The Relationship between Core Muscle and Sport Activities

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Abstract: The core muscle has been subject to research since the early 1980s. The significance of the core muscle in all kinds of activities is increasingly recognized. The core muscle is being regarded as the key point for efficient biomechanical function in generation of force and reduction of joint loads and the coordination of the core muscle is pivotal to successful dynamic balance in those activities. There are many studies that promote core training and exercises for performance enhancement without providing a strong scientific rationale of the physiological function of the core muscle, especially in the sporting sector. The aim of this study was to review the current literature on the function of the core muscle in sport activities. A review of the literature was conducted on the PubMed, Elsevier and Web of Science electronic databases for studies on this topic. In this article, a rather comprehensive illustration of the core muscle group from an anatomical and physiological view was reviewed. The composition, position, classification and function of the core muscle group were introduced. For different functions of the core muscle, the corresponding exercises which could be referred to were provided. The participation of the core muscle was explained in detail in three different sport activities, i.e. running, dancing and boxing, as specific examples. The main findings indicate that the enhancement of the core muscle group could be an important factor of athletic performance. However, a lack of specific data and values indicating the degree of engagement of the core muscles in sport activities was revealed.

1. Introduction

In recent years, research on the core muscle has raised the awareness of sport scientists worldwide due to the important role in which the core muscle plays in all kinds of activities. Several literatures have provided information on the significance of core muscle from the aspect of reduction of the injury risk and improvement of athletic performance.

Willson, J. D., et al. discussed about the relationship between core stability and lower extremity function and the relationship between core stability and injury [1]. Hibbs, A. E., et al. examined how to optimize performance by improving core stability and core strength [2]. Shinkle, J., et al. discussed the effect of core strength on the measure of power in the extremities [3]. Reed, C. A., et al. examined the effects of isolated and integrated core stability training on athletic performance measures [4].

The significance of the core muscle is increasingly being recognized. There are many studies that promote core training and exercises for performance enhancement. The core muscle is being regarded as the key point for efficient biomechanical function in generation of force and reduction of joint loads and the coordination of the core muscle is pivotal to successful dynamic balance in those activities.

Since in the course of research in recent years, there have also been new findings indicating the importance of the core muscle, it would be desirable to collate the existing literature by providing a strong scientific rationale of the physiological function of the core muscle, especially in the sporting sector.

This review literature mainly focuses on the relationship between core muscles and sport activities. A clearer understanding of the functions that core muscle have during sport activities would enable more specific core training programs to be implemented, which may result in a more effective improvement of athletic performance to actual sport activities.

In this review article, a rather comprehensive illustration of the core muscle group from an anatomical and physiological view is reviewed. We introduce the composition, position, classification and function of the core muscle group. For the different functions of the muscles, we provide the corresponding exercises which can be referred to. Then we use three different sport activities to detail the participation of core muscles in these activities.

However, less research has been performed on the benefits of specific data and values indicating the degree of engagement of the core muscles in sport activities. To tailor the core training program more oriented to different sport activities to more effectively improve athletic performance, it will be necessary to include experimental data and values demonstrating the degree of involvement of the core muscles in the activities.

2. The Profile of Core Muscle

2.1 The Position and Composition of Core Muscle

The core muscle is defined as an anatomical box which consists of several muscle groups (Figure 1,2,3,4,5), such as the rectus abdominis at the ventral side, the erector spinae, lumbar multifidus muscle, and quadratus lumborum at the dorsal side, the internal and external obliques on the lateral sides under which lies the transversus abdominis, the diaphragm on the top, the pelvic and hip girdle and the iliac psoas at the bottom [5].

