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TITLE PAGE

The effect of beach volleyball training on muscle performance of indoor volleyball players

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ABSTRACT

BACKGROUND: Beach volleyball is frequently used as a conditioning activity for indoor volleyball players, but little information exists regarding any performance benefits when transitioning from sand to hard court. The present study examined the effect of 12 weeks beach volleyball training on muscle performance of indoor volleyball players.0

METHODS: Eleven athletes who completed an indoor volleyball season and were willing to train and compete at beach volleyball, participated in the study. Muscle endurance of knee extensors and plantar flexors (torque at 120°·s^{-1} following 40 contractions), muscle strength of knee extensors/ flexors (60, 180, 300°·s^{-1}), dorsi/ plantar flexors (torque at 60, 120, 180°·s^{-1}) trunk flexors (60, 90, 180°·s^{-1}) and power (squat (SJ) and countermovement (CMJ) jumps performed on sand and hard court surfaces) were assessed pre- and post-12 weeks of beach volleyball training.

RESULTS: Knee extensors and plantar flexors endurance was higher post-12 weeks, as less torque decrease was found after 40 contractions for both muscle groups at post-12 weeks time points. Knee extensors strength was higher post-12 weeks for 60 and 300°·s^{-1}, while dorsi flexors strength was higher post-12 weeks for all speeds. SJ and CMJ vertical jump height was improved when measured on sand and on hard court.

CONCLUSIONS: Twelve weeks of systematic training and competition at beach volleyball can improve muscular endurance of lower limbs and jumping height in indoor volleyball players. More importantly, these improvements are transferrable to hard court, making beach volleyball a very attractive alternative for conditioning indoor volleyball players during the off-indoor volleyball season.

Key words: Sand Training, Strength, Vertical Jump, Endurance, Conditioning

TEXT

Introduction

Volleyball is a very popular sport worldwide, which is divided in two related disciplines, indoor and beach volleyball, with indoor volleyball played during winter (until spring) whereas beach volleyball played during summer time. Although related, the two disciplines have some distinct differences in regulations and playing environment, imposing different demands and training adaptations on the players.[1] Indoor volleyball is played on firm surface, with each team consisting of six players covering an area of 81m^2 ,[2] and games can be played over 44 rallies per set, lasting around 67 minutes.[3] On the other hand, beach volleyball is played on sand, with each team consisting of two players covering an area of 64m^2, [2] and games typically played 78-96 rally points ranging from 30 to 64 minutes. [4-6]

These differences introduce several adaptations when playing beach volleyball in comparison to indoor volleyball. The difference in the playing surface compliance, in particular, can result in differences in the technical execution of various performance skills that require pushing off the ground, such as jumping, “diving”, short sprinting etc. When pushing off to initiate such a movement, the foot sinks in the sand, increasing the push-off phase duration of these skills. When jumping vertically, for example, this results in a greater hip extension to maintain balance during vertical jumping,[7] interfering with the co-ordination of the necessary motor tasks and the transformation of rotational to vertical velocity.[8]

This technical adaptation can, in turn, impact on the physical demands of beach volleyball, as repetitively overcoming the initial lack of fixed resistance before a skill is performed, requires exerting additional effort, increasing the energy cost of performing such tasks.[9] Players perform 219.0 ±7.4 jumps per beach volleyball match between them,[10] while each player also needs to cover a larger playing surface, and this additional effort can impose considerable stresses to the players’ bodies. The effect the playing surface can have on performance is supported by the increased jumping (by 6.5%) and 10m sprinting (by 4.3%) performances realized following sand training.[11] Similarly, maximum oxygen uptake was improved by 6.6%[2] following an 8-week sand training program. Interestingly, following 12 weeks of systematic beach volleyball training, maximum oxygen uptake was improved by 5.3%,[12] which is very comparable to Binnie et al [9] sand training improvement. Further, a 6-

week plyometric training programme, including 5 sets of 20 drop jumps, improved vertical and standing long jump (by 8% and 4%, respectively), as well as 20m and 40m sprinting performance (by 9% and 4%, respectively) and change of direction performance (by 5%); crucially, the improvements were similar to those observed with the same training on firm surface. Collectively, these results suggest that sand training can be an effective way of improving several cardiovascular and muscular performance parameters, while decreasing the impact and injury risk.[9]

