med* 34:34-39, 2013.

58. Wisloff, U, Castagna, C, Helgerud, J, Jones, R, and Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38:285-288, 2004.

59. Zamparo, P, Perini, R, Orizio, C, Sacher, M, and Ferretti, G. The energy cost of walking or running on sand. *Eur J Appl Physiol Occup Physiol* 65:183-187, 1992.

FIGURE CAPTIONS

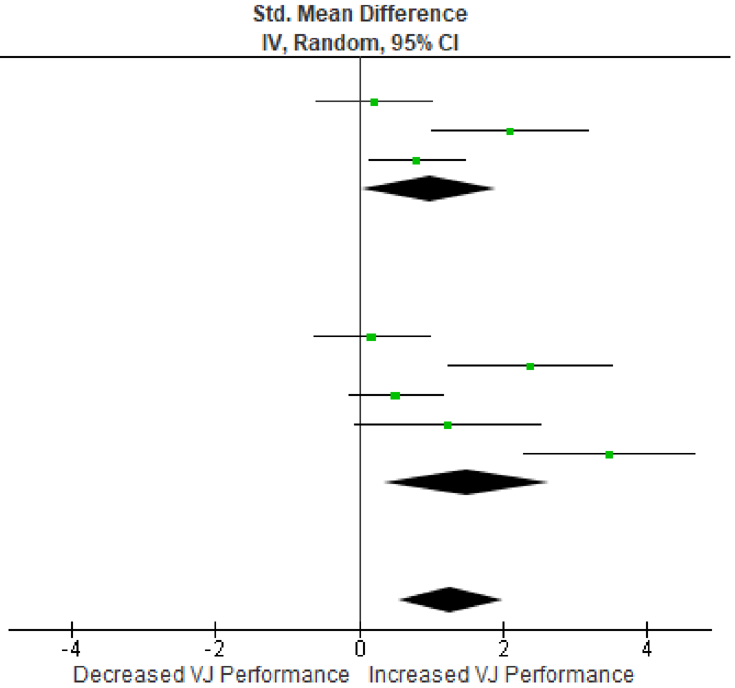
Figure 1. Standardized mean difference (SMD) between post- and pre-interventions for vertical jump (VJ) performance in team-sport players. Squares represent the SMD for each trial. Diamonds represent the pooled SMD across trials. SJ: squat jump; CMJ: countermovement jump; BJ: block jump.

Figure 2. Standardized mean difference (SMD) between post- and pre-interventions for sprint time in team-sport players. Squares represent the SMD for each trial. Diamonds represent the pooled SMD across trials.

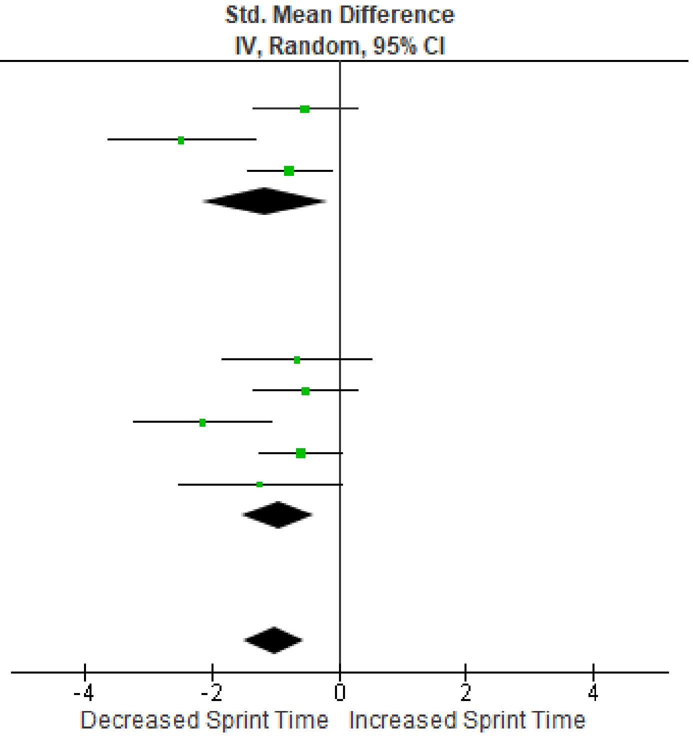
Figure 3. Standardized mean difference (SMD) between interventions on sand and hard surfaces for vertical jump (VJ) performance in team-sport players. Squares represent the SMD for each trial. Diamonds represent the pooled SMD across trials. SJ: squat jump; CMJ: countermovement jump; BJ: block jump.