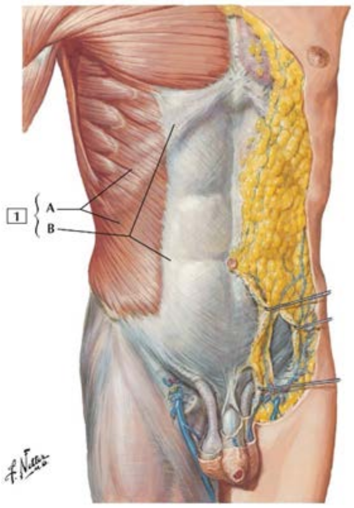

Figure 1. Anterior Abdominal Wall: Superficial Layers. 1. External Oblique Muscle: Muscular Part (A) and Aponeurotic Part (B). [6]

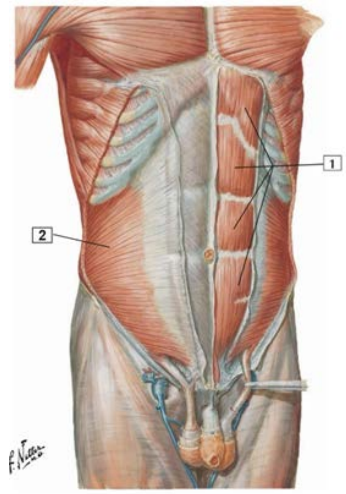

Figure 2. Anterior Abdominal Wall: Deep Layers. 1. Rectus Abdominis Muscle; 2. Internal Oblique Muscle.

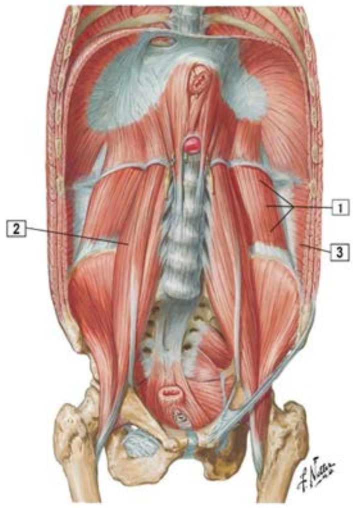

Figure 3. Posterior Abdominal Wall: Internal View. 1. Quadratus Lumborum Muscle; 2. Transversus Abdominis Muscle; 3. Psoas Major Muscle.

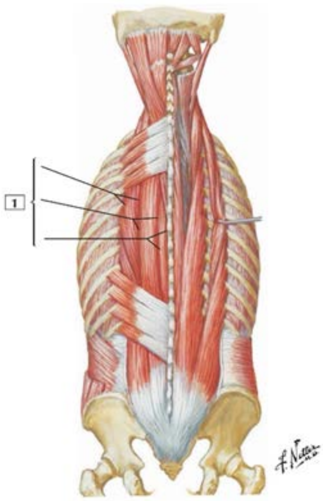

Figure 4. Intrinsic Muscles of Back: Superficial Layers. 1. Erector Spinae Muscle.

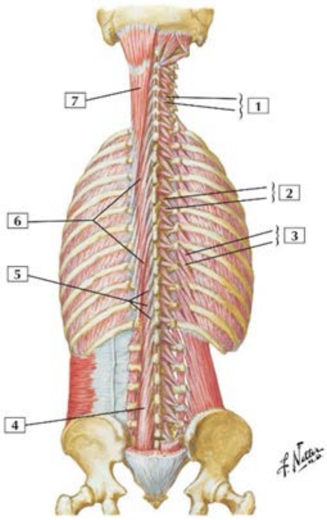

Figure 5. Intrinsic Muscles of Back: Deep Layers. 1. Rotator Cervicis Muscle; 2. Rotator Thoracis Muscle; 3. Levatores Costarum Muscle; 4. Multifidus Lumborum Muscles; 5. Multifidus Thoracis Muscles; 6. Semispinalis Thoracis Muscle; 7. Semispinalis Capitis Muscle.

With regard to the whole body, the core muscle group is located in the center of human body, where most kinetic chains transfer forces to the extremities [7]. They are attached by most of the prime mover muscles for distal segments of both upper and lower bodies such as latissimus dorsi, pectoralis major, hamstrings, quadriceps [8]. In addition, the core muscle group is also responsible for the maintenance of the stability of the spine and the pelvis, with attachment of major stabilizing muscles for extremities such as trapezius, hip rotators and gluteal muscles [8].

