Journal of Sports Medicine & Doping Studies
ISSN: 2161-0673
Gortsila et al., J Sports Med Doping Stud 2013, 3:2
DOI: 10.4172/2161-0673.1000128
Research Article
Open Access

Effect of Training Surface on Agility and Passing Skills of Prepubescent Female Volleyball Players

Eugenia Gortsila[1], Apostolos Theos[1], Goran Nesic[2] and Maria Maridaki[1]*

[1]Department of Physical Education & Sports Science, National & Kapodistrian University of Athens, Greece
[2]Faculty of Sport and Physical Education, University of Belgrade, Serbia

Abstract

The purpose of the present study was to investigate the effect of different training surfaces (hard or sand surface) on agility and passing skills of prepubescent female volleyball players. 45 prepubescent girls (age: 11.1 ± 0.5 years) participated in this study and were separated in three groups. Groups S (N=15) and I (N=15) consisted of volleyball players, while group C (N=15) consisted of girls that had no volleyball training experience. All groups participated in a 10-week (3 days/week) volleyball training program that included technical and passing skills exercises. The program of groups S and I also included jumping and sprinting exercises. The training program of group S was conducted on sand surface, while groups I and C trained on hard surface. Measurements of agility (T-test and 505-test) and passing skills were conducted on both hard and sand surface before, in the middle (5th week) and after the end of the training program for groups S and I. Group C was tested only on hard surface before and after the training period. Data were analyzed using two-way ANOVA for independent samples. Agility T-test and 505-test were significantly ($p<0.001$) improved in all three groups after the 10-week training program. Agility improvement of group S was significantly ($p<0.001$) greater than the other two groups (I and C), regardless of the surface (hard or sand) that the test was executed. Group S achieved greater improvements than the other two groups in passing skills too. All three groups were significantly ($p<0.001$) improved in overhead and forearm passing accuracy after the 10-week training period, but it was group S that achieved the greatest improvement, regardless of the (hard or sand) that the test was executed. In conclusion training on sand surface could be a useful and effective tool for improving agility and passing skills in prepubescent female volleyball players.

Keywords: T-test; 505-test; Sand surface; Overhead pass; Forearm pass

Introduction

Volleyball is a competitive sport played on many different court surfaces depending on whether it is being conducted indoors or outdoors. Thus indoor volleyball is played upon a hard flat surface that is mostly made out of wood or other synthetic materials, while outdoor volleyball is played upon concrete, grass or most commonly sand.

Strength and muscle power of both upper and lower extremities as well as neuromuscular coordination and technical skills are elements that a good volleyball player aims to develop [1]. Several studies have investigated the anthropometric and physiological characteristics of both teenage and adult volleyball players and their impact on volleyball performance [1-5].

Agility is recognized as the ability to maintain and control body's position while rapidly moving and changing directions as a response to a stimulus [6,7]. It seems to be related to athletic abilities like strength, power, speed and balance and it's a determinant of sport performance in field and court sports like volleyball, soccer and rugby [6-8,10,11].

T-test is a well accepted standard agility test that is easy to administer, since it does not require complex equipment and long hours of preparation [11,12]. Pauole et al. evaluated the reliability and validity of the T-test as a measure of leg power, leg speed and agility in college students [13]. T-test performance was highly associated with all three performed skill tests (40-yard dash, counter-movement vertical jump and hexagon test) [13]. Thus T-test appeared to be a highly reliable tool in measuring a combination of physical components including agility, speed and power of lower limbs [13]. Especially in volleyball Barnes et al. showed that countermovement jumping ability is correlated with agility and can be used as a predictor of agility test time [11]. More recently Sassi et al. tried to establish a modified agility T-test and showed that is still highly correlated to countermovement jump and 10m sprint highlighting the significance of agility on sport performance [12].

