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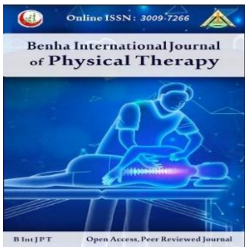

Original research

Time to Peak Torque of Trunk Muscles in Response to Core Stability training.

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Abstract

Background: Core stability training has recently attracted attention for optimizing performance and improving muscle recruitment and neuromuscular adaptation in both healthy and injured individuals. However, the specific impact of such training on the temporal characteristics of muscle activation remains unclear. **Purpose:** This study aimed to investigate the effect of a beginner's core stability program on time to peak torque of trunk flexor and extensor muscles. **Methods:** Thirty-five healthy participants were randomly assigned to either a study group (n=20) or a control group (n=15). The study group comprised 10 males and 10 females with a mean age, weight, and height of 20.7±2.4 years, 66.5±12.1 kg and 166.7±7.8 cm respectively. The control group consisted of 6 males and 9 females with a mean age, weight, and height of 20.3±0.61 years, 68.57±12.2 kg and 164.28 ±7.59 cm respectively. Time to peak torques for both trunk flexors and extensors were measured pre- and post-intervention using the Biodex Isokinetic System. The study group participated in a 6-week core stability training program, while the control group maintained their usual activity level. **Results:** While no significant changes in time to peak torques were observed for either muscle groups within the control group ($p > 0.05$), the study group exhibited a significant decrease in the time to peak torque for both trunk flexors and extensors following the intervention period ($p < 0.0001$). Moreover, at the post-intervention measurement, the study group had a significantly lower time to peak torque for both muscle groups compared to the control group ($p < 0.0001$). **Conclusion:** The observed improvements in the muscle response indicated by the decrease in the trunk flexors and extensors' time to peak torques in the study group, suggest that core stability training can be a valuable component of exercise programs designed to improve neuromuscular adaptation and overall fitness.

Keywords: Core stability, Isokinetic, Time to peak torque, Trunk muscles.

INTRODUCTION:

Core stability or core strengthening has become a well-known fitness trend that serves both patients and healthy individuals. Broad benefits of core stabilization have been established, from improving athletic performance and preventing injuries, to relieving low back pain. The core can be anatomically defined as a muscular box that consists of the abdominals in the front, the paraspinals and glutes at the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature at the bottom [1]. Within this box are 29 pairs of muscles that assist in stabilizing the spine, pelvis, and

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kinetic chain during functional movements. Without these muscles, the spine would become mechanically unstable with compressive forces as low as 90 N, which is lower than the weight of the upper body [2]. When the system functions properly, it results in optimal force distribution and maximal force generation with minimal compressive, translational, or shearing forces at the joints of the kinetic chain [3]. The core strength is particularly important in sports because it provides ‘‘proximal stability for distal mobility’’ [4].

Lumbar spine stability is achieved through the combination of three control subsystems: passive (bones and ligaments), active (muscles) and neural control (nerves). This means that spinal stability does not rely solely on muscular strength, but also on adequate sensory input that informs the central nervous system about interaction between the body and the environment, providing continuous feedback and enabling refinement of movement [5].

Previous studies have examined the effects of core stability training on trunk muscle performance. Yilmaz et al. [6] found that eight weeks of dynamic lumbar stabilization exercises significantly enhanced spinal mobility, trunk muscles' strength and endurance. Abdallah & Beltagi [7] observed a significant impact of the beginner’s core stability exercises on the peak torques of both trunk flexors and extensors. Frizziero et al. [8] stated that the aim of core stability exercises is to restore normal muscle function to increase spinal stability, neuromuscular control within the lumbopelvic region, generate inter-segmental stiffness and prevent shear force that leads to injury to the lumbar spine.

According to Kibler et al. [4], core stability refers to the capacity of controlling the movements of the trunk over the pelvis and lower extremities, which enables optimal force transmission throughout the kinetic chain to the terminal segment. Kumar et al. [9] also demonstrated that core strengthening exercises can effectively enhance the strength of all trunk muscles that are involved in maintaining a robust and stable spine, without exceeding the safe injury thresholds for compressive and shear loading. Similarly, Suh et al. [10] indicated that Lumbar stabilization exercises aim primarily at improving the neuromuscular control, strength, and endurance of the muscles that are essential for maintaining dynamic spinal and trunk stability.

According to Coulson [11], muscular strength is the ability to produce the highest possible contractile force against a resistance in one contraction. Peak torque is a measure of the maximal force that a muscle or a group of muscles can generate at a certain velocity. It is calculated by multiplying mass, acceleration, and lever arm length. It is the highest value of the map curve [12]. The speed of muscle activation and force production is a key factor for providing dynamic joint stability and ligament protection [13]. Isokinetic dynamometry is the gold standard method for measuring muscle performance in sport and rehabilitation settings [14]. This method allows us to evaluate maximal strength at a constant speed. Peak torque is a commonly used parameter, and it is especially important to assess it in athletes [15].

The Peak torque (PT) parameter has been used in different investigations to detect strength deficits and evaluate the effect of interventions or treatments on muscle strength [16]. However, it has been stated that strength measurements do not reflect muscle performance characteristics [17]. Peak torque as a definitive measure and time to peak torque have been considered of value. Peak torque values give an indication of the ability to generate force against resistance [18].

The quick activation of muscles in response to sudden threats is also an important aspect of efficiency that needs to be measured. Therefore, from a functional point of view, the capacity to produce torque rapidly (Time to peak torque) may have more relevance than the ability to produce high maximal force [19]. Time to peak torque measurement, rather than peak torque (PT), which is the common parameter used to assess strength, may reflect the most significant adaptations resulting from training or rehabilitation [20]. For example, the peak torque value may indicate the muscle power required to jump a certain distance. Time to peak torque may indicate how fast the muscles can act to control landing [21,22].

Time to peak torque has recently become quite popular for characterizing "explosive strength" [23]. This variable reflects the neuromuscular capacity to activate the muscles rapidly and maximally [24], which is a crucial skill for many athletic activities [25]. The assessment of muscle recruitment patterns in athletes may provide better indications of the functional performance than the evaluation of peak torque alone [26]. However, there is a lack of research on isokinetic assessment of muscle recruitment patterns [17]. Therefore, this study aimed to assess the effect of core stability exercises on trunk muscle performance in terms of time to peak torque.

METHODS

Subjects: This study included 35 healthy college students from the Faculty of Physical Therapy, Cairo University, who were randomly allocated to two groups: study and control groups. The study group consisted of 20 participants (10 males and 10 females), with age, height and weight ranging from 17 to 24 years, 170 to 185 cm, and 65 to 85 kg respectively. The control group comprised 15 participants (6 males and 9 females) with similar demographic characteristics as the study group.

Participant eligibility was based on two primary criteria: adequate abdominal muscle strength and normal lower back flexibility. Abdominal muscle strength was assessed using the manual muscle test, with a minimum score of four required for inclusion. Lower back flexibility was evaluated using the Modified Schober test. For this test, a mark was placed at the level of the posterior iliac spine on the L5 vertebra. Two additional marks were placed on the participant's spine, one 5 cm below and the other 10 cm above the initial mark. The participant was then instructed to touch their toes. If the increase in distance between the two additional marks exceeded 5 cm, the participant was considered to have normal lower back flexibility and was eligible for study participation.

Conversely, if the increase was less than 5 cm, this suggested restricted lumbar flexion [27], leading to the participant's exclusion. Exclusion criteria also included a history of back or abdominal surgery/injury, previous episodes of low back pain within the preceding year, and participation in any