2.2 Anatomy of Core Muscle – Superficial and Deep Muscle

2.2.1 Anatomy of Superficial Core Muscle.

The superficial layer of the core consists of 4 different systems: the anterior oblique system, the posterior oblique system, lateral system, and deep longitudinal system. The superficial layer serves a dual purpose: to assist in the stabilization of the deeper muscles; and to produce movement. Deep muscles are usually stabilizer muscles, while superficial muscles are usually phasic muscles [9].

The anterior oblique system consists of the external abdominal obliques and the contralateral internal abdominal obliques and adductor muscles. They work in concert with each other to produce rotational work of the trunk and pelvis. The anterior oblique system aids in trunk stabilization and plays an important role in gait [9].

The posterior oblique system consists of the gluteus maximus and the contralateral latissimus dorsi muscles and the thoracolumbar fascia that connects them. During the propulsive phase of gait, the posterior oblique system contracts to propel the body forward. It also plays a stabilizing role in martial arts and boxing when retracting after throwing a punch [9].

The lateral system consists of the hip adductor group, the ipsilateral gluteus medius, gluteus minimus and the contralateral quadratus lumborum. The lateral system stabilizes the hip joint, maintains trunk stability over the supporting leg, and reduces the risk of injury to the ankle, knee, hip, and lower back [9].

The deep longitudinal system consists of the peroneus longus, biceps femoris, sacral tuberosity ligament, thoracolumbar fascia, and erector spinae. The deep longitudinal system transmits kinetic energy to the trunk, helps the spine to rotate and reduces energy expenditure in gait [9].

2.2.2 Anatomy of Deep Core Muscle.

The deep muscles of the core are the multifidus, pelvic floor, transversus abdominis, and diaphragm. These muscles form a structure shaped like a cylinder around the lumbar spine from the base of the rib cage to the pelvis. The deep muscles stabilize the lumbar spine, pelvis and thoracic cavity in three ways: by increasing abdominal pressure, by thoracolumbar fascial strengthening mechanisms and by hydraulic strengthening mechanisms [9].

All movement occurs outward from the deep core muscles. The greater the stability of the deep core muscles, the greater the force that will be generated in the extremities. One study has proven that the contraction of the transverse abdominis, pelvic floor, and diaphragm muscles produce movement on average 30 milliseconds earlier than the arms and 110 milliseconds earlier than the legs [10].

2.3 Function of Core Muscle

Since the core is involved in almost all kinds of activities such as walking, running, dancing [8], it is important for the core muscle group to function properly during daily or physical activities. Dysfunction of any of these core muscle may increase the susceptibility to injury. Assessment of the core is usually carried out from the following three perspectives, core stability, core strength and core endurance.

2.3.1 Core Stability.

Core stability is defined as the ability to control the position and motion of the trunk to allow optimum production, transfer and control of force and motion to the terminal segment in integrated athletic activities. The core stability requires control of trunk motion in all three planes, which are coronal plane, sagittal plane and horizontal plane [8]. Contraction of core muscles is not separated but should be coordinated in a certain order and degree to maintain the core stability. For example, simultaneous contraction of the diaphragm, the pelvic floor, rectus abdominis, internal oblique, external oblique and transversus abdominis provides a more rigid cylinder for trunk support, at the meantime, decreases the load on the spine muscles, allowing increase of trunk stability [8].

Enhancing core stability often employs static training such as plank, etc. This kind of exercise aims to strength the deep muscles. During exercise, the burning sensation of sustained muscle contraction occurs in the deeper parts of the body.

In the core stability training, exercises in all four directions, i.e. front, back, left and right, also need to be carried out, in order to improve stability in a balanced way and enhance the overall strength of the deep core muscle.

These core stability training exercises usually include plank or plank on knees for beginners, side plank with or without leg raise, back bridge or split back bridge for the advanced. These exercises are mostly static support movements, which, on the basis of keeping the movement standard, can be maintained for a certain time, such as thirty seconds to one minute.