505-test is also a reliable and valid test for the evaluation of agility in many sports but it requires the use of dual beam electronic timing gates (photocells) [14,15]. Gabbett et al. investigated the relationship among speed, change of direction speed and reactive agility in forty-two rugby league players and showed that 505-test is the most reliable (r=0.90, typical error of measurement=1.9%) of all change of direction speed tests conducted in their study [16]. Furthermore they concluded that 505-test simulates the "general" movement patterns in team sports like rugby, basketball and volleyball. In accordance Gabbett reported that 505-test is a reliable and valid test (r=0.84, typical error of measurement=1.9%) for the evaluation of agility in female rugby players and concluded that it can be used in both sexes [15].

Technical skills like serving, spiking, setting, blocking and passing accuracy along with tactical skills seem to play a critical role in volleyball performance [17]. Gabbett et al. evaluated the technical skills of junior volleyball players before and after an 8-week skill-based training program [18]. Investigators reported that training induced significant improvements in spiking, setting and passing accuracy and spiking and passing technique. The above mentioned study along with many other volleyball studies were all conducted on hard-court surface and according to our knowledge there is little or no research regarding the influence of different training surfaces on volleyball performance

***Corresponding author:** Maria Maridaki, Associate Professor, Department of Physical Education & Sports Science, National & Kapodistrian University of Athens, Greece, Tel: +302107276043; Fax: +302107276113; E-mail: mmarida@phed.uoa.gr

Received August 20, 2013; **Accepted** September 20, 2013; **Published** September 27, 2013

Citation: Gortsila E, Theos A, Nesic G, Maridaki M (2013) Effect of Training Surface on Agility and Passing Skills of Prepubescent Female Volleyball Players. J Sports Med Doping Stud 3: 128. doi:10.4172/2161-0673.1000128

[11,18-21]. Furthermore in all the above mentioned studies the physiological and technical characteristics of volleyball players were evaluated on hard- court surface and there are no studies investigating volleyball performance and characteristics on sand surface. Therefore the purpose of the present study was to investigate the effect of different training surfaces (hard or sand surface) on agility and passing skills of prepubescent female volleyball players.

Methods

Participants

Thirty female prepubescent volleyball players took part in this study and were randomly allocated in two groups (Table 1). Group S (N=15) participated in a 10 week training programme on sand surface, while group I (N=15) participated in a same programme on hard surface indoors. Maturity status was also evaluated (Table 1) according to Tanner's scale [22]. None of the girls had experienced menstruation before or reported any menstruation signs during the study.

All participants were randomly recruited from regional volleyball teams of Athens and had a volleyball training experience of at least two years. Participants and their parents were informed on the purposes of the study, the methods and the possible risks involved and informed consents were signed by the children's parents. A third training group (N=15), that served as control (Group C, Table 1) and had no volleyball training experience was recruited from elementary schools and exercised in volleyball three times per week (45 minute-training session) for 10 weeks according to the program of the Greek Ministry of Education.

Procedures

Measurements of agility and passing skills were conducted in groups S and I before the beginning of the 10-week training program, in the middle of it (end of the 5th week) and right after the end of it, while group C conducted agility and skill tests only before and after the end of the 10-week training program. Participants of groups S and I were tested on both hard surface indoors and on the sand, on the same court surfaces that were used for training, while participants of group C were tested only on hard surface indoors.

The 10 week- training program for groups S and I included three 90 minute-training sessions per week separated by at least a 1-day interval and the level of difficulty and complexity of the exercises were gradually increased during the training program (Table 2). Each training session consisted of exercises aiming to improve technical skills in overhead and forearm pass and agility. Weekly training plan was designed according to guidelines described elsewhere [23-25]. T-test and 505 agility tests were used in order to assess agility and time was recorded with the use of photocells [13,14]. For the evaluation of passing skills, overhead passing test and forearm passing test were conducted [26,27]. Participants were fully familiarized with the testing procedure a week before the beginning of the training program and the best out of two trials was recorded for each test [28]. All tests were executed in a random and balanced order and subjects had the chance to fully recover in between tests.

