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Core Stability and Strength Assessment for Performance and Health

Erika Zemková[1, 2]

[1]Department of Biological and Medical Sciences, Faculty of Physical Education and Sport, Comenius University, Bratislava, Slovakia
[2]Faculty of Health Sciences, University of Ss. Cyril and Methodius, Trnava, Slovakia

ABSTRACT

Given the importance of core stability and strength in athletic performance and in the activities of daily living, its assessment should be considered an integral part of functional diagnostics. This paper presents our approach to assessing the power performance during exercises involving muscles of the core, such as lifting tasks and trunk rotations under a variety of conditions and in various population. Experience showed that core stability and strength tests are able to reveal within and between-group differences in core performance and the effectiveness of training or rehabilitation programs in competitive athletes, as well as in general population of different age and physical fitness.

***Key words:** lifting task, maximum isometric back muscle strength, power performance, sport-specific training, trunk rotations, within and between-group differences*

Introduction

Core strengthening and core stabilization exercises have become a part of athletic training, as well as prevention and rehabilitation programs[1–4]. However, there is limited and conflicting scientific evidence about their effectiveness[3]. This is mainly due to a lack of tests assessing the core stability and strength under sport-specific conditions or those tailored to general population of different age and physical fitness[5–10]. Recently, both traditional field tests and newly developed methods assessing the core performance have been included in the Long-Term Sport Diagnostic Model[11]. This paper presents an overview of our findings related to the assessment of core strength and power in athletes, as well as general physically active and sedentary population.

A new method assessing power performance during a lifting task in physically active and sedentary adults

To assess the power produced during a lifting task, one can apply a deadlift to high pull exercise (Figure 1), which engages major muscle groups such as the lower and upper back, erector spinae, abdomen, gluteus maximus, quadriceps, and hamstrings. The exercise is performed with stepwise increasing loads using the Smith machine or free weights (e.g., for physically active population). The power increases from lower loads, reaches maximum values (peak at ~80% 1RM and mean at ~70% 1RM), and then towards higher loads, decreases again. Power values are significantly higher when this exercise is performed with free weights compared to the one on the Smith machine at loads ≥50 kg[12]. Alternatively, this exercise can be performed only with a light bar (e.g., for sedenatry population). This test is reliable as evidenced by the ICC above 0.80 for both peak and mean power[12]. However, SEM >10% for peak power and SEM <10% for mean power indicates that the latter represents a more reliable parameter and should be used for data analysis[12]. This test is also sensitive in revealing within and between-group differences in power performance. Marked individual differences can be observed during the second part of the exercise (i.e., while performing the upright row). This may be corroborated by a significant relationship between the power produced during deadlift to high pull and upright row using both the Smith machine and free weights. Furthermore, there are greater differences in mean power during the deadlift to high pull than deadlift between physically active and sedentary young adults. These differences may be attributed to the increased task-lifting difficulty because it requires coordinating activation of major muscle groups in the upper body and lower body. In addition, maximal

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values of power are achieved at higher weights in physically active than sedentary young adults. The use of these values for assessing the lifting performance in sedentary adults may be a more appropriate alternative than traditional 1RM approach. Moreover, the movement pattern during the deadlift to high pull with free weights is most likely closer to task-lifting requirements of daily life and many sport activities as compared to the one performed on the Smith machine. This exercise may also be more easily applied in practice as it does not require a special weight stack machine for testing. It may be used for functional performance assessment of healthy people engaging in sedentary behaviour (e.g., college graduate students or office workers), as well as those whose jobs involve lifting tasks (e.g., construction workers). For instance, this test was used for assessing the effect of 3-month resistance and aerobic training on power performance during a lifting task in overweight and obese individuals[13]. While the resistance training group significantly enhanced the power produced during the deadlift to high pull with free weights from 30 to 50 kg (~40–60% 1RM), the aerobic training group failed to show any significant improvements[13]. This indicates that this test simulating the lifting task is sensitive in revealing changes in muscle power over time.