With training suggestions regarding continuing conditioning throughout the season,[13] it is becoming more common for indoor volleyball players to utilize beach volleyball training as a form of conditioning activity. However, the literature typically examines specific sand training, such as a number of sets and repetitions performed regularly on sand with the rest of the training completed on normal ground (e.g. Arazi et al, 2014) [14], rather than completing full training sessions on sand. In other words, 'sand training' refers to a specific, defined exercise rather than to a complete training session performed exclusively on sand. With the exception of one study,[12] there is a dearth of evidence on the effects of beach volleyball training on muscle performance of indoor volleyball players. It is important to fully understand these effects to allow better and safer designs of training programs, as well as to ensure indoor volleyball performance is not impaired, due to the altered technical and tactical demands required to play beach volleyball. Therefore, in a novel approach, the aim of the present study was to examine the muscle performance of indoor volleyball players following 12 weeks of beach volleyball training.

Materials and methods

The study aimed to examine the effect of 12 weeks of beach volleyball training on muscular performance, using a pre-post test without a control group design. Eleven trained, competitive indoor volleyball players, planning to train systematically and compete in tournaments of the Hellenic Volleyball Federation were assessed pre- and post-12 weeks on muscular endurance (torque after 40 knee extension repetitions), strength (torque at three different velocities) and power (countermovement and squat jumps). Analysis of variance of the results was utilized to make respective comparisons between pre- and post-12 weeks.

Subjects

Following Institutional ethical approval, eleven male amateur indoor volleyball players (mean ± SD: age 26.5 ±3.3 years, height 1.87 ± 0.05m, body mass 84.6 ± 6.2 kg) provided written, informed consent to participate in the study. All players had training and competitive playing experience of 13.2 ±3.3 years. Just before taking part to the study, all players had completed an indoor volleyball season with their clubs and were free of any injuries. These players were approached as they were going to train systematically at beach volleyball in order to participate in tournaments of the Hellenic Volleyball Federation during summer time. The sand volleyball training took place over 12 weeks from mid-May to mid-August and was not manipulated as the players followed their own structured training routine (same for all players). More specifically, the players participated in 4-6 training sessions per week of 1.5-2 hours duration each, including specific beach volleyball drills, exercises, tactics and several friendly matches. During weekends (after the fourth weekend), they participated in beach volleyball tournaments, playing 2 up to 5 matches per day. A priori exclusion criteria were set for players to be excluded if they trained less than 4 sessions a week, competed in less than 5 official tournaments and got injured resulting in more than two rest days. However, none of the players fell under the above criteria and all players were included in the study.

Measurements of muscle performance

Lower limb muscle endurance, strength and power were assessed at pre- and post-12 weeks of beach volleyball training. Knee extensors and plantar flexors were assessed for muscular endurance, while knee extensors/flexors, plantar flexors, dorsi flexors and trunk flexors were assessed for muscular strength. Knee extensor / flexors assessment was conducted with the subjects sat in a dynamometer chair (Humac Norm, model 770, Computer Sports Medicine Inc., Sloughton, M.A., USA). Straps were placed at the shoulders, pelvis and tested thigh, to avoid extraneous movement, while the non-tested limb was immobilized. The ankle of the tested leg was securely strapped to the dynamometer arm, just above the lateral malleolus. The subjects were instructed to have their arms crossed over their chest and grip the shoulder straps. For the plantar extensors and dorsi flexors assessment, the subjects laid prone to the dynamometer chair, while a strap was placed around their pelvis. The tested leg's foot was securely strapped to a footplate at the dynamometer arm. Subjects were instructed to grip the dynamometer handles at the back of the dynamometer chair. Finally, for trunk flexors strength assessment the subject stood erect, with their back and legs against a supporting frame. Two stabilizing pads were fixed above and below the patella, while a strap was placed around their pelvis. An extension to the dynamometer's arm was fixed across the subjects' back at shoulder height and a strap was securely placed around the chest at the same height, allowing measurement of trunk flexion.