Statistical analysis

Comparisons between and within groups (C, S and I) for agility and passing skills were performed by two-way ANOVA (groups x time) for independent samples. Significant differences between means were determined using Tukey's Post hoc tests. Statistical analysis was performed using the SPSS statistical package (SPSS, v. 17, Chicago, IL). Results are presented as mean ± standard deviation.

Results

Anthropometrical data of the subjects are presented in Table 1 and there was no significant difference between participants in groups S and I in body height ($p = 0.72$), body mass ($p = 0.27$), chronological age ($p = 0.74$) and Tanner stage for pubic hair ($p = 0.80$) and genitals development ($p = 0.84$).

Agility

The changes in agility T-test over the 10-week training program are presented in Table 3. Training induced significant ($p<0.001$)

Groups	Age (years)	Body weight (kg)	Body height (cm)	Tanner Stage (P)	Tanner Stage (G)
S (N=15)	11.2 ± 0.6	40.8 ± 6.8	151.6 ± 7.1	2.3 ± 0.1	2.1 ± 0.1
I (N=15)	11.3 ± 0.6	39.9 ± 6.4	151.3 ± 7.5	2.3 ± 0.1	2.1 ± 0.1
C (N=15)	10.8 ± 0.2	35.4 ± 6.0	147.0 ± 7.4	-	-

Tanner stage (P): Tanner stage for pubic hair

Tanner stage (G): Tanner stage genitals development

Table 1: Subjects anthropometrical characteristics *(mean ± SD)*.

	Groups S and I		Group C
Warm-up	15-min general activity		10-min general activity
Main part	15-min speed and jumping exercises	45-min technical and passing skills exercises	30-min technical and passing skills exercises
Cool-down	15-min cool-down and stretching		5-min cool-down and stretching

Table 2: Training program used over the 10 weeks for all three groups.

Groups	Pre-training		5th week		Post-training	
	Hard	Sand	Hard	Sand	Hard	Sand
S	15.3 ± 0.4	18.0 ± 0.5	14.4 ± 0.5*§	16.8 ± 0.6*§	13.2 ± 0.2*§	15.0 ± 0.5*§
I	15.1 ± 0.6	18.1 ± 0.8	14.7 ± 0.6*	17.6 ± 0.7*	14.4 ± 0.6*	17.2 ± 0.7*
C	15.3 ± 1.0				15.1 ± 1.1*	

*$p<0.001$ from the pre-training value

§$p<0.001$ from group I

Table 3: Performance time (sec) in agility T-test for all three groups before (pre), in the middle (5th wk) and after the end (post) of the 10-week training program *(mean ± SD)*.

improvements of performance time in both groups (S and I) and in both courts (hard and sand surface) even from the 5th week. The % improvement achieved from group S at the end of the training program was significantly greater than the one achieved from group I (Group S=13.8 ± 1.6% vs. group I = 4.9 ± 1.2%, p < 0.001). When tested on sand surface the % improvement achieved from group S was even greater (Group S = 16.5 ± 1.7% vs. group I = 4.7 ± 0.9%, p < 0.001). Group C also showed a slight but significant improvement over the 10-week training period (1.0 ± 0.4%, p < 0.001).

The changes in 505 agility test over the 10-week training program are presented in Table 4. Training induced significant (p<0.001) improvements of performance time in both groups (S and I) and in both courts (hard and sand surface) even from the 5th week. The % improvement achieved from group S at the end of the training program was significantly greater than the one achieved from group I (Group S=13.8 ± 0.7% vs. group I=4.7 ± 0.7%, p<0.001). When tested on sand surface the % improvement achieved from group S was even greater (Group S=14.4 ± 0.9% vs. group I=4.3 ± 0.8%, p<0.001). Group C also showed a slight but significant improvement over the 10-week training period (1.3 ± 1.0%, p<0.001).