Figure 4. Standardized mean difference (SMD) between interventions on sand and hard surfaces for sprint time in team-sport players. Squares represent the SMD for each trial. Diamonds represent the pooled SMD across trials.

Study or Subgroup	Post-Training Mean	Post-Training SD	Post-Training Total	Pre-Training Mean	Pre-Training SD	Pre-Training Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 SJ								
Binnie et al 2014 (SJ)	917	300	12	849	315	12	13.3%	0.21 [-0.59, 1.02]
Hammami et al 2020 (SJ)	36.6	3.3	11	28.6	4	11	11.8%	2.10 [1.02, 3.18]
Impellizzeri et al 2008 (SJ)	37.8	4	19	34.3	4.5	19	14.1%	0.80 [0.14, 1.47]
Subtotal (95% CI)			**42**			**42**	**39.2%**	**0.97 [0.03, 1.91]**
Heterogeneity: $Tau^2 = 0.50$; $Chi^2 = 7.57$, df = 2 (P = 0.02); $I^2 = 74\%$								
Test for overall effect: Z = 2.03 (P = 0.04)								
1.1.2 CMJ, BJ								
Binnie et al 2014 (CMJ)	1,063	327	12	1,003	349	12	13.3%	0.17 [-0.63, 0.97]
Hammami et al 2020 (CMJ)	40.3	5.3	11	29.2	3.5	11	11.4%	2.38 [1.24, 3.52]
Impellizzeri et al 2008 (CMJ)	39.6	5.5	19	37.2	3.6	19	14.2%	0.51 [-0.14, 1.15]
Ozen et al 2020 (CMJ)	63.3	6.03	6	54.9	6.61	6	10.7%	1.23 [-0.05, 2.51]
Sharma and Chaubey 2013 (BJ)	52.9	1.23	15	48.3	1.35	15	11.2%	3.47 [2.28, 4.65]
Subtotal (95% CI)			**63**			**63**	**60.8%**	**1.49 [0.34, 2.64]**
Heterogeneity: $Tau^2 = 1.44$; $Chi^2 = 28.63$, df = 4 ($P < 0.00001$); $I^2 = 86\%$								
Test for overall effect: Z = 2.54 (P = 0.01)								
Total (95% CI)			**105**			**105**	**100.0%**	**1.27 [0.55, 2.00]**
Heterogeneity: $Tau^2 = 0.86$; $Chi^2 = 36.76$, df = 7 ($P < 0.00001$); $I^2 = 81\%$								
Test for overall effect: Z = 3.45 (P = 0.0006)								
Test for subgroup differences: $Chi^2 = 0.47$, df = 1 (P = 0.49), $I^2 = 0\%$								