The relationship between muscle power during a loaded-lifting task and variables of maximum isometric back extensor strength test

The use of higher additional loads during the deadlift to high pull should be avoided when this exercise is performed by sedenatry individuals. In particular, the loaded lifting task should be performed with caution in people prone to low back pain. The alternative is to assess the ability of subjects to develop a high force in a short period of time during maximum voluntary isometric contraction (MVC) of the back muscles using the FiTRO Back Dynamometer (Figure 2). This assumption is based on a significant correlation between the power produced during the deadlift to high pull at light loads and the peak rate of force development (RFD) during MVC of the back muscles[14]. Presumably, peak RFD measured during MVC of the back muscles might predict a lifting performance at light loads. However, a greater isometric back muscle strength is needed for power generation at heavier loads. This may be corroborated by a significant correlation between MVC peak force and the power produced during a loaded lifting task at higher weights[14].

Other useful information can be obtained by assessing the subjects' ability to differentiate the strength of back muscle contraction. Their task is to estimate pre-determined percentage (e.g. 50%) of MVC of the back muscles either with or without feedback information on force produced under fatigue and non-fatigue conditions[15]. In such a case, force feedback contributes to a more accurate force regulation during MVC of the back muscles under fatigue.

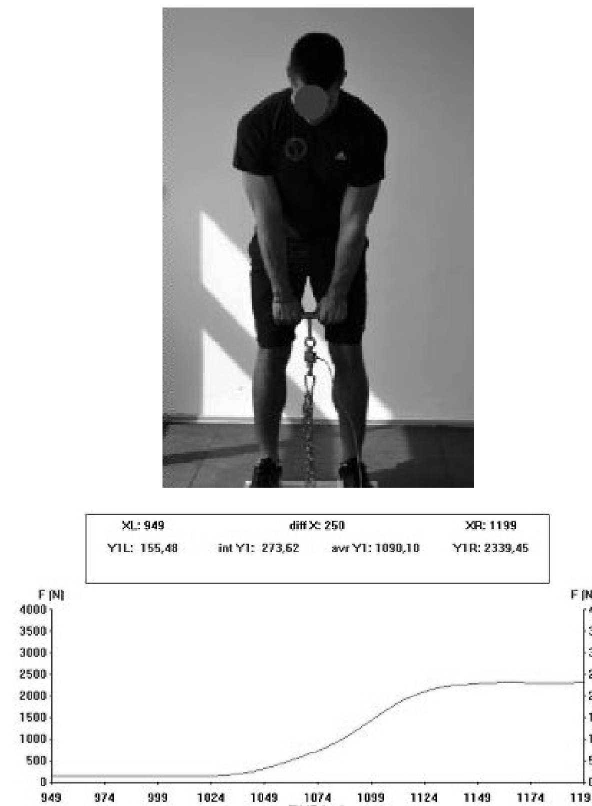

Fig.2. Assessment of maximal isometric strength using the FiTRO Back Dynamometer (FiTRONiC, Slovakia).

Fig. 1. Assessment of power during the deadlift to high pull exercise with free weights using the FiTRO Dyne Premium (FiTRONiC, Slovakia).

How can trunk rotation power and strength be assessed?