Passing skills

The changes in overhead passing skills over the 10-week training program are shown in Table 5. All three groups were significantly improved after the training period (Group S=39.7 ± 7.5%, group I=13.5 ± 3.7% and group C=12.0 ± 9.1%, p<0.001) with group S showing the greater improvement and differing significantly from the other two groups (p < 0.001). When tested on sand surface group S showed even greater improvement (47.9 ± 5.9%) and differed significantly from group I (9.6 ± 6.0%, p<0.001).

Forearm passing skills were also significantly (p<0.001) improved in all three groups after the 10-week training period (Table 6). The % improvement of group S was 56.6 ± 7.5% and differed significantly (p<0.001) from the other two groups (Group I=16.9 ± 5.1% and group C=11.3 ± 10.5%). When tested on sand surface group S showed a slightly smaller improvement (48.3 ± 9.7%) compared to the % improvement shown on hard surface, but still remained significantly different from group I (12.3 ± 5.2%, p<0.001).

Discussion

The main findings of the present study were that a) agility improved significantly more in the S group compared to the I group after the 10-week training program, b) passing skills were also improved significantly more in the S group compared to the I group after the 10-week training program, highlighting the importance of training surface. Factors such as height and body mass are of great importance and have a significant impact on performance while training during the developmental stages of growth and maturity [29,30]. In our study subjects does not differ in any of their anthropometric characteristics neither before nor after the 10-week training program. Therefore differences between groups in agility and passing skills should be attributed to the impact of training surface.

Improvements in speed, power and balance seem to improve agility [6,8,9,16]. In a more recent study Sassi et al. tried to investigate the relationship of agility T-test to the countermovement jump (CMJ) and the 10m straight sprint and therefore they tested 86 subjects [12]. The

Groups	Pre-training		5th week		Post-training	
	Hard	Sand	Hard	Sand	Hard	Sand
S	3.45 ± 0.07	3.55 ± 0.09	3.25 ± 0.12*	3.32 ± 0.10*§	2.98 ± 0.06*§	3.04 ± 0.07*§
I	3.34 ± 0.15	3.50 ± 0.11	3.25 ± 0.12*	3.40 ± 0.11*	3.18 ± 0.14*	3.35 ± 0.11*
C	3.41 ± 0.18				3.36 ± 0.20*	

*p<0.001 from the pre-training value

§p<0.001 from group I

Table 4: Performance time (sec) in 505 agility test for all three groups before (pre), in the middle (5th wk) and after the end (post) of the 10-week training program *(mean ± SD)*.

Groups	Pre-training		5th week		Post-training	
	Hard	Sand	Hard	Sand	Hard	Sand
S	15.0 ± 1.0†	11.5 ± 0.8	18.2 ± 1.0*§	14.2 ± 0.9*§	20.9 ± 0.8*§†	16.9 ± 0.7*§
I	14.9 ± 0.9†	11.9 ± 0.9	15.8 ± 1.1*	12.6 ± 0.9*	16.9 ± 1.1*†	12.9 ± 0.9*
C	8.2 ± 1.8				9.1 ± 2.0*	

*p<0.001 from the pre-training value

§p<0.001 from group I

†p<0.001 from group C

Table 5: Overhead passing skills score for all three groups before (pre), in the middle (5th wk) and after the end (post) of the 10-week training program *(mean ± SD)*.

