ASSESSMENT OF POWER AND STRENGTH OF TRUNK MUSCLES: FROM THE LAB TO THE FIELD

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Keywords:

- core stability and strength,
- maximal isometric voluntary contraction,
- muscle power during a lifting task,
- trunk rotational power,
- sport-specific testing.

Abstract:

Given the importance of core stability in athletic performance and in the activities of daily living, its assessment should be considered an integral part of functional diagnostics. Above all, such testing should differentiate between athletes with different demands on the strength and endurance of their trunk muscles and provide relevant information on the efficiency of sport-specific training. Therefore, the torso movement during testing should be as close as possible to the movement used during training or competition. While for some athletes the trunk rotational power may represent a sport-specific ability (e.g., a karate stroke), for others it may be the strength endurance of trunk muscles that is important for their athletic performance (e.g., canoe slalom). Though bilateral concentric rotations available at most of systems are suitable for canoeing, for many other sports, such as hockey or tennis, unilateral movement performed separately on the right and left side would be a more specific alternative. It is equally important to identify possible risk factors associated with low back pain. For instance, the asymmetric pattern of trunk rotation during the golf swing or tennis stroke may cause side-to-side imbalances in rotational strength and endurance characteristics among elite athletes who frequently play and practice. These imbalances may contribute to increased susceptibility to low back pain. The present study deals with novel alternatives for assessment of power and strength of trunk muscles in various populations using portable diagnostic systems. Experience showed that these tests and methods are appropriate for both sport-specific and fitness-oriented testing.

INTRODUCTION

The importance of function of the central core of the body for stabilization and force generation in all sports activities is being increasingly recognized. The „core“ has been described as a box with the abdominals in the front, paraspinals and gluteals in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom (Richardson et al., 1999). While the term of core strength refers to the strength of these muscles, core stability is the ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, tranfer and control of force and motion to the terminal segment in integrated kinetic chain activities (Kibler et al., 2006).

Core stabilization and core strenghtening exercises have been promoted as a preventive regimen, as a form of rehabilitation, and as a performance-enhancing program for various lumbar spine and musculoskeletal injuries. However, there is a limited and conflicting scientific evidence on their efficiency for enhancement of athletic performance or prevention and rehabilitation of injuries. It is mainly due to a lack of standard evaluation system of core stability and core strength (Zemková, 2013; Zemková, 2015a,b; Zemková, 2017).

Measurement of core stability is more challenging to measure than core muscle strength as it requires incorporating parameters of coordination and balance. An example of testing ones core stability is a lunge which requires the deep trunk muscles to control the spine, pelvis and hips, while lifting the body´s weight. A more challenging example of testing core stability would be the Olympic weight lift of the “clean and jerk” which requires very strong core muscles, correct spinal alignment, while lifting a progressively heavier weight. Another example is to maintain the spine and trunk in a stable alignment while, sitting, or standing on an unstable surface such as a gym ball, or balance board while lifting weight with the arms or legs (Behm et al., 2010).

Core strength is measured in terms of how much weight can be lifted, how many repetitions can be performed, or how long a neutral stable position can be maintained (Faries, Greenwood, 2007). Because triaxial lumbar dynamometers are scarce (Parnianpour et al., 1988; Gomez et al., 1991; Balague et al., 2010), isometric and isokinetic dynamometers are frequently used (Flory et al., 1993; McGill et al., 1999). However, the external validity of isokinetic trunk strength and isometric trunk endurance tests for physical tasks is ambiguous. While some authors have shown that measures of core strength and sports performance are related (Nesser et al., 2008; Sato, Mokha, 2009), others have not (Schibek et al., 2001; Stanton et al., 2004; Tse et al., 2005). For instance, the synergistic relationship between the muscles of the core and limbs has been documented for a variety of sports specific tasks, such as overhead throwing in baseball, forehand and backhand strokes in tennis, cycling, and various lifting tasks (Brown, Abani, 1985; Thelen et al., 1996; Stodden et al., 2001; Cholewicki, VanVliet, 2002; Ellenbecker, Roetert, 2004; Abt et al., 2007; Aguinaldo et al., 2007). These studies highlight the role the core musculature plays in the transfer of torques and momentum throughout the kinetic chain during sports performance. Deficiencies in any part of the kinetic chain could lead to suboptimal performance or injury (Behm et al., 2010). Therefore, when assessing the role of the core musculature during sports tasks, it is important to consider the demands at all joints and muscles in the kinetic chain, including those distal and proximal to the core.