Torso isoinertial dynamometers are usually used for assessment of velocity and power during trunk rotations. Test-retest reliability of these parameters measured by the FiTRO Torso Isoinertial Dynamometer is good to excellent (ICC >0.90, SEM ~7%) when a weight of 1 kg is used; however their values should be interpreted with caution when the exercise is performed with 20 kg (ICC <0.80, SEM >10%)[16]. This test is also sensitive in discriminating trunk rotational velocity in athletes of different sports. Its values are the highest in ice-hockey players, then canoeists, rock & roll dancers, judoists, wrestlers, tennis players, golfers, karateists, and finally ballroom dancers when a 1 kg barbell is used. Similarly, the highest trunk rotational velocity is in canoeists, followed by ice-hockey players, rock & roll dancers, judoists, wrestlers, tennis players, golfers, karateists, and finally ballroom dancers when a 20 kg barbell is used. More specifically, mean velocity in the acceleration phase of trunk rotation was significantly higher in tennis players than in golfers when a 1 kg but not a 20 kg barbell was used. Its values were significantly higher in rock & roll than ballroom dancers with both 1 kg and 20 kg additional loads. However, mean velocity did not differ significantly between judoists and wrestlers during trunk rotations with 1 kg and 20 kg barbell placed on their shoulders. Furthermore, mean power produced during trunk rotations with a weight of 20 kg was significantly higher in tennis players than golfers, in rock & roll dancers than ballroom dancers, and in judoists than wrestlers. Individual comparisons of these parameters revealed higher values in a weightlifter than a bodybuilder, a canoeist than a rower, and an ice-hockey player than a karateist. These between and within-group differences in velocity and power produced in the acceleration phase of trunk rotations may be ascribed to training specificity involving trunk rotations at different velocities under different load conditions.

However, to simulate testing conditions specific to demands imposed by sports, in which athletes perform rotational movements of the trunk, one can use a pulley system and an external dynamometer for assessing the rotational power[17]. Such a measurement provides reliable data when performing a rotational exercise of the axial skeleton in the transverse plane while sitting on a box[17]. This test is suitable for sports like canoeing, however trunk rotations performed in a standing position would be a more specific alternative for many other sports, such as baseball, golf, tennis, hockey or karate. The test adapted from the woodchop exercise may most likely provide similar conditions (Figure 3). Subjects perform single repetitions of the standing cable woodchop exercise with increasing weights up to the weight at which maximal values of power are achieved. They can also perform a set of a predetermined number of repetitions at a previously established weight at which a maximal value of power was achieved in order to assess strength endurance of the trunk muscles. Mean power during the standing cable woodchop exercise is a reliable parameter with ICC values above 0.90 in the entire load range[18]. This test is also able to reveal differences in trunk rotational power among physically active individuals, especially at higher weights. However, one should be aware that this exercise allows more involvement of the lower body, thus it may be less confined to the trunk. It may be applied in functional performance assessment of athletes who require the production of rotational power during their training and competition.

Fig. 3. Assessment of power during the standing cable woodchop exercise using the FiTRO Dyne Premium (FiTRONiC, Slovakia).

Although such a computer-based system, FiTRO Dyne Premium, that can be directly connected to the weight stack machine can be considered practical for sport-specific and fitness-oriented testing of trunk rotational power, for some practitioners the exercise performed with free weights represents a more suitable alternative. Machines are good for training of muscle strength, however they neglect key stabilization components of the core. Using free weights during trunk rotations places greater demands on stabilizing muscles. The exercise that closely replicates the upper/lower body rotation movements should be preferred for assessing sport-specific rotational power. The test consists of single repetitions of trunk rotations with a barbell placed on the shoulders (Figure 4). Participants perform two repetitions of trunk rotations to each side per load. Bars of different weights are placed on their shoulders behind the neck. The load increases stepwise from 1 kg by ~5 kg up to the weight at which maximal values of power are achieved (usually it is at 30–45% 1RM). They are asked to perform rotations of the trunk with maximal effort in the acceleration phase. They rotate their torso from the right (or the left) side towards the opposite side, and then they slowly return to the starting position. The test is then repeated for the opposite side of the body. The diagnostic system FiTRO Torso Premium consists of an inertia measurement unit in a small box with an integrated USB interface and software. While inserted on the barbell axis, the sensor unit registers instant angular of rotation movement. Calculations of force and power are based on the Newton´s second law of mechanics. Force produced to accelerate and decelerate a rotation movement is obtained as a product of barbell mass and acceleration of its center of gravity (CoG). Angular acceleration is obtained by derivation of angular velocity. For the transformation of angular velocity and acceleration into their real values, a rotation radius (distance between rotation axis and barbell mass CoG) is used. Power is calculated as a product of force and velocity. Peak and mean values of force, torque, power, and velocity in the acceleration and the deceleration phase of trunk rotations can be analysed. There are significant correlations between their values obtained in the acceleration and the decelaration phase of trunk rotations with weights from 1 kg to 20 kg, i.e. mean force and mean torque (from –0.56 to –0.78), mean power (from –0.77 to –0.92), and mean velocity (from 0.64 to 0.84). It seems that when attempting to perform a powerful rotational movement of the trunk and maximize its velocity over the entire range of motion, muscle power is not significantly different in the acceleration and the deceleration phase, regardless of weight applied.