2.3.2 Core Strength.

Core strength is defined as the maximal force that a muscle or muscle group can generate at a specific velocity [11]. For measuring the core strength and muscle activation patterns, researchers in recent years usually apply the method of surface electromyography (sEMG) [12]. Given that the greater the electromyographic activity (EMG activity), the greater the challenge to neuromuscular system, the amplitude of sEMG signal can be used to analyze degrees of muscle activation [5]. So the data collected from surface electromyography can give an approximate evaluation of core strength.

Core strength training is mainly to exercise the superficial muscles. Core strength is needed when the trunk completes large movements. The core muscles are distributed in the front, back and sides of the trunk, so the same training should be done for these muscles in a comprehensive manner.

The upper abdominal muscles are usually trained using the crunch exercise. The torso is raised about thirty to forty degrees above floor during the curl, which is the best angle to stimulate the upper abdomen, leading to a more significant training effect.

Lower abdominal exercises are mainly performed through posterior pelvic tilt movements. The classic training movements are supine leg lifts and supine bicycle crunches. The supine leg raise is done with the hips raised and the knees moving upward rather than toward the head to prevent excessive pressure on the lumbar spine. When completing the supine cycle, the abs need to stay hard so that the waist is close to the ground and the feet simulate the action of cycling.

The exercises for the lateral front of the trunk primarily work the internal and external oblique muscles. These movements include rotations and lateral flexions such as side crunches and curls to touch the ankles.

The exercises for the two sides of the trunk mainly work the quadratus lumborum muscles. The quadratus lumborum muscle plays an important role in stabilizing the up and down swing of the pelvis. These exercises include side lying up with or without leg lift.

The exercises for the trunk in posterior mainly work the erector spinae muscle. The erector spinae muscle can keep the trunk straight and enhance the strength of the lower back. Lower back muscle training mainly includes all kinds of back extension such as back extension on floor, back extension on stability ball, back extension on bench, etc. [13].

2.3.3 Core Endurance.

Core endurance is described as the time during which the core muscle group contracts to maintain its posture. Lack of core endurance appears to a potential factor to injury and the core endurance has been found to be related to athletic performance in such activities as running and jumping [14]. To test the core endurance, researchers usually apply the Mcgill endurance tests. In this test, the isometric endurance holding times are measured and are represented as the core endurance results [15].

2.4 Relationship between Core and Athletic Performance

Athletes are constantly striving for better performance. Performance can be defined as the accomplishment of goals by meeting or exceeding predefined goals [16]. The concept of performance is multidimensional. It is related to both physiological factors such as endurance, strength, speed or flexibility [17] and psychological factors such as concentration, motivation and volition [18].

Improvement of the core can better those physiological factors mentioned above in that all kinds of sport activities originate from the core in essential. For example, in a running game, to obtain maximum propulsion, the combined contraction of the internal and external obliques in the anterior chain stabilizes the upper body and assists in pelvic rotation. In dancing competition, to make the movements more extended and graceful, dancers need strong stabilizing power in their core to keep their center of gravity from shifting. In boxing, to achieve better performance, boxers need to develop maximal velocity and force at the distal segment of the kinematic chain, of which the origin is the core muscle. In general, the enhancement of the core muscle group plays a vital role in athletic performance.

3. Core Muscle Activity and in Specific Sport Activities

3.1 Core Muscle Activity in Running

Running is a kind of sport activities which involves both balance and powerful movements. The efficient firing patterns from the postural muscles and phasic muscles are demanded in sprinting as well as in middle-, long- distance race.

To propel the body forward and catch the body in complex motor patterns, a stable core and a strong foundation of muscular balance are crucial to runners. Insufficient coordination or weakness of the core can lead to less efficient running gait, compensatory movement, strain, overuse and even injuries [19].

During running, the internal and external abdominal obliques contract and work together with the internal thigh muscle groups to produce a rotational action of the trunk and pelvis. They help to keep one leg off the ground and the other leg stable on the ground, facilitating the ideal position for the floating foot to land [9]. The quadratus lumborum muscle raises the hips to provide enough space for the leg to swing. The thoracolumbar fascia connects the gluteus maximus and the contralateral latissimus dorsi to advance the body forward, producing hip extension and shoulder extension. The fascia also stores kinetic energy generated by muscle contraction; when the muscle relaxes, the energy is released [9]. Thereby, this mechanism increases running efficiency.