For the assessment of muscular endurance, subjects completed 40 repetitions of knee extension at $120°\cdot s^{-1}$. Subsequently, subjects performed a maximum voluntary contraction (MVC) at $120°\cdot s^{-1}$ for both knee extensors and plantar flexors. Two trials were performed and if the coefficient of variation (calculated as standard deviation of the two trials / average of the two trials x 100) was less than 5%, then the average of the two was used. Otherwise, a third trial was performed and the two closest ones were averaged. Rest of one minute was provided between MVC efforts.

For the assessment of muscular strength, subjects performed three isokinetic contractions at three different speeds for the knee extensors / flexors (at 60, 180, and $300°\cdot s^{-1}$), plantar / dorsi flexors (at 60, 120 and $180°\cdot s^{-1}$), and trunk flexors (at 60, 90, $180°\cdot s^{-1}$) and the average was recorded and used for further analysis.

Finally, for lower limb power, a squat (SJ) and a countermovement (CMJ) jump were performed. Subjects were instructed to jump with (and maintain) their arms by their side and aim for maximum jump height. For both SJ and CMJ, a 90° knee flexion was used. Both SJ and CMJ took place on hard court as well as on dry sand. The sand was contained into a special box with depth and the grain size in accordance with the sport's governing body rules.[2] Three trials from each jump were performed on both surfaces, with at least one minute's rest, and the best jump (defined as the highest jump) was selected. Jump height was assessed with an accelerometer (Myotest Pro, Sion, Switzerland), attached to the lumbar region of the subject and on a Velcro belt which was securely placed around the subjects' waist [15] SJ and CMJ heights were also used to calculate pre-stretch augmentation ((CMJ-SJ)/SJ*100)) as an indicator of stretch shortening cycle.[16]

All muscular endurance and strength testing took place on the right limb. All contractions performed were concentric (CON/CON dynamometer mode). The order by which each subject muscles' group and velocities was tested, was randomized between subjects (but kept the same for each subject's pre-post measurements). All subjects were tested at the same time of day pre- and post-12 weeks. Each subject completed all tests on the same day, with the CMJ and SJ always performed first. Finally, all subjects refrained from caffeine two hours prior to testing and alcohol consumption 48 hours prior to testing.

Statistics

Normality of data was examined using the Shapiro-Wilk test and subsequently confirmed for all variables. A paired samples t-test was used to compare knee extensors and plantar flexors muscular endurance between pre- and post-12 weeks. Knee extensors, knee flexors, plantar flexors, dorsi flexors and trunk flexors strength were examined with a 2 (pre-post 12 weeks) x 3 (testing velocity) repeated measures ANOVA. When a significant difference was revealed, paired samples t-test with Holm-Bonferroni correction were used to examine where that difference was. Finally, squat and countermovement jump height for pre- and post-12 weeks, respectively, was examined using a paired samples t-test. Effect sizes were calculated for significant differences to indicate practical significance, with 0.2, 0.5 and 0.8 representing small, moderate and large effects, respectively.[17]

Results

Endurance performance

Knee extensors endurance differences were found when comparing knee extensors torque scores pre- and post-12 weeks, with higher scores post-12 weeks (pre: 89.6 ± 13.8 N·m, post: 97.5 ± 14.2 N·m, $p = 0.042$, ES= 0.6). Similarly, significantly higher torque was revealed for the plantar flexors post-12 weeks training (pre: 40.3 ± 12.5 N·m, post: 44.6 ± 14.2 N·m, $p = 0.01$, ES = 0.8).

Strength performance

Descriptive statistics for all muscles and all velocities pre-post 12 weeks can be seen in Table I.

TABLE I ABOUT HERE

Knee extensors strength showed differences between pre- and post-12 weeks and at different speeds, with higher torque scores at post-12 weeks revealed for $60°·s^{-1}$ ($p = 0.030$, ES = 0.2) and $300°·s^{-1}$ ($p = 0.043$, ES = 0.03) but not for $180°·s^{-1}$ ($p = 0.064$). Dorsi flexors strength also showed pre-post differences for the 12 weeks programme with higher scores at post-12 weeks ($60°·s^{-1}$: $p = 0.036$, ES = 1.0; $120°·s^{-1}$: $p = 0.047$, ES = 0.7; $180°·s^{-1}$: $p = 0.036$, ES = 1.0). In contrast, knee flexors, plantar flexors and trunk flexors strength was not different ($p < 0.05$) following 12 weeks of beach volleyball training.