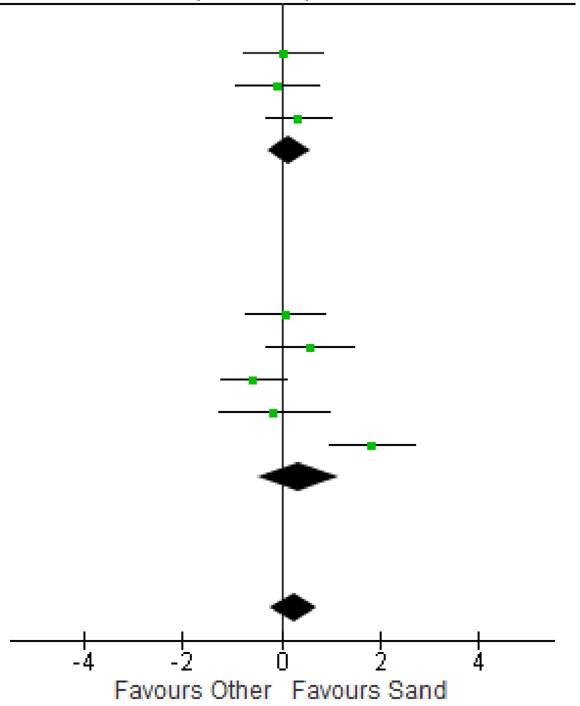


Study or Subgroup	Post-Training Mean	Post-Training SD	Post-Training Total	Pre-Training Mean	Pre-Training SD	Pre-Training Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 10-m								
Binnie et al 2014 (10-m)	2.03	0.08	12	2.08	0.1	12	14.1%	-0.53 [-1.35, 0.28]
Hammami et al 2020 (10-m)	1.68	0.23	11	2.17	0.14	11	9.8%	-2.48 [-3.64, -1.31]
Impellizzeri et al 2008 (10-m)	1.8	0.11	19	1.88	0.09	19	16.5%	-0.78 [-1.44, -0.12]
Subtotal (95% CI)			**42**			**42**	**40.4%**	**-1.17 [-2.15, -0.18]**
Heterogeneity: Tau² = 0.56; Chi² = 7.87, df = 2 (P = 0.02); I² = 75%								
Test for overall effect: Z = 2.32 (P = 0.02)								
2.1.2 >10-m								
Binnie et al 2013 (20-m)	3.41	0.22	6	3.57	0.23	6	9.7%	-0.66 [-1.83, 0.52]
Binnie et al 2014 (20-m)	3.49	0.16	12	3.58	0.17	12	14.1%	-0.53 [-1.34, 0.29]
Hammami et al 2020 (20-m)	3.14	0.11	11	3.57	0.25	11	10.6%	-2.14 [-3.23, -1.05]
Impellizzeri et al 2008 (20-m)	3.11	0.11	19	3.19	0.15	19	16.7%	-0.60 [-1.25, 0.06]
Ozen et al 2020 (30-m)	3.7	0.25	6	4.03	0.24	6	8.7%	-1.24 [-2.53, 0.04]
Subtotal (95% CI)			**54**			**54**	**59.6%**	**-0.95 [-1.51, -0.38]**
Heterogeneity: Tau² = 0.18; Chi² = 7.05, df = 4 (P = 0.13); I² = 43%								
Test for overall effect: Z = 3.26 (P = 0.001)								
Total (95% CI)			**96**			**96**	**100.0%**	**-1.02 [-1.49, -0.55]**
Heterogeneity: Tau² = 0.24; Chi² = 15.04, df = 7 (P = 0.04); I² = 53%								
Test for overall effect: Z = 4.24 (P < 0.0001)								
Test for subgroup differences: Chi² = 0.14, df = 1 (P = 0.70), I² = 0%								



Study or Subgroup	Sand Mean	Sand SD	Sand Total	Other Surface Mean	Other Surface SD	Other Surface Total	Weight	Std. Mean Difference IV, Random, 95% CI
3.1.1 SJ								
Binnie et al 2014 (SJ)	68	379.8	12	53	184.1	12	12.8%	0.05 [-0.75, 0.85]
Hammami et al 2020 (SJ)	8	4.63	11	8.4	4.19	10	12.2%	-0.09 [-0.94, 0.77]
Impellizzeri et al 2008 (SJ)	3.5	5.32	19	1.8	3.96	18	14.4%	0.35 [-0.30, 1.00]
Subtotal (95% CI)			**42**			**40**	**39.4%**	**0.15 [-0.28, 0.58]**
Heterogeneity: Tau² = 0.00; Chi² = 0.73, df = 2 (P = 0.69); I² = 0%								
Test for overall effect: Z = 0.68 (P = 0.50)								
3.1.2 CMJ, BJ								
Binnie et al 2014 (CMJ)	60	418.6	12	34	208.5	12	12.8%	0.08 [-0.72, 0.88]
Hammami et al 2020 (CMJ)	11.1	5.13	11	8.3	4.05	10	12.0%	0.58 [-0.30, 1.46]
Impellizzeri et al 2008 (CMJ)	2.4	5.3	19	5.5	5.51	18	14.3%	-0.56 [-1.22, 0.10]
Ozen et al 2020 (CMJ)	8.42	7.87	6	9.69	8.11	6	9.5%	-0.15 [-1.28, 0.99]
Sharma and Chaubey 2013 (BJ)	4.6	1.61	15	0.67	2.46	15	12.0%	1.84 [0.97, 2.71]
Subtotal (95% CI)			**63**			**61**	**60.6%**	**0.35 [-0.49, 1.19]**
Heterogeneity: Tau² = 0.73; Chi² = 19.76, df = 4 (P = 0.0006); I² = 80%								
Test for overall effect: Z = 0.81 (P = 0.42)								
Total (95% CI)			**105**			**101**	**100.0%**	**0.25 [-0.24, 0.74]**
Heterogeneity: Tau² = 0.33; Chi² = 20.63, df = 7 (P = 0.004); I² = 66%								
Test for overall effect: Z = 1.00 (P = 0.32)								
Test for subgroup differences: Chi² = 0.17, df = 1 (P = 0.68), I² = 0%								