An efficient running gait allows the runner to run faster with less energy consumption. The core muscle group is responsible for providing a stable base for extremity function and force transfer. It has been theorized that a strong core will allow a transfer of forces with a minimal dissipation of energy in the torso. A good dynamic running posture is able to transfer more force to the horizontal direction rather than the other. To achieve maximal horizontal power output that leads to greater speed, the core plays a vital role in conducting the force to extremities through kinetic chains.

In running, the core formulates a stable base which assists with the hips and pelvis rotation to allow forward movement of the body. The function of the core muscle group is to resist the rotational forces of the activity, transfer the forces to lower extremities to keep all motion moving in the desired direction [20].

A strong core also contributes to less compensatory movement. The pelvis relies on symmetry to function during the running cycle. The right motion of pelvis during running is rotational, anterior-posterior and mediolateral. As the pelvis rotates during each stride, the core keeps the spine stable around the axis of the vertebrae. During the float phase, the psoas and other pelvic muscles, along with the core rotate the ipsilateral pelvis forward and cause hip flexion. Abnormal pelvic orientation such as anterior pelvic tilt, excessive lateral tilt and asymmetric hip movement causes the most injuries and might lead to excessive strain on the hamstrings, fascia latae, adductors, quadratus lumborum, etc.

Besides the stability provided by pelvis, sacrum and lumbar vertebrae, the core muscle helps absorb and distribute impact forces and allow body movements in a controlled and efficient manner. When optimized in function, muscles work in unison to allow breathing during running and the twisting motion required during the running cycle [21].

A study examining the effect of core muscle training has figured out that an eight-week core training program may improve core endurance and running economy. The study found that, in a treadmill test, the heart-rate (HR) values for the first three stages were lower in the post-test than in the pre-test in the core training group and the post-test VO2 in stage 4 was lower than that in the pre-test in core training group (Table 1). These results suggest that 6-8 weeks of core training may improve the running economy which is beneficial for the running performance [22].

Table 1. Results on the Treadmill Test

	Pre-training Test				**Post-training Test**			
Stage	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
VO2(ml/kg /min)								
CON	30.25±2.82	37.71±2.36	42.13±5.22	47.63±5.48	29.36±1.9	37.81±2.26	43.06±2.04	47.39±3.04
CT	30.12±3.22	38±3.11	46.25±3.8	52.38±3.54	32.65±4.34	37.80±2.94	46.45±5.32	49.98±2.89*
HR (bmp)								
CON	136.4±15.2	153.8±10.9	171.2±11.9	182±9.3	124.9±17.7*	150.8±10	169.5±9.8	181.3±5.8
CT	142.3±14.6	161.6±15.8	176.1±14.2	185±14.9	132.2±13.9*	151.8±14.5*	170.3±14.8*	182±13.2

CON: control group, n=10; CT: core training group, n=11.

* $p<0.05$ pre-test vs. post-test

Data resource: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6407754/

3.2 Core Muscle Activity in Dancing

Every dance technique is dependent on strong control of core. For example, in the incredible dance technique of Irish tap, the dancer needs to keep the spine exceptionally stable from beginning to end of the performance so that the torso is in an extremely secure position. This allows the dancers to move their legs and feet with agility.

Ballet requires the body to be always located in the center, so the dancer needs to control the abdomen and spine all the time. When completing a ballet jump, the movement can be divided into five steps: preparation, ascent, in air, descent, and landing. In the ascent, the muscles contract centripetally; in air, strong core strength and isometric contraction are required; in the descent, the muscles contract centrifugally to minimize injury; and in the landing, the muscles elongate and support the body. In jumping, control is critical for the dancer in order to show the visual effect of lightness and agility. And this control comes from the core [23].