Sport-specific differences in power-velocity-force profiling during trunk rotations at different loads

While force–velocity–power characteristics of resistance exercises, such as squats and bench presses, have been well documented, little attention has been paid to load, force and power–velocity relationships in trunk rotation exercises. Given that power and velocity produced during trunk rotations play an important role in athlete performance, their assessment should represent a crucial part of the testing battery. There are significant differences between groups of athletes in power produced during trunk rotations at lower velocities (≤334.2 rad/s) or at higher weights (≥10.5 kg)[19]. The highest power is achieved in combat sports athletes (maximum at 10.5 kg), then in water sports athletes (maximum at 20.0 kg), grappling sports athletes (maximum at a 15.5 kg), and ball sports athletes (maximum at a 10.5 kg)[19]. Additionally, angular velocity is the highest at lower weights in combat sports athletes and at higher weights in water sports athletes. Alternatively, combat sports athletes produce the highest force at higher velocities, whereas water sports athletes produce the highest force at lower velocities. While the highest power is produced at higher velocities or at lower weights in ball sports players (golf, hockey, tennis) and combat sports athletes (tae kwon do, thai boxing, karate, boxing) who generate high force in a short period of time, the highest power at higher weights is produced in grappling sports athletes (judo, wrestling) who require a great explosive power of upper and lower body to lift and throw the opponent and water sports athletes (canoeing, kayaking) who exert a great force against the water. These variations in power production in athletes of different sports may be attributed to adaptations to the training undertaken and reflect its specificity including trunk rotations at various velocities under different load conditions.

Between-gender differences in trunk rotational power in athletes of gymnastic and dance sports

Since body rotations represent one of the essential elements of performance also in athletes of gymnastic

Fig. 4. Assessment of power during standing and seated trunk rotations using the FiTRO Torso Premium (FiTRONiC, Slovakia).

(aerobic and acrobatic gymnastics) and dance sports (ballroom and rock & roll dancing), we were interested in whether between-gender differences exist in trunk rotational power under various load conditions[20]. As expected, mean power in the acceleration phase of trunk rotations was significantly higher in male than female athletes at loads from 10.5 kg to 20 kg. Similar significant between-gender differences for angular velocity at weights ≥10.5 kg were observed. Alternatively, power and force were greater at lower velocities in male than female athletes. The highest values of power were produced at a higher weight of 15.5 kg in males (in few of them at 20 kg) as compared to 10.5 kg in females. This may be ascribed to both the genetic predispositions and the specificity of their acrobatic and dance elements including trunk rotations at various velocities under different load conditions. While both males and females perform repetitive rotational movements of the trunk, male athletes also need to exert high forces of upper and lower body in order to lift female counterparts during sport-specific movements.