Predictably, comparisons between the three different velocities at pre- and post-12 weeks showed the higher velocities having consistently lower force with large effect sizes (ES> 0.8) for all muscles (Table I).

Power performance

Pre- to post-12 weeks jump height was improved when measured on sand for both SJ (5.6% increase, $p = 0.030$, ES = 0.44) and CMJ (11.6% increase, $p = 0.033$, ES = 0.93) as well when measured on hard court, for both SJ (6.4% increase, $p = 0.001$, ES = 0.52) and CMJ (6.0% increase, $p = 0.030$, ES = 0.63) (Figure 1).

FIGURE 1 ABOUT HERE

Pre-stretch augmentation was not different pre- to post-12 weeks for either jumping surfaces (hard court: 19.7 ± 8.4% and 17.3 ± 5.9% pre- and post-12 weeks, respectively, $p=0.402$; sand: 18.3 ± 8.6% and 19.8 ± 7.0% pre- and post-12 weeks, respectively, $p=0.472$), suggesting no improvement in stretch shortening cycle activity.

Discussion

The aim of the present study was to examine the effect of 12 weeks of beach volleyball training on muscle strength, endurance and power of indoor volleyball players. The results suggest that 12 weeks of beach volleyball training enhances endurance of knee extensors and plantar flexors, strengthen the dorsi flexors, and improves leg power but not through enhanced stretch shortening cycle. These findings support the use of beach volleyball training as a viable conditioning activity for volleyball players.

The improvement in knee extensors and plantar flexors endurance is likely the result of the higher energy demands of moving and performing the various skills on sand.There is evidence suggesting that sand training is more demanding compared to training on firm surfaces, as the energy cost rises significantly.[18-21] More specifically, repetitive jumping on sand requires ~1.2 times the energy expenditure of that needing to jump on solid surface [21] and this ratio reaches the one for comparing running on sand and running on solid surface, which is 1.2–1.6 higher.[18-21] Indeed, a significant increase in VO_{2max} was seen after 8 weeks of training on sand,[9] while VO_{2max} also increased after 12 weeks of systematic beach volleyball training and competition.[12]

Statistically significant strength improvements were only seen for knee extensors and dorsi flexors, but not for knee flexors, plantar flexors and trunk flexors. The effect sizes for the knee extensors, however, were small, suggesting that the magnitude of the change is probably too small to have practical significance. Our results are largely in agreement with findings from trained male volleyball players, who showed no improvement in strength following an 8-week volleyball training programme, including resistance exercises.[23] Interestingly, strength was shown to improve in trained female volleyball players in two previous reports.[24 25] Although gender differences might be a factor, it is also likely that the strength training status of the female players in Pereira [25] study (‘None of the participants had a history of strength training’) compared to the Newton [23] study (‘All subjects had a minimum of 2 yr resistance training..’) could result in one group more likely to show improvements in strength. Notwithstanding the above discrepancies, when considering that the above studies used some form of resistance exercises, while the present study only used beach volleyball training, it would seem reasonable to suggest that the training stimulus in the present study was not sufficient to induce strength changes.

The above conclusion, however, appears to not hold true for the dorsi flexors, as a substantial increase in strength following the 12-week beach volleyball training programme was revealed. A possible explanation revolves around the function of these muscles, as dorsi flexors assist in maintaining balance.[26] Performance on an unstable absorptive ground, such as sand, is likely to require more work by these muscles in order to maintain better balance and consequently perform the various game skills described before. This, in turn, will lead to increase strength production. Indeed, some support for this notion can be found in results from Binnie et al [9] who reported improved balance after 8 weeks of sand training in team sports athletes, attributed to increased muscle's activation during sand training increasing stability and proprioception.[27]

It is generally accepted that good jumping performance is considered as critical performance indicator for the elite volleyball athlete,[13] as First Division players demonstrate a significantly higher jump height compared to Second Division players,[28] due to its importance in performing jump-related game tasks (blocking or spiking,[29] jump power serve [30]). In the present study, maximal SJ and CMJ height on sand was predictably found to be lower in comparison to solid surface. More importantly, both jump types showed a greater jump height on both surfaces following the 12-week program. Indeed, the increases obtained are within the improvement range (5-10%) expected following explosive training in trained volleyball players.[13]