Contemporary dance choreography incorporates more sophisticated and innovative combinations requiring even challenging ways of moving the spine. If the dancer does not have the enough core strength to support the spine, the movement will seem to be flabby and weak. If the spine and pelvis are less prepared, dancers can easily be injured during the landing of some non-traditional jumps. In more difficult choreography, dancers must fully stimulate the body's limitations and repeatedly strengthen the spine and pelvis with stability exercises [23].

No matter what type of dance, mastering this core control skill is a necessity; otherwise dancers are extremely vulnerable to injury and unable to complete competitions and training. Therefore, incorporating core training into dance training is a mandatory requirement to improve dance orientation and reduce the risk of injury. Strong core muscles help to lift the spine upwards effectively and powerfully. Once the upper back begins to extend safely, the spinal rotation can be displayed better and the physique becomes more graceful [23].

3.3 Core Muscle Activity in Boxing

Boxing is one kind of combat sport which demands a high physical level. A combination of strength, coordination, velocity,

and stamina is required for boxers to succeed in beating the opponent while evading adversary punches [24].

There are three main attacking techniques in boxing, namely cross, hook and uppercut. The cross implies a forward translation of the body while hook and uppercut involve an overall rotation of the body.

In order to improve performance in boxing, boxers need to develop maximal velocity and force at the distal segment of the kinematic chain. This high velocity and force at the end of distal segment is usually a result of a proximal-to-distal sequencing motion as the summation of velocity principle states [24].

Related literature has figured out that the elbow contributed the most to the punch during the cross, and the shoulder contributed the most to the execution of the hook and uppercut. Besides, other body segments such as the trunk and the pelvis also participate in force generation [24].

However, an experiment examining the biomechanical patterns and resulting punching forces and velocities produced by Elite vs. Junior boxers showed that, the body segment contributions including shoulder, trunk and pelvis were systemically higher in Junior with less force generated in comparison to Elite boxers [24].

According to another study related with analysis of proximal-to-distal sequential segment motion patterns, pelvis and torso kinematics throughout this motion pattern are inversely related to shoulder parameters [25]. We assume that junior boxers engaged more segments in the punch in an attempt to compensate the loss of force during conduction related with less ability of ore muscle, whereas the elite boxers are more effective in generating force during the punch.

4. Core Muscle Training Program for Reference

A voluminous body of research has been devoted to the training of core muscle. However, there exists a considerable gap between theory and best practice in how principles and training methods are applied. We have found that most of the core muscle training programs in the experiments that have been conducted were similar to one and another. No consensus has been reached regarding what is the most effective core muscle training exercise protocol.

In general, a core muscle training program is composed of training 2 to 4 times a week in a duration of 4 to 8 weeks. [26,27] The following 8-week core muscle training program for reference include mainly 3 stages: fundamental strengthening (3 weeks), stabilization (3 weeks), and functional strengthening (2 weeks). Assisted equipment such as mini-bands, air pad and stability balls are used in certain exercises during the core muscle training. Details of the core muscle training program are illustrated in Table 2.

Each stage in the core muscle training program consists of exercises for upper abdominal muscles, lower abdominal muscles, oblique muscles, deep core, and back and hip muscles in order to improve the overall core stability and core strength. The level of difficulty is increased by adding unstable surface or putting unilateral movements into the exercise.

Table 2. Core Muscle Training Program

Exercise protocol	Reps/Time	Assisted Equipment	Sets
Warm-up Exercise			
Dead-bug Exercise	30 reps	Mini-band	1
Beast Hold	60 seconds	/	1
Week 1-3			
Crunch	20 (week1-2)/ 25 (week 3)	/	3
Supine Toe Tap	20 (week1-2)/ 25 (week 3)	Mini-band	3
Glute Bridge	20 (week1-2)/ 25 (week 3)	Mini-band	3
Plank	45s (week 1-2)/ 60s (week 3)	/	3
Side Plank	35s (week 1-2)/ 50s (week 3)	/	3
Week 4-6			
Heel Touches	25 reps	/	3
Bicycle Crunch	20 per side	/	3
Split Leg Bridge	20 per side	Air Pad	3
Plank with March	60 seconds	/	3
Side Plank with Hip Dip	50 seconds	/	3
Bird Dogs	20 per side	/	3
Week 7-8			
Legs Up Crunch	25 reps	/	3
Windshield Wipers	20 per side	/	3
Split Leg Bridge	20 per side	Stability Ball	3
Mountain Climbers	60 seconds	/	3
Plank Jack	60 seconds	/	3
Side Plank Toe Touches	50 seconds	/	3