However, most of the testing methods evaluating the efficiency of training programs for improving core stability and strength are insufficient. Rather, they are based on the biomechanical analysis of technique, the experience of conditioning specialists or cross-sectional training evidence. In addition, low reliability and sensitivity of current diagnostic methods evaluating the strength of back muscles limits their practical application. Another drawback is that current methods do not target the major stabilizers of the spine in spite of the fact that studies have shown that the most important stabilizers are task specific.

Assessment of maximal isometric strength

In the sporting field, a potrable version of the device allowing the measurement of maximal isometric strength may be used (Figure 1). Preliminary measurements were provided in order to standardize the testing procedure (Zemková et al., 2015a). While testing, one has to take into account that maximal isometric force is significantly higher when the test is performed with slightly flexed than straight knees (Poór et al., 2015). Performing this test with slightly flexed knees showed significanly higher values of peak force and rate of force development in an initial 100 ms, 200 ms and 300 ms in physically active participants as compared to those with a prevalently sedentary lifestyle (Poór et al., 2016). Further studies are needed to estimate the validity of this system and its applicability for highly resitance-trained individuals.

Figure 1. Assessment of maximal isometric strength using the FiTRO Back Dynamometer system (FiTRONiC, Slovakia).

Assessment of muscle power during a lifting task

Recently we developed a test evaluating power performance during a lifting task (Figure 2) and a related methodology quantifying data variability under various conditions (Zemková et al., 2016a). A deadlift to high pull exercise that involves working the major muscle groups in the upper body and lower body, such as the abdomen, erector spinae, lower back and upper back, quadriceps, hamstrings and the gluteus maximus may best simulate the demands of particular sport or job comprising of lifting tasks.

The ICC of peak power and mean power during deadlift to high pull above 0.80, along with no significant differences between the test results obtained on the first and second test sessions signify good reliability. However, SEM >10% for peak power and SEM <10% for mean power during deadlift to high pull with free weights as well as on the Smith machine indicate that the latter represents a more reliable parameter and should be used for data analysis. This fact has to be taken into account when power performance during lifting tasks is evaluated.

During the diagnostic set, the power increases from lower weights, reaches a maximum, and then toward higher weights, decreases again. Maximal values of peak power are achieved at about 80% 1RM and mean power at about 70% 1RM. There are no significant differences in peak power during the deadlift to high pull on the Smith machine and with free weights from 20 kg to 45 kg. However, their values are significantly higher during deadlift to high pull with free weights than on the Smith machine when weights ≥50 kg are lifted. Mean power during deadlift to high pull on the Smith machine and with free weights shows a similar tendency. On the other hand, there are no significant differences in peak and mean power during upright rows with free weights and on the Smith machine. Likewise, their values do not differ significantly during deadlift with free weights and on the Smith machine.

Furthermore, there are substantial individual differences in velocity and power production during deadlift to high pull with the weight at which maximal power is achieved (e.g., 50 kg), which can be seen mainly during the second part of the exercise (i.e., while performing the upright row). This may be ascribed to a significant association (r >0.80) between the power produced during deadlift to high pull and upright row on the Smith machine as well as with free weights.

The muscle power obtained from deadlift to high pull also provides better potential for differentiation of physically active and sedentary young adults than deadlift, plus is more specific to lifting tasks. This may be corroborated by greater differences in mean power during deadlift to high pull (23.1%) than during deadlift (18.6%) between physically active and sedentary young adults (Zemková et al., 2016b). These differences may be ascribed to the increased task-lifting difficulty because this exercise requires coordinating activation of major muscle groups in the upper body and lower body during the performance of lifting movement.