Groups	Pre-training		5th week		Post-training	
	Hard	Sand	Hard	Sand	Hard	Sand
S	18.6 ± 1.1†	15.3 ± 1.0	22.2 ± 1.4*§	18.9 ± 1.3*§	†29.1 ± 1.0*§	22.7 ± 0.9*§
I	18.2 ± 1.3†	15.3 ± 1.3	19.5 ± 1.6*	16.7 ± 1.6*	†21.3 ± 1.6*	17.2 ± 1.4*
C	8.4 ± 1.7				9.1 ± 1.7*	

*p< 0.001 from the pre-training value

§p< 0.001 from group I

†p<0.001 from group C

Table 6: Forearm passing skills score for all three groups before (pre), in the middle (5th wk) and after the end (post) of the 10-week training program *(mean ± SD)*.

results showed that there is a strong negative correlation between agility T-test and CMJ (r=-0.74) and agility T-test and 10m straight sprint (r=-0.78). Such a strong negative correlation between CMJ and agility was also reported in previous studies [8,11]. In accordance Sekulic et al. reported that speed and power are the most significant predictors of agility, especially in women [10].

In our study the 10-week training program included jumping (CMJ and Squat Jump) and sprinting exercises. Even in the technical skills training part, that was the major part of each training session; all exercises were designed and conducted in a constant move with sudden changes of direction and short sprints (2-3 m). Such a training intervention is supposed to improve jumping ability and power resulting in significant improvements in agility, like the ones we observed in our study in both groups (S and I). In the S group, in particular, the improvement in both agility tests (T-test and 505-test) was significantly greater than the one observed in the I group, regardless of the surface upon which the tests were performed (sand or indoors). The absorption and energy release upon different ground surfaces have been examined by several researchers in the past [31]. Lejeune et al. used oxygen consumption along with video analysis in order to determine the mechanical work and the energy cost of walking and running on sand and on firm surface [32]. The results of this research showed that walking on the sand requires 1.6-2.5 times more mechanical work than walking with the same speed on a hard surface while running on the sand requires 1.15 times more mechanical work than running with the same speed on a hard surface. In accordance, in a recent study Gaudino et al. reported that the energy cost of sprinting on dry, soft sand was 30% greater than the values achieved while sprinting on grass or artificial grass [33].

The above mentioned results lead us to the assumption that the relative intensity of the exercises conducted by the S group on sand surface was higher than the relative intensity of the same exercises conducted by the I group on hard surface indoors. Differences in relative intensity of the exercises induce different training adaptations and therefore may explain the greater agility improvement observed in the S group.

Furthermore a non solid ground, like sand, may evoke changes in the neuromuscular junctions [31]. An unstable surface may lead to repeated losses of balance, which in turn and in order to avoid falling may promote neuromuscular communication and therefore improve balance [34,35]. But as it was mentioned before balance is correlated to agility and any improvements in balance would lead to improvements in agility [10]. Hence the greater agility improvement of group S may be the result of improvements in balance, which occurred due to the non solid of the training surface.

In our study the major part of each training session included exercises aiming to improve technical and more specifically passing skills. In a previous study Gabbett et al. reported significant improvements (40-76%) of overhead passing, forearm passing and attacking after an 8-week training program [18]. In accordance groups S and I improved their forearm and overhead passing skills, after the 10-week training program, but group S showed significantly greater improvement compared to group I. A possible explanation for the above mentioned results could be that subjects in group S increased their arm strength more than subjects in group I during the 10-week training program and therefore managed to perform better in passing skills tests.

Arms seem to significantly contribute to jumping performance and power despite the fact that when running they seem to contribute only 1% to total mass center acceleration and propulsion [36,37]. According to Lees & Barton arms contribute more than 12% in total vertical momentum in case of vertical jumping while even in running Hamner et al. and Pontzer et al. reported that arms counterbalance changes in angular momentum of the legs and reduce torso rotations [37-39]. Therefore arms seem to play a critical role when sprinting or jumping on sand counterbalancing angular momentum and retaining balance.

In the present study training on sand surface could result on greater contribution of the arms to sprinting and jumping and therefore a greater increase on arm strength. When sprinting on sand surface and because of the instability of the ground, there are no changes on stride frequency but there is a significant reduction on stride length and a larger number of surface contacts are needed in order to cover the same distance [33]. Consequently the larger number of strides during sprinting or the lower contribution of plantar flexion during jumping on sand surface would result in more arm swinging movements and possible greater strength gains [31]. Although we did not measure arm strength a possible greater increase of it in group S could explain differences observed in passing skills between groups S and I.