These increases were achieved without any differences in the pre-stretch augmentation, suggesting no change in the effectiveness of the stretch-shortening cycle. Our results are in disagreement with Impellizzeri et al [11] who reported a decreased eccentric utilisation ratio (i.e. the ratio of countermovement jump over the squat jump) following an 8-week training program. Although the present study had a longer duration than the Impellizzeri et al [11] study, the duration is unlikely to have impacted on these results. The more likely explanation is the type of training used in the two studies; sand training in Impellizzeri et al [11] while beach volleyball training in the present one. As friendly games and tournaments were included in the present study, it is likely the demands of the game for successful outcomes following a jump, have improved coordination of the jump movement, in particular the countermovement one, as more specific to the game. Indeed, the percentage increases achieved on sand for the present study support this notion. CMJ performance improved by 11.6% while SJ only by 5.6%. As the pre-stretch augmentation was not different and the strength of the knee extensors and plantar flexors did not increase, better segment co-ordination appears as the more feasible explanation. Both jump performance and pre-stretch augmentation results taken together, suggest that beach volleyball training can be a very effective conditioning method to improve leg power.

To our knowledge, there are only a few studies examining the effects of systematic long term sand training on jump performance. Impellizzeri et al [11] revealed that plyometric training on sand can cause improvements both on vertical jump and sprint. In agreement to these results, our study revealed that improvements were realised in vertical jump performance on sand but, more importantly, also on solid surface after 12 weeks of beach volleyball training and competition. Therefore, transition of the improved vertical jump performance on sand can be achieved on solid surface, increasing the chances of successful volleyball performance.[13] These findings add to a previous study showing transfer of sand training adaptations in agility performance to solid surfaces.[31] Taken together, these findings support the use of beach volleyball as a conditioning activity by indoor volleyball players, as it not only it can improve several muscle performance parameters comparably to other forms of training but the performance improvements are transferrable to the hard court, consequently aiding improved physical performance in indoor volleyball.

The lack of a control group potentially requires careful consideration of the results. The difficulty in obtaining a control group for longer training studies has been previously highlighted; reasons can include ethical considerations, difficulty in finding a matching control group, access to testing equipment and sessions [11] [24] or a ‘natural experiment’ approach, where the point of interest happens without the researcher manipulating the intervention, such as in the present study.[32] Regardless of this limitation, the large effect sizes obtained as well as the magnitudes of improvement being in line with published literature, makes us confident that the results are not circumstantial and they can assist coaches in planning appropriate conditioning programmes for volleyball.

Conclusions

Twelve weeks of systematic training and competition at beach volleyball can improve muscular endurance of lower limbs as well as jumping height in indoor volleyball players. More importantly, these improvements are transferrable to hard court, making beach volleyball a very attractive alternative to for conditioning indoor volleyball players in during the off-indoor volleyball season

References

1. Smith R. Movement in the sand: Training implications for beach volleyball. Strength Cond J 2006;28(5):19-21.

2. Fédération Internationale de Volleyball. Official beach volleyball rules [Internet]. 2015; Available from: http://www.fivb.org/EN/Refereeing-Rules/RulesOfTheGame_BVB.asp

3. Mrozcek D, Januszkiewicz A, Kawczynski AS, Borysiuk Z, Chmura J. Analysis of male volleyball players' motor activities during a top level match. J Strength Conditioning Res 2014;28(8):2297-2305.
4. Giatsis G, Kollias I, Panoutsakopoulos V, Papaiakovou G. Biomechanical differences in elite beach-volleyball players in vertical squat jump on rigid and sand surface. Sports Biomech 2004;3(1):145-158.
5. Giatsis G, Zetou E. The influence of regulations changes on the fluctuation of score of beach volleyball games. Inquiries in Sport and Physical Education, 2003;1:43-48.
6. Palao JM, Valades D, Ortega E. Match duration and number of rallies in men's and women's 2000-2010 world tour beach volleyball. J Human Kin 2012;34:99-104.
7. Giatsis G. The effect of changing the rules on score fluctuation and match duration in the FIVB women's beach volleyball. International Journal of Performance Analysis in Sport 2003;3:57-64.