In addition, there are significant between-group differences in power outputs during deadlift to high pull at weights ≥45 kg (Zemková et al., 2016c). Maximal values of peak and mean power are achieved at higher weights in physically active (about 79% and 86% 1RM) than sedentary young adults (about 71% and 79% 1RM). In practice, the use of maximal power for assessing of lifting performance in adults with a prevalently sedentary lifestyle may be more appropriate alternative than traditional 1RM approach.

These findings indicate that the deadlift to high pull with free weights may be applied for evaluation of power performance during lifting tasks. The movement pattern during this exercise 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. It may also be more easily applied in practice as it does not require a special weight stack machine for testing. It has been shown that deadlift to high pull with free weights is an acceptably reliable test when considering both stability of measurement and test-retest reliability. Mean rather than peak values of power are recommended to be used for the analysis because of their better reliability. The test is also sensitive in distinguishing lifting performance in healthy young subjects. Since this task involves working major muscle groups in the upper body and lower body, it may be applied in functional performance testing of healthy college graduate students and office workers with a prevalently sedentary lifestyle as well as construction workers with job demands based on lifting tasks.

This test was applied in the study that evaluated the effect of three months of resistance and aerobic training programs on power produced during a lifting task in the form of a deadlift high pull in the overweight and obese (Zemková et al., 2017a). The resistance training enhanced power outputs during a lifting task with weights from 30 to 50 kg (~40-60% 1RM) in these individuals. However, the group that participated in the aerobic training failed to show any significant improvement of power performance during the deadlift high pull. This was the first study to demonstrate that the deadlift high pull with free weights may be a suitable test for evaluating lifting performance in the overweight and obese. The test was sensitive to changes in power outputs during a modified lifting task following the training. Therefore, it may be implemented in the functional diagnostics for overweight and obese individuals and complement so existing testing methods.

Figure 2. Assessment of musle power during a lifting task using the FiTRO Dyne Premium system (FiTRONiC, Slovakia).

Assessment of trunk rotational power

Given the importance of trunk rotational power in sports such as baseball, basketball, cricket, golf, hockey, tennis, soccer, canoeing etc., core strengthening and core stabilization exercises should be considered an integral part of functional training. Core exercises incorporated into strength and power training regimens require bilateral agonist-antagonist coactivation to produce movement and stabilize the spine. When the trunk muscles must be co-activated to stabilize the spine, that exercise is by definition a core stability exercise (Lehman, 2006). Core stability is the ability of the lumbopelvic-hip structures and musculature to withstand compressive forces on the spine and return the body to equilibrium after perturbation (Willson et al., 2005). Factors such as the endurance, strength, power, and coordination of the abdominal, hip, and spine musculature are important components of core stability. The study by Keogh et al. (2010) suggests that similar to strength, core stability exhibits relatively high levels of task specificity. The implication of this is that once some initial conditioning of the core musculature is obtained, core stability training should be as specific as other aspects of the conditioning program if functional performance is to be improved. It could be argued that one way to achieve this would be the use of functional total body exercises that mimic in some respects actual movements that are routinely performed by the athletes in their sports. These total body exercises may also be used to assess functional core stability. The challenge remains as to what aspects of performance in these total body tasks would be assessed and how this would be quantified in an objective manner.