5. Conclusion

This review literature mainly focuses on the relationship between core muscles and sport activities. A clearer understanding of the functions that core muscle have during sport activities would enable more specific core training programs to be implemented, which may result in a more effective improvement of athletic performance to actual sport activities.

In this review article, a rather comprehensive illustration of the core muscle group from an anatomical and physiological view is reviewed. We introduce the composition, position, classification and function of the core muscle group. For the different functions of the muscles, we provide the corresponding exercises which can be referred to. Then we use three different sport activities, i.e. running, dancing and boxing, to detail the participation of core muscles in these activities. In a running game, to obtain maximum propulsion, the combined contraction of the internal and external obliques in the anterior chain stabilizes the upper body and assists in pelvic rotation. In dancing competition, to make the movements more extended and graceful, dancers need strong stabilizing power in their core to keep their center of gravity from shifting. In boxing, to achieve better performance, boxers need to develop maximal velocity and force at the distal segment of the kinematic chain, of which the origin is the core muscle.

This review article has proved that a strong and stable core provides a necessary foundation for performance of a variety of athletic movements. However, less research has been performed on the benefits of specific data and values indicating the degree of engagement of the core muscles in sport activities. To tailor the core training program more oriented to different sport activities to more effectively improve athletic performance, it will be necessary to include experimental data and values demonstrating the degree of involvement of the core muscles in the activities.

References

[1] Willson, J. D., Dougherty, C. P., Ireland, M. L., & Davis, I. M. (2005). Core stability and its relationship to lower extremity function and injury. The Journal of the American Academy of Orthopaedic Surgeons, 13(5), 316–325. https://doi.org/10.5435/00124635-200509000-00005Nn.

[2] Hibbs, A. E., Thompson, K. G., French, D., Wrigley, A., & Spears, I. (2008). Optimizing performance by improving core stability and core strength. Sports medicine (Auckland, N.Z.), 38(12), 995–1008. https://doi.org/10.2165/00007256-200838120-00004.

[3] Shinkle, J., Nesser, T. W., Demchak, T. J., & McMannus, D. M. (2012). Effect of core strength on the measure of power in the extremities. Journal of strength and conditioning research, 26(2), 373–380. https://doi.org/10.1519/JSC.0b013e31822600e5Nn.

[4] Reed, C. A., Ford, K. R., Myer, G. D., & Hewett, T. E. (2012). The effects of isolated and integrated 'core stability' training on athletic performance measures: a systematic review. Sports medicine (Auckland, N.Z.), 42(8), 697–706. https://doi.org/10.2165/11633450-000000000-00000.

[5] Oliva-Lozano, J. M., & Muyor, J. M. (2020). Core Muscle Activity During Physical Fitness Exercises: A Systematic Review. International journal of environmental research and public health, 17(12), 4306. https://doi.org/10.3390/ijerph17124306

[6] Netter, F. K. (2018). Atlas of Human Anatomy, 7th edition. Amsterdam: Elsevier.

[7] Shinkle, J., Nesser, T. W., Demchak, T. J., & McMannus, D. M. (2012). Effect of core strength on the measure of power in the extremities. Journal of strength and conditioning research, 26(2), 373–380. https://doi.org/10.1519/JSC.0b013e31822600e5.

[8] Kibler, W. B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. Sports medicine (Auckland, N.Z.), 36(3), 189–198. https://doi.org/10.2165/00007256-200636030-00001.

[9] Brandon, L., & Berrange, J. (2010). Anatomy for strength and fitness training for speed and sport. London: New Holland Publishers Ltd.