Between-side differences in trunk rotational power in athletes trained in asymmetric sports

The asymmetric loading of the trunk muscles in sports like golf or tennis may cause side-to-side imbalances in rotational muscle strength and endurance. Such imbalances may be compounded by the presence of low back pain and related injuries. Yet, only few indicators of back pain were identified. We assumed that trunk rotational power may reveal these asymmetries/dysbalances in athletes trained in asymmetric sports. Our preliminary study showed higher trunk rotational velocity on the dominant than non-dominant side in tennis players (9.4%) and golfers (11.9%), whereas there were no significant side-to-side differences in a control group of physically active subjects (6.2%). Further study showed that also power in the acceleration phase of trunk rotations is significantly higher on the dominant (D) than non-dominant (ND) side at 5.5 kg – 20 kg in ice-hockey players, at 5.5 kg – 15.5 kg in tennis players, and at 5.5 kg – 10.5 kg in golfers, whereas its values do not differ significantly in the age-matched control group[21]. Taking into account significantly higher trunk rotational power on the dominant than the non-dominant side in golfers (~15%), tennis players (~12%) and ice-hockey players (~14%) at lower and/or higher weights and no significant side-to-side differences in a control group of physically active subjects (~7%), this parameter may be considered specific to their asymmetric loading during trunk rotations. These findings may have implications in designing training programs for these athletes in order to avoid even greater side-to-side differences in trunk rotational power. However, whether these asymmetries/dysbalances expressed by the D/ND ratio could identify the likelihood of low back pain, needs to be investigated.

Muscle power during standing and seated trunk rotations with different weights

In sports involving standing loaded trunk rotations, those should be preferred when testing athlete´s specific performance as opposite to frequently used dynamometers allowing movements of the trunk in seated and fixed position. However, standing trunk rotational movements are less confined to the trunk. They allow more involvement of legs and greater contribution of thoracic/hip mobility to the upper-body rotational power. The force is transferred sequentially from the proximal segments (i.e., hips), toward the more distal segments (i.e., shoulders and arms). This kinetic linkage of the proximal to distal segments may play an important role in production of trunk rotational power. Our study revealed higher power during standing than seated trunk rotations, with more pronounced differences at weights ≥10.5 kg[22]. This may be ascribed to a greater range of trunk motion while standing as compared to sitting, which allows participants to accelerate the movement more forcefully at the beginning of rotation. As a result is a greater trunk rotational velocity and consequently also overall power outputs. This assumption may be corroborated by significantly higher velocity in the acceleration phase of trunk rotation and the respective angular displacement during standing than seated trunk rotations at weights ≥10.5 kg. Moreover, there are low correlations between the power achieved during standing and seated trunk rotations with weights ≥10.5 kg, suggesting that these tests measure distinct qualities. This is because core muscles facilitate the movement of the trunk easier when the body is in an upright position. On the contrary, there is a strong relationship between power produced during standing and seated trunk rotations with a lower weight of 5.5 kg. This indicates that these exercises are similar in terms of power production. This fact has to be taken into account when assessing the trunk rotational power in either the standing or the seated position. Additionally, relative values of power should be used when trunk rotation performance in a standing position is evaluated. The power expressed relative to body weight is more important measure than absolute power for most athletes to consider, namely for those whose performance depends heavily on rotational movements of the trunk while standing.

The relationship between velocity of trunk rotations and the range of angular motion in young and older adults

Increased trunk stiffness with age may reduce the trunk range of motion (ROM), and probably also compromise velocity and power production during trunk rotational movements. Indeed, a significant interaction between age and trunk angular displacement in determining velocity of trunk rotations was found[23]. More specifically, velocity in the acceleration phase of trunk rotation and the respective angular displacement were significantly higher in young (~21.8 years old) as compared to older adults (~62.2 years old). Trunk rotational velocity correlated significantly with trunk angular displacement in both older (r ranged from 0.77 to 0.93, $p<0.01$) and young adults (r ranged from 0.65 to 0.79, $p<0.05$)[23]. The respective r^2 values explained a higher proportion of variance in older than young adults (60–86% and 42–62%, respectively)[23]. This indicates that slower velocity of trunk rotations is most likely due to a limited range of trunk rotational motion, which is more evident in older adults. This finding should be taken into account in sports that require rotational movements of the trunk under unloading or loading conditions (e.g., canoeing, golf, table tennis, tennis etc.).