Selecting a single appropriate test to fully evaluate core stability is difficult, given the complex interaction of the lumbopelvic-hip structures and musculature. A number of static single-joint core stability measures and ratios were unable to distinguish resistance-trained subjects with high and low strength and power levels or to evaluate the efficiency of training involving complex dynamic core exercises. Implements, such as the medicine ball and cable pulleys, can be very useful in developing and quantifying power as they allow motion in all three planes. Both medicine ball throws (side, overhead, scoop) and the chop and lift for rotational power assessment have shown high reliability (ICC=0.84-0.99 and 0.87-0.98, respectively) (Kohmura et al., 2008; Palmer, Uhl, 2011; Rivilla-García et al., 2011; Lehman et al., 2013). Rivilla-Garcia et al. (2011) reported a high correlation (r=0.90) between a light overhead medicine ball throw (0.8 kg) and handball-throwing velocity. Conversely, Kohmura et al. (2008) reported that the scoop medicine ball throw has very little shared variance with baseball fielding (throwing distance, standing long jump, and agility T-test) (~7%) compared with batting (~14%). Recently, Talukdar et al. (2015) examined the role of rotational power and mobility on cricet ball throwing velocity using a linear position transducer attached to the weight stack of a cable pulley system to measure chop and lift power. According to the authors, greater ROM at proximal segments, such as hips and thoracic, may not increase throwing velocity in cricet as reduced ROM at proximal segments can be useful in transfering the momentum from the lower extremity in an explosive task such as throwing. These discrepancies may be ascribed to the task specificity and weight of the medicine ball or amount of load used during the chop and lift.

In the laboratory, isokinetic machines (Newton et al., 1993; Kumar et al., 1995; Kumar, 1997) or electromyography (Pope et al., 1986; McGill, 1991; Kumar, Narayan, 1998) are used to measure strength characteristics during axial rotation movements. However, when using an isokinetic dynamometer with a torso rotation attachment, no significant differences in peak torque were found within or between groups of healthy individuals who do not play golf and those who are highly skilled at the sport (Lindsay, Horton, 2006). The authors also reported no significant difference in the endurance of trunk muscles between the healthy elite golfers and the non-golfing controls. Similarly, Suter and Lindsay (2001) were unable to show any significant differences in the static holding times or a decline in the electromyography median frequency between low-handicap golfers with low back pain and healthy, age-matched controls who did not golf. The limitation of these measurements is that torso rotation performed while sitting on the chair with straps around the back and legs provides artificial movement patterns.

Thus, there is a need to develop a sport-specific test able to evaluate rotational power of the trunk. It is especially important to design the test that require little or no equipment and hence is inexpensive and fast to administer. Most current tests evaluate the endurance (e.g., trunk flexor and extensor endurance tests and the lateral bridge test) rather than the strength and power component of core stability. Given that rotational power is a better predictor of athlete performance, the test that measure this component of the core may be more useful, especially because it may better mimic the demands imposed by sports.

In order to provide testing conditions specific to demands imposed by most sports, one can use a system that allows monitoring of basic biomechanical parameters during rotational movement of the trunk. So far, the study of Andre et al. (2012) determined the test-retest reliability of the kinetic rotational characteristics of the pulley trainer when performing a rotational exercise of the axial skeleton in the transverse plane while sitting on a box. The authors found that a pulley system and an external dynamometer can be used together as a reliable research tool to assess rotational power. Although such a test is suitable for canoeing, for example, for many other sports, such as hockey or tennis, rotational movement performed during standing would be a more specific alternative. As athletes prefer free weights or weight exercise machines to improve the strength of their trunk muscles, the testing should be as close as possible to the movement used during training or competition. Presumably, the test adapted from the wood chop exercise may provide conditions similar to those imposed in many sports involving trunk rotation (baseball, golf, karate, etc.). However, such rotational movement allowing more involvement of the lower body may be less confined to the trunk, which in turn might increase the movement variability and influence the reliability.

Nevertheless, our recent study showed that evaluation of the maximal power and endurance of core muscles during the standing cable wood chop exercise on a weight stack machine (Figure 3) is both a reliable method and sensitive to differences among physically active individuals (Zemková et al., 2017b). Mean power during the standing cable wood chop exercise is a reliable parameter with ICC values above 0.90 at all weights tested. It is also a sensitive parameter able to discriminate within-group differences in the maximal values of mean power and the endurance of core muscles. Substantial individual differences are observed in the mean power produced, especially at higher weights, and in its maximal values achieved at about 75, 67, and 83% 1RM. At these weights, significant differences between the initial and the final repetitions of the wood chop exercise can also be found. Therefore, this method of assessing (a) maximal power using maximal effort single repetitions of the standing cable wood chop exercise with increasing weights and (b) the endurance of the core muscles using a set of a predetermined number of repetitions performed at a previously established weight at which maximal power was achieved may be used in functional performance testing, namely, for athletes who require the production of rotational power during training or competition (tennis players, ice hockey players, etc.).