Conclusion

In conclusion the present study showed that training on sand surface could be a useful and effective tool for improving agility and passing skills in prepubescent female volleyball players. Agility was significantly improved in both groups after the 10-week training program, because each training session included sprinting and jumping exercises. Even passing drills during training were conducted in constant movement and included short sprints and changes of direction. The greater % improvement observed in group S should be attributed to the increased energy cost of moving on sand surface and therefore the greater effort needed when sprinting or jumping that possibly induced larger increases in strength compared to group I. The instability of the sand surface also seems to promote improvements of balance, which in turn improve agility. Furthermore, when sprinting and jumping on the sand, arms seem to contribute more to performance result and therefore training on the sand could enhance strength improvements. Although we did not measure arm strength in our study, differences in passing skills between groups should be attributed to possible greater arm strength gains achieved by group S.

References

1. Smith DJ, Roberts D, Watson B (1992) Physical, physiological and performance differences between Canadian national team and universiade volleyball players. J Sports Sci 10: 131-138.
2. Gabbett T, Georgieff B (2005) Physiological characteristics of elite junior volleyball players over competitive season. J Strength Cond Coach 13: 2-7.
3. Gabbett T, Georgieff B (2007) Physiological and anthropometric characteristics of Australian junior national, state, and novice volleyball players. J Strength Cond Res 21: 902-908.
4. Fleck SJ, Case S, Puhl J, Van Handle P (1985) Physical and physiological characteristics of elite women volleyball players. Can J Appl Sport Sci 10: 122-126.
5. Thissen-Milder M, Mayhew JL (1991) Selection and classification of high school volleyball players from performance tests. J Sports Med Phys Fitness 31: 380-384.
6. Little T, Williams AG (2005) Specificity of acceleration, maximum speed, and agility in professional soccer players. J Strength Cond Res 19: 76-78.
7. Sheppard JM, Young WB (2006) Agility literature review: classifications, training and testing. J Sports Sci 24: 919-932.
8. Markovic G, Sekulic D, Markovic M (2007) Is agility related to strength qualities?--Analysis in latent space. Coll Antropol 31: 787-793.
9. Nimphius S, McGuigan MR, Newton RU (2010) Relationship between strength,

power, speed, and change of direction performance of female softball players. J Strength Cond Res 24: 885-895.