Association of trunk rotational velocity with spine mobility and curvatures in para table tennis players

The core musculature is a foundation for efficient movement and power production in para-athletes. Though there are various tests of core muscle strength and endurance, these are not specifically designed for wheelchair users. The FiTRO Torso Isoinertial Dynamometer that allows them to perform trunk rotations in the seated position can be used for this purpose. As it has been shown, trunk rotational velocity and respective angular displacement are significantly lower in paralympic table tennis players compared to able-bodied athletes[24]. Both groups showed similar values of thoracic kyphosis. However, para table tennis players exhibited lower lumbar inversion and pelvic retroversion compared to able-bodied athletes. Velocity in the acceleration phase of trunk rotation correlated with angular displacement in both groups. In addition, velocity values were associated with lumbar curvature and pelvic tilt angle in para table tennis players. This indicates that slower velocity of trunk rotations in para table tennis players may be due to their limited range of trunk rotational motion. Decreased posterior concavity could also contribute to these lower values. However, other biomechanical factors may also have an impact on the association between these variables and have yet to be documented.

The effect of sport-specific training in the preparatory and competitive periods on trunk rotational power

Besides assessing acute effects of different forms of exercise on trunk rotational power, its adaptive changes in athletes whose performance requires the production of power during trunk rotations (canoeists, tennis players, ice-hockey players, golfers, etc.) should also be evaluated. The trunk rotational power is assumed to increase at higher weights after the preparatory period, whilst at lower weights (or at higher velocities) after the competitive period due to different training loads used. As it has been shown, mean power in the acceleration phase of trunk rotations increased significantly after both 6-week preparatory (at weights from 10 to 26 kg) and 6-week competitive period (at weights from 6 to 26 kg) in tennis players[25]. Its values increased significantly also after 6-week preparatory period in ice-hockey players (at weights ≥12 kg), whereas there were no significant changes after 6-week competitive period[25]. Similarly, mean power produced during trunk rotations increased significantly only after 6-week preparatory period (at weights ≥10 kg) in canoeists[25]. These findings demonstrate that changes in trunk rotational power reflect the specificity of their training programs. This information may provide a basis for designing exercises focused on improvements of power produced during trunk rotations under loading conditions.

Conclusion

The present study provided an overview of our findings related to the assessment of core strength and power during the lifting task and trunk rotations under a variety of testing conditions in various population. A better understanding of their role in athlete performance and physical fitness of general population would help us to design specific exercise programs tailored to their needs. It may provide useful information on within and between-group differences in power produced during exercises involving trunk muscles, as well as on the effectiveness of training or rehabilitation programs focused on improvements of core stability and strength. Some variables of the core tests can potentially predict back problems in individuals of different age and physical fitness due to overloading of their spine or, on the contrary, due to their prevalently sedentary lifestyle.

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E. Zemková

Department of Biological and Medical Sciences, Faculty of Physical Education and Sport, Comenius University in Bratislava, Nábr. arm. gen. L. Svobodu 9, 814 69 Bratislava, Slovakia
e-mail: erika.zemkova@uniba.sk

PROCJENA STABILNOSTI TRUPA I SNAGE ZA SPORTSKU IZVEDBU I ZDRAVLJE

S A Ž E T A K

S obzirom na važnost stabilnosti trupa i snage za sportsku izvedbu te kod aktivnosti u svakodnevnom životu, procjena istih treba se smatrati sastavnim dijelom funkcionalne dijagnostike. Ovaj rad predstavlja naš pristup procjeni snage tijekom izvođenja vježbi koje uključuju mišiće trupa, kao što su zadaci podizanja i rotacija trupa u različitim uvjetima te među različitim populacijama. Iskustvo je pokazalo da testovi stabilnosti trupa i snage mogu ukazati na razlike unutar i između grupa po pitanju snage trupa i učinkovitosti treninga ili rehabilitacijskog programa kod sportaša natjecatelja, kao i u općoj populaciji različite dobi i tjelesne spremnosti.