[10] Richardson, C., Jull, G., Hodges, P., & Hides, J. (1998) Therapeutic Exercises for Spinal Segmental Stabilization in Low Back Pain: Scientific Basis and Clinical Approach. Amsterdam: Elsevier-Health Sciences Division.

[11] Lehman G. J. (2006). Resistance training for performance and injury prevention in golf. The Journal of the Canadian Chiropractic Association, 50(1), 27–42.

[12] Vigotsky, A. D., Halperin, I., Lehman, G. J., Trajano, G. S., & Vieira, T. M. (2018). Interpreting Signal Amplitudes in Surface Electromyography Studies in Sport and Rehabilitation Sciences. Frontiers in physiology, 8, 985. https://doi.org/10.3389/fphys.2017.00985.

[13] Dai, J. S., & Zheng, J. X. (2018). Injury-free Running. Beijing: Posts & Telecom Press.

[14] Reiman, M. P., Krier, A. D., Nelson, J. A., Rogers, M. A., Stuke, Z. O., & Smith, B. S. (2012). Comparison of different trunk endurance testing methods in college-aged individuals. International journal of sports physical therapy, 7(5), 533–539.

[15] McGill, S. M., Childs, A., & Liebenson, C. (1999). Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. Archives of physical medicine and rehabilitation, 80(8), 941–944. https://doi.org/10.1016/s0003-9993(99)90087-4.

[16] Kellmann, M., Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Kallus, K. W., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and Performance in Sport: Consensus Statement. International journal of sports physiology and performance, 13(2), 240–245. https://doi.org/10.1123/ijspp.2017-0759.

[17] Mujika I. (2017). Quantification of Training and Competition Loads in Endurance Sports: Methods and Applications. International journal of sports physiology and performance, 12(Suppl 2), S29–S217. https://doi.org/10.1123/ijspp.2016-0403.

[18] Beckmann, J., & Elbe, A. M. (2015). Sport Psychological Interventions in Competitive Sports. Newcastle: Cambridge Scholars Publishing.

[19] Fredericson, M., & Moore, T. (2005). Muscular balance, core stability, and injury prevention for middle- and long-distance runners. Physical medicine and rehabilitation clinics of North America, 16(3), 669–689. https://doi.org/10.1016/j.pmr.2005.03.001.

[20] Shinkle, J., Nesser, T. W., Demchak, T. J., & McMannus, D. M. (2012). Effect of core strength on the measure of power in the extremities. Journal of strength and conditioning research, 26(2), 373–380. https://doi.org/10.1519/JSC.0b013e31822600e5.

[21] Rivera C. E. (2016). Core and Lumbopelvic Stabilization in Runners. Physical medicine and rehabilitation clinics of North America, 27(1), 319–337. https://doi.org/10.1016/j.pmr.2015.09.003.

[22] Hung, K. C., Chung, H. W., Yu, C. C., Lai, H. C., & Sun, F. H. (2019). Effects of 8-week core training on core endurance and running economy. PloS one, 14(3), e0213158. https://doi.org/10.1371/journal.pone.0213158.

[23] Haas, J. G. (2017). Dance anatomy. Champaign: Human Kinetics Inc.

[24] Dinu, D., & Louis, J. (2020). Biomechanical Analysis of the Cross, Hook, and Uppercut in Junior vs. Elite Boxers: Implications for Training and Talent Identification. Frontiers in sports and active living, 2, 598861. https://doi.org/10.3389/fspor.2020.598861.

[25] Oliver, G. D., & Keeley, D. W. (2010). Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball pitchers. Journal of strength and conditioning research, 24(12), 3241–3246. https://doi.org/10.1519/JSC.0b013e3181cc22de.

[26] Cissik, J.M. (2011). The Role of Core Training in Athletic Performance, Injury Prevention, and Injury Treatment, Strength and Conditioning Journal, 33(1), 10-15.

[27] Rahmat, A., Naser. H., Belal. M., & Hasan. D. (2014). The effect of core stabilization exercises on the physical fitness in children 9-12 years. Medicina Sportiva, 10(3):2401-2405.