10. Sekulic D, Spasic M, Mirkov D, Cavar M, Sattler T (2013) Gender-specific influences of balance, speed, and power on agility performance. J Strength Cond Res 27: 802-811.
11. Barnes JL, Schilling BK, Falvo MJ, Weiss LW, Creasy AK, et al. (2007) Relationship of jumping and agility performance in female volleyball athletes. J Strength Cond Res 21: 1192-1196.
12. Sassi RH, Dardouri W, Yahmed MH, Gmada N, Mahfoudhi ME, et al. (2009) Relative and absolute reliability of a modified agility T-test and its relationship with vertical jump and straight sprint. J Strength Cond Res 23: 1644-1651.
13. Pauole K, Madole K, Garhammer J, Lacourse M, Rozenek R (2000) Reliability and Validity of the T-Test as a Measure of Agility, Leg Power, and Leg Speed in College-Aged Men and Women. Journal of Strength and Conditioning Research 14: 443-450.
14. Draper JA, Lancaster MG (1985) The 505 test: A test for agility in the horizontal plane. Aust. J. Sci Med Sport 17: 15-18.
15. Gabbett TJ (2007) Physiological and anthropometric characteristics of elite women rugby league players. J Strength Cond Res 21: 875-881.
16. Gabbett TJ, Kelly JN, Sheppard JM (2008) Speed, change of direction speed, and reactive agility of rugby league players. J Strength Cond Res 22: 174-181.
17. Häkkinen K (1993) Changes in physical fitness profile in female volleyball players during the competitive season. J Sports Med Phys Fitness 33: 223-232.
18. Gabbett T, Georgieff B, Anderson S, Cotton B, Savovic D, et al. (2006) Changes in skill and physical fitness following training in talent-identified volleyball players. J Strength Cond Res 20: 29-35.
19. Lidor R, Ziv G (2010) Physical and physiological attributes of female volleyball players--a review. J Strength Cond Res 24: 1963-1973.
20. Nikolaidis PT, Ziv G, Arnon M, Lidor R (2012) Physical characteristics and physiological attributes of female volleyball players--the need for individual data. J Strength Cond Res 26: 2547-2557.
21. Schaal M, Ransdell LB, Simonson SR, Gao Y (2013) Physiologic performance test differences in female volleyball athletes by competition level and player position. J Strength Cond Res 27: 1841-1850.
22. Tanner JM (1962) Growth at adolescence. (2nd Edn),bBlackwell Scientific Publications, Oxford.
23. Diallo O, Dore E, Duche P, Van Praagh E (2001) Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players. J Sports Med Phys Fitness 41: 342-348.
24. Kotzamanidis C (2006) Effect of plyometric training on running performance and vertical jumping in prepubertal boys. J Strength Cond Res 20: 441-445.
25. Witzke KA, Snow CM (2000) Effects of plyometric jump training on bone mass in adolescent girls. Med Sci Sports Exerc 32: 1051-1057.
26. Bartlett J, Smith L, Davis K, Peel J (1991) Development of a valid volleyball skills test battery. J Phys Edu Recr Dance 62: 19-21.
27. Barzouka K, Bergeles N, Hatziharistos D (2007) Effect of simultaneous model observation and self-modeling of volleyball skill acquisition. Percept Mot Skills 104: 32-42.
28. Mirkov DM, Nedeljkovic A, Milanovic S, Jaric S (2004) Muscle strength testing: evaluation of tests of explosive force production. Eur J Appl Physiol 91: 147-154.
29. Claessens AL, Lefevre J, Beunen G, Malina RM (1999) The contribution of anthropometric characteristics to performance scores in elite female gymnasts. J Sports Med Phys Fitness 39: 355-360.
30. Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B (2003) Anthropometry of young competitive sport rock climbers. Br J Sports Med 37: 420-424.
31. Muramatsu S, Fukudome A, Miyama M, Arimoto M, Kijima A (2006) Energy expenditure in maximal jumps on sand. J Physiol Anthropol 25: 59-61.
32. Lejeune TM, Willems PA, Heglund NC (1998) Mechanics and energetics of human locomotion on sand. J Exp Biol 201: 2071-2080.
33. 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 16: 271-275.
34. Hewett TE, Paterno MV, Myer GD (2002) Strategies for enhancing proprioception and neuromuscular control of the knee. Clin Orthop Relat Res 402: 76-94.
35. Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, et al. (2010) Balance training for neuromuscular control and performance enhancement: a systematic review. J Athl Train 45: 392-403.
36. Walsh MS, Böhm H, Butterfield MM, Santhosam J (2007) Gender bias in the effects of arms and countermovement on jumping performance. J Strength Cond Res 21: 362-366.
37. Hamner SR, Seth A, Delp SL (2010) Muscle contributions to propulsion and support during running. J Biomech 43: 2709-2716.
38. Lees A, Barton G (1996) The interpretation of relative momentum data to assess the contribution of the free limbs to the generation of vertical velocity in sports activities. J Sports Sci 14: 503-511.
39. Pontzer H, Holloway JH 4th, Raichlen DA, Lieberman DE (2009) Control and function of arm swing in human walking and running. J Exp Biol 212: 523-534.