Std. Mean Difference
IV, Random, 95% CI



Study or Subgroup	Sand Mean	Sand SD	Sand Total	Other Surface Mean	Other Surface SD	Other Surface Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.1.1 10-m								
Binnie et al 2014 (10-m)	0.05	0.11	12	0.03	0.12	12	13.7%	0.17 [-0.63, 0.97]
Hammami et al 2020 (10-m)	0.49	0.21	11	0.13	0.14	10	9.7%	1.92 [0.85, 2.99]
Impellizzeri et al 2008 (10-m)	0.08	0.12	19	0.07	0.09	18	16.8%	0.09 [-0.55, 0.74]
Subtotal (95% CI)			**42**			**40**	**40.1%**	**0.65 [-0.35, 1.65]**
Heterogeneity: Tau² = 0.60; Chi² = 8.87, df = 2 (P = 0.01); I² = 77%								
Test for overall effect: Z = 1.27 (P = 0.20)								
4.1.2 >10-m								
Binnie et al 2013 (20-m)	0.16	0.28	6	0.14	0.2	6	9.0%	0.08 [-1.06, 1.21]
Binnie et al 2014 (20-m)	0.09	0.2	12	0.03	0.19	12	13.6%	0.30 [-0.51, 1.10]
Hammami et al 2020 (20-m)	0.43	0.26	11	0.18	0.24	10	11.8%	0.96 [0.04, 1.87]
Impellizzeri et al 2008 (20-m)	0.08	0.17	19	0.09	0.1	18	16.8%	-0.07 [-0.71, 0.58]
Ozen et al 2020 (30-m)	0.33	0.3	6	0.13	0.41	6	8.7%	0.51 [-0.65, 1.67]
Subtotal (95% CI)			**54**			**52**	**59.9%**	**0.28 [-0.11, 0.67]**
Heterogeneity: Tau² = 0.00; Chi² = 3.52, df = 4 (P = 0.48); I² = 0%								
Test for overall effect: Z = 1.42 (P = 0.15)								
Total (95% CI)			**96**			**92**	**100.0%**	**0.42 [0.01, 0.83]**
Heterogeneity: Tau² = 0.15; Chi² = 12.68, df = 7 (P = 0.08); I² = 45%								
Test for overall effect: Z = 2.00 (P = 0.05)								
Test for subgroup differences: Chi² = 0.45, df = 1 (P = 0.50), I² = 0%								