8. Bobbert MF, Van Soest AJ. Why the people jump the way they do? Exerc Sport Sci Rev 2001;29(3):95-102.

9. Binnie MJ, Dawson B, Arnot MA, Pinnington H, Landers G, Peeling P. Effect of sand versus grass training surfaces during an 8-week pre-season conditioning programme in team sport athletes. J Sport Sci 2014;32(11):1001-1012.

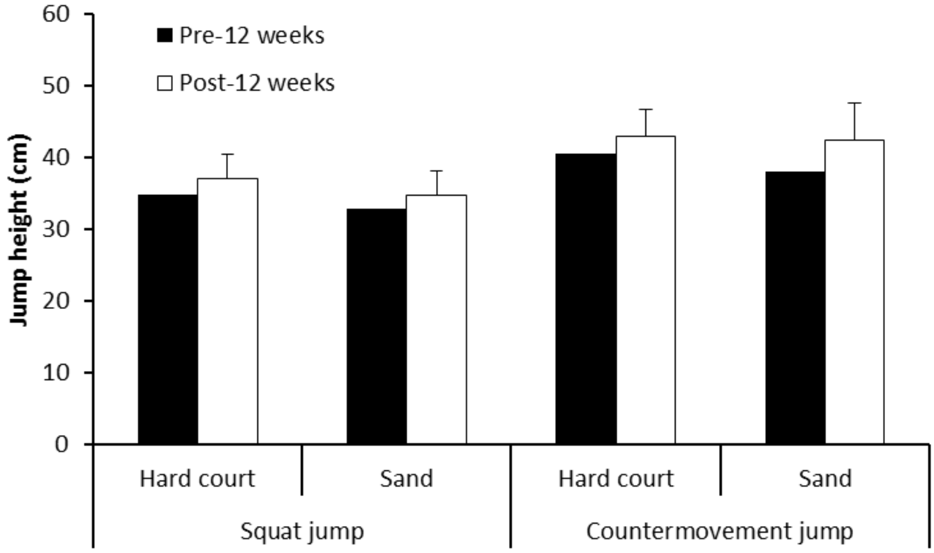
10. Turpin JPA, Cortell JM, Chinchilla JJ, Cejuela R, Suarez C. Analysis of jump patterns in competition for elite male beach volleyball players. Int J Perform Anal Sport 2008;8(2):94-101.
11. Impellizzeri FM, Rampinini E, Castagna C, Martino F, Fiorini S, Wisloff U. Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. Br J Sports Med 2008;42:42-46.

12. Balasas D, Vamvakoudis E, Christoulas K, Stefanidis P, Prantsidis D, Papaevangelou, E. The effect of beach volleyball training on running economy and VO2max of indoor volleyball players. J Phys Educ Sport 2013;13(1):33-38.
13. Ziv G, Lidor R. Vertical jump in female and male volleyball players: a review of observational and experimental studies. Scand J Med Sci Sports 2010;20:556-567.
14. Arazi H, Mohammadi M, Asadi A. Muscular adaptations to depth jump plyometric training: Comparison of sand vs. land surface. Interv Med Appl Sci 2014; 6(3):125-30.
15. Casartelli N, Muller R, Maffiuletti N. Validity and reliability of the myotest accelerometric system for the assessment of vertical jump height. J Strength Cond Res 2010;24(11):3186-3193.
16. Walshe AD, Wilson GJ, Murphy AJ. The validity and reliability of a test of lower body musculotendinous stiffness. Eur J Appl Physiol Occup Physiol 1996;73(3-4):332-9.
17. Fritz CO, Morris PE, Richler JJ. Effect size estimates: Current use, calculations, and interpretation. J Exp Psychol 2012;141(1):2-18.
18. Gaudino P, Gaudino C, Alberti G, Minetti AE. (2013). Biomechanics and predicted energetics of sprinting on sand: Hints for soccer training. J Sci Med Sport 2013;16:271-275.
19. Lejeune TM, Willems PA, Heglund NC. Mechanics and energetics of human locomotion on sand. J Exp Biol 1998;201:2071-2080.
20. Pinnington HC, Dawson B. The energy cost of running on grass compared to soft dry sand. J Sci Med Sport 2001;4(4):416-430.
21. Zamparo P, Perini R, Orizio C, Sacher M, Ferretti G. The energy cost of walking or running on sand. Eur J Appl Physiol 1992;65:183-187.
22. Muramatsu S, Fukudome A, Motoyoshi M, Arimoto M, Kijima A. Energy expenditure in maximal jumps on sand. J Physiol Anthrop 2006;25:59-61.