Figure 3. Measurement of strength parameters during the standing cable wood chop exercise on a weight stack machine using the FiTRO Dyne Premium system (FiTRONiC, Slovakia).

Such a computer-based system that can be directly connected to the weights on stack machine may be considered to be a suitable and practical alternative for sport-specific and fitness-oriented testing of trunk rotational power. However, some practitioners prefer free weights in their weight training workout routine. While machines are good for training of muscle strength they neglect key stabilization components of the core. Using free weights is a way to 'functional' training that places greater demands on stabilizing muscles. In addition, exercises with free weights allow performing a full range of trunk motion. Moreover, free-weight exercises are closer to many sports and daily activities, can be performed in any sporting fields and are less expensive than exercises on weight machines.

Therefore, the exercise that closely replicates the upper/lower body rotation movements should be preferred in testing in order to assess sport-specific power. A suitable alternative represents a system that allows evaluation of power performance during trunk rotations in either seated or standing position with a barbell placed on the shoulders (Figure 4). The system 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, power, velocity, and torque in the acceleration and the deceleration phase of trunk rotations may be analysed.

Significant negative correlations were found between mean power in the acceleration and the decelaration phase of trunk rotations with weights of 1 kg (-0.77), 5.5 kg (-0.78), 10.5 kg (-0.82), 15.5 kg (-0.90), and 20 kg (-0.92) (Zemková et al., 2015b). Significant negative associations were also observed between mean force as well as mean torque in the acceleration and the decelaration phase of trunk rotations. In both cases r values ranged between -0.56 and -0.78. However, significant positive correlations were detected between mean velocity in the acceleration and the decelaration phase of trunk rotations ranging from +0.64 to +0.84. These findings indicate 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.

Usually, single repetitions of a particular exercise with increasing weights stepwise up to the 1RM are performed to obtain individual force-velocity and power-velocity curves or to analyze power- and velocity-weight lifted relationship. It is known that maximum force production occurs when the speed of movement is very low. As the speed of movement increases, force decreases and at very high speeds force production is very low. Consequently, maximal values of power occurs at intermediate velocities when lifting moderate weights, i.e. 50-60% 1RM during typical resistance exercises such as bench presses or squats (Hamar, 2008). However, maximal power during trunk rotations occurs at loads from 30 to 45% of 1RM (Zemková et al., 2017c). This variation in power production at light to moderate weights in athletes of various specializations may be ascribed to the specificity of training adaptation. Hence, this exercise that closely replicates the trunk rotation should be used to assess the sport-specific rotational power.

Poór (2017a) and Poór et al. (2017a,b) evaluated the changes in muscle power during trunk rotations with different weights (6, 10, 12, 16, 20, 22, and 26 kg) prior to and after the preparatory and competitive periods in tennis players, hockey players, and canoeists. Mean power in the acceleration phase of trunk rotations significantly increased after the preparatory period in tennis players with weights of 10 kg, 12 kg, 16 kg, 20 kg, 22 kg, and 26 kg. Its values increased significantly also after the competitive period at weights of 6 kg, 10 kg, 12 kg, 16 kg, 20 kg, 22 kg, and 26 kg. Significant improvement of mean power after the preparatory period was also found in hockey players during trunk rotations with weights of 12 kg, 16 kg, 20 kg, 22 kg, and 26 kg, whereas its values did not change significantly after the competitive period. Mean power significantly increased also in a group of canoeists, however only after the preparatory period with weights of 10 kg, 12 kg, 16 kg, 20 kg, 22 kg, and 26 kg. These findings indicate that changes in trunk rotational power reflect the specificity of the training program. There was a significant increase of mean power after both preparatory and competitive periods in tennis players at almost all weights (10-26 kg and 6-26 kg, respectively). While its values increased significantly after the preparatory period also in hockey players during trunk rotations with higher weights (≥12 kg), no significant changes after the competitive period were found. Similarly, mean power increased significantly only after the preparatory period in canoeists during trunk rotations with weights ≥10 kg.