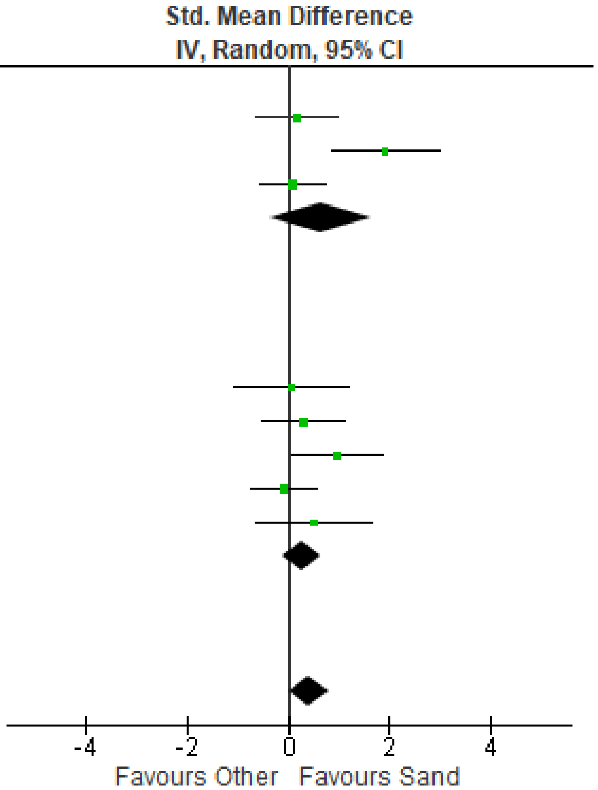


Table 1. PEDro scale scores of the studies included in the meta-analysis.

PEDro Scale Items	**Binnie et al. (2013)**	**Binnie et al. (2014)**	**Hammami et al. (2020)**	**Impellizzeri et al. (2008)**	**Ozen et al. (2020)**	**Sharma and Chaubey (2013)**
1. Eligibility Criteria (item does not score)	1	1	1	1	1	1
2. Random Allocation	1	1	-	1	1	1
3. Concealed Allocation	1	1	1	1	1	1
4. Similar Groups at Baseline	1	1	1	1	1	-
5. Blinding of Subjects	-	-	-	-	-	-
6. Blinding of Therapists	-	-	-	-	-	-
7. Blinding of Assessors	-	-	-	-	-	-
8. Measure of one Key Outcome - 85% of Subjects	1	1	1	1	1	1
9. Intention to Treat	1	1	1	1	1	1
10. Between-Group Comparison	1	1	1	1	1	-
11. Point Estimate and Variability	1	1	1	1	1	1
Total Score	7 (High)	7 (High)	6 (High)	7 (High)	7 (High)	5 (Moderate)

Table 2. Characteristics of the studies included in the meta-analysis in relation to training intervention and/or jump and sprint assessments.

Reference	Groups	n	Age (years) Mean ± SD	Gender	Sport	Season Period	Level	Training Description	Freq.	Duration	Jump		Sprint	
											Measure	Type	Measure	Distance
Binnie et al. (2013)	Sand	6	22.2 ± 2.7	10 F 2 M	Netball and field hockey	NR	Well-trained	Short sprint and agility drills	3x/wk	8 wks	-		Photocell	20-m
	Grass	6	20.2 ± 1.9											
Binnie et al. (2014)	Sand	12	19.3 ± 7.1	F	Netball and field hockey	Pre-season	Well-trained	Mix of HIIT, SPD, CODS, RSA, SSG	3x/wk	8 wks	Yardstick	SJ, CMJ	Photocell	10- and 20-m
	Grass	12	20.8 ± 4.3											
Hammami et al. (2020)	Sand	11	16.2 ± 0.6	M	Handball	NR	Junior Under 17	Hopping, lateral and frontal hurdles, and horizontal jumps, 10-m linear sprints	3x/wk	7 wks	Infrared photocell mat	SJ, CMJ	Photocell	10- and 20-m
	Gym Floor	10	16.4 ± 0.5											
Impellizzeri et al. (2008)	Sand	19	25 ± 4	NR	Soccer	Competitive	Amateur	Vertical, horizontal and drop jumps	3x/wk	4 wks	Contact mat	SJ, CMJ	Photocell	10- and 20-m
	Grass	18												
Ozen et al. (2020)	Sand	6	17.6 ± 0.5	M	Basketball	Off-Season	Under 19 highly trained	Unilateral, bilateral and repeated vertical jumps, and horizontal jumps	3x/wk	6 wks	Digital jump meter device	CMJ	Photocell	30-m
	Wood	6												
Sharma and Chaubey (2013)	Sand	15	16 – 19	NR	Volleyball	NR	Under 20	Squat jumps with weighted vest; depth, box and tuck jumps	2-3x/wk	6 wks	Measuring tape	BJ	-	
	Court Floor	15						Regular volleyball training on hard court	NR					

BJ: block jump; CODS: change of direction speed; CMJ: countermovement jump; F: female; HIIT: high-intensity interval training; M: male; NR: not reported; RSA: repeated sprint ability; SD: standard deviation; SJ: squat jump; SPD: speed and power drills; SSG: small-sided games.