23. Newton RU, Kraemer WJ, Hakkinen K. Effects of ballistic training on preseason preparation of elite volleyball players. Med Sci Sports Exerc, 1999;31(2):323-330.
24. Marques MC, Van den Tillaar R, Vesconi JD, Gonzalez-Badillo JJ. Changes in strength and power performance in elite female professional volleyball players during the in-season: A case study. J Strength Conditioning Res 2008;22(4):1147-1155.
25. Pereira A, Costa AM, Santos P, Figueiredo T, Joao PV. Training strategy of explosive strength in young female volleyball players. Medicina, 2015;126-131.
26. Di Giulio I, Maganaris CN, Baltzopoulos V, Loram ID. The proprioceptive and agonist roles of gastrocnemius, soleus and tibialis anterior muscles in maintaining human upright posture. J Physiol 2009;587(10):2399-2416.
27. Pinnington HC, Lloyd DG, Besier TF, Dawson B. Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. Eur J Appl Physiol 2005;94:242–253.
28. Forthomme B, Croisier JL, Giccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. Am J Sports Med 2005;33(10):1513–1519.
29. Sheppard JM, Gabbett TJ, Taylor KL, Dorman J, Lebedew AJ, Borgeaud R. Development of a repeated-effort test for elite men's volleyball. Int J Sports Physiol Perform 2007;2(3):292-304.
30. Laios Y. Comparison of the basic characteristics of men's and women's beach volley from the Athens 2004 Olympics. International Journal of Performance Analysis in Sport 2008;8(3):130-137.
31. Gortsila E, Theos A, Smirnioti A, Maridaki M, editors. The effect of sand based training in agility of pre-pubescent volleyball players. Proceedings of at the 16th annual congress of the European College of Sport Science, Liverpool; 2011.
32. Marques MC, Gonzalez-Badillo JJ. In season resistance training and detraining in professional team handball players. J Strength Cond Res 2006;20(3):563-571.

Table I. Average torque from isokinetic muscular contractions for the five muscle groups at the respective testing velocities (low, middle and high), at pre- post- 12 weeks of beach volleyball training. Data is presented as mean and SD. *significant difference with the respective velocity at baseline.. [b]significant difference with middle velocity. [c]significant difference with high velocity.

	Pre			Post		
			Knee Extensors			
Velocity (°·s^{-1})	60	180	300	60	180	300
Torque (N.m)	288.2 ± 36.0[b,c]	210.8 ± 21.0[c]	157.4 ± 18.0	293.7 ± 35.7[b,c]*	217.8 ± 20.7[c]	161.1 ± 15.8*
			Knee Flexors			
Velocity (°·s^{-1})	60	180	300	60	180	300
Torque (N.m)	157.2 ± 25.7[b,c]	107.3 ± 18.6[c]	77.6 ± 15.1	157.3 ± 23.7[b,c]	107.9 ± 21.2[c]	76.4 ± 19.4
			Plantar Flexors			
Velocity (°·s^{-1})	60	120	180	60	120	180
Torque (N.m)	96.8 ± 18.9[b,c]	71.0 ± 17.2[c]	54.1 ± 16.6	102.8 ± 19.7[b,c]	73.9 ± 14.3[c]	57.6 ± 12.3
			Dorsi Flexors			
Velocity (°·s^{-1})	60	120	180	60	120	180
Torque (N.m)	45.3 ± 10.7[b,c]	32.3 ± 9.5[c]	21.3 ± 7.5	54.7 ± 8.1[b,c]*	38.8 ± 8.0[c]*	29.2 ±8.0*
			Trunk Flexors			
Velocity (°·s^{-1})	60	90	180	60	90	180
Torque (N.m)	273.8 ± 63.1[b,c]	238.3 ± 45.1[c]	198.6 ± 58.5	276.4 ± 70.4[b,c]	243.2 ± 57.1[c]	206.5 ± 38.9



Fiure 1. Average jump height from Squat and countermovemoment jumps, on sand and hard court, pre- and post-12 weeks of beach volleyball training. Data is presented as means±SD.