Core strength does have a significant effect on an athlete's ability to create and transfer forces to the extremities (Shinkle et al., 2012). It is obvious that the effective execution of the tennis stroke or golf swing not only requires rapid movement of the extremities but also substantial rotational power and/or velocity of the trunk muscles. Trunk extensors, flexors, rotators, and lateral bend agonists are active throughout the stroke in baseball and tennis as well as the golf swing. Actually, all trunk muscles are relatively active during the acceleration phase of the golf swing with the trail-side abdominal oblique muscles showing the highest level of activity (Watkins et al., 1996). We have found that mean values of power and velocity in the acceleration phase of trunk rotation are sensitive parameters able to identify group and individual differences (Zemková et al., 2013a; Zemková et al., 2014a). More specifically, mean power produced with the weight of 20 kg was significantly higher in tennis players than golfers, in rock & roll dancers than ballroom dancers, and in judoists than wrestlers. Comparison of power outputs between individuals showed higher values in ice-hockey player than karate competitor, in canoeist than rower, and in weightlifter than bodybuilder. Furthermore, mean velocity in the acceleration phase of trunk rotation with the weight of 1 kg was significantly higher in tennis players than in golfers. However, its values did not differ significantly between these groups when the weight of 20 kg was used. Significantly higher mean velocity in the acceleration phase of trunk rotation with weights of 1 kg and 20 kg was found in rock & roll dancers as compared to ballroom dancers. On the other hand, there were no significant differences in mean velocity in the acceleration phase of trunk rotation between judoists and wrestlers with weights of 1 kg and 20 kg. There were also individual differences between athletes in mean velocity in the acceleration phase of trunk rotation with weights of 1 kg and 20 kg, i.e. higher values in ice-hockey player than in karate competitor, in canoeist than in rower, and in weightlifter than in bodybuilder. These within and between groups differences in trunk rotational power and velocity may be attributed to specificity of training involving trunk movements of different velocities under different load conditions.

The asymmetric loading of 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. They comprise 15 to 34% of all golf injuries and 5 to 25% of all tennis injuries. Yet, only few indicators of back pain were identified. For instance, golfers with low back pain demonstrate significantly less endurance in the non-dominant direction (the follow-through of the golf swing) than the healthy group (Lindsay, Horton, 2006). If the left and right side scores in the time which the subject can hold the sidelying position differ more than 5%, dysfunction exists. Conversely, maximal isometric strength and peak torque have shown no significant differences. We also tested whether side-to-side differences exist in rotational velocity and power of trunk muscles in golfers and tennis players when compared to healthly fit controls (Zemková et al., 2014b; Zemková et al., 2015c). Mean velocity in the acceleration phase of trunk rotation was higher in the dominant than non-dominant side in golfers with 1 kg and tennis players with weights of 1 and 20 kg, whereas no significant side-to-side differences were found in control fit individuals. Taking into account also no significant side-to-side differences in muscle power in control fit individuals (6.2%) and its higher values in the dominant than non-dominant side in tennis players (9.4%) and golfers (11.9%), this parameter may be considered specific to asymmetric loading of trunk rotation. Presumably, this parameter might identify likelihood of low back pain.

In sports involving loaded trunk rotations, standing posture should be preferred when testing athlete´s specific performance as opposite to currently used dynamometers allowing movements of the trunk in seated and fixed position. However, standing rotational movement allowing more involvement of the lower body is less confined to the trunk. It is likely that it is much more effective in power production than seated trunk rotations. This assumption may be corroborated by finding of our study that showed greater muscle power during standing as compared to seated trunk rotations, with more pronounced differences at higher weights (≥10.5 kg) (Zemková et al., 2017d,e). 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. Indeed, peak and mean values of velocity in the acceleration phase of trunk rotation as well as respective angular displacements were significantly higher during standing than seated trunk rotations with weights of 20, 15.5, and 10.5 kg but not with the weight of 5.5 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 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 testing the trunk rotational power in the standing and in the seated position.

Seated trunk rotations reduce the involvement of legs and contribution of thoracic/hip mobility to the upper-body rotational power. Reduced range of motion of the hips and the thoracic spine, which allow the greatest rotation because of the orientation of the joints (Sahrmann, 2002), could contribute to lower movement velocity of the trunk and consequently influence ball velocity in throwing and striking sports. These sports that involve throwing motions require production of explosive movement in either the transverse or oblique planes (Earp, Kraemer, 2010). The force is transferred sequentially from the proximal segments, such as hips, toward the more distal segments, such as the shoulders and arms. Because of the kinetic linkage of the proximal to distal sequence in throwing (Putnam, 1993), the rotational mobility may play an important role in production of trunk rotational power. This power transference of the proximal segments, such as the hips and upper trunk, may be crucial to throwing velocity.

Though there are various tests of core strength and endurance, these are not specifically designed for paralympic athletes, in particular for wheelchair users. In these athletes, core musculature is a foundation for efficient movement and maximum power production. To evaluate power and/or velocity during trunk rotation in these athletes, one can use the FiTRO Torso Isoinertial Dynamometer (FiTRONiC, Slovakia) allowing them to exercise in the seated position. Using this system, we estimated the within-subject variation in the trunk rotation velocity and acceleration and its relationship with angular distance covered in paralympic table tennis players tested before London Paralympics (Zemková et al., 2013b). Findings indicate that peak and mean velocity and acceleration of trunk rotation are sensitive parameters able to discriminate among performance levels of paralympic table tennis players. These parameters were in high or moderate relation with distance covered. Angular distance correlated strongly with peak and mean velocity of trunk rotation, whereas peak and mean acceleration of trunk rotation showed no significant correlation. Coefficients of variation were greater for peak and mean acceleration than for peak and mean velocity. Within-subject variation was unaffected by angular distance of trunk movement. It is therefore likely that performance level plays a role in underlying variation within individuals.

Our other study investigated of the relationship between the range of angular motion and mean velocity in the acceleration phase of trunk rotation in young and older adults (Zemková et al., 2015d). We assumed that increased trunk stiffness with age (Gill J et al., 2001; McGibbon, Krebs, 2001; Allum et al., 2002) may reduce the range of trunk motion, and presumably may compromise velocity and power production during rotational movement. Trunk ROM was significantly higher in young than in older subjects with both 1 kg and 20 kg. Mean velocity in the acceleration phase of trunk rotation was also significantly higher in young than in older subjects with both 1 kg and 20 kg. Angular distance strongly correlated with mean rotational velocity of the trunk with 1 kg as well as 20 kg in both groups (r ranged from 0.83 to 0.93). These findings suggest that screening of older adults should include both the trunk ROM and trunk velocity measurements, rather than assume overall trunk movement differences exist between young and older populations.

Figure 4. Measurement of muscle power during standing and seated trunk rotations using the FiTRO Torso Premium system (FiTRONiC, Slovakia).

CONCLUSIONS

The present study provided an overview of tests designed for the assessment of power and strength of trunk muscles. As an example were introduced tests for assessment of maximal isometric strength, muscle power during a lifting task in a form of deadlift to high pull, maximal power and endurance of core muscles during the standing cable wood chop exercise on a weight stack machine, and trunk rotational power in the seated and standing position with a barbell of different weights placed on the shoulders. We believe that above described tests and methods using portable diagnostic systems may be considered to be a suitable and practical alternative to laboratory and/or field testing.

Acknowledgment: This work was supported by the Slovak Research and Development Agency under the contract No. APVV-15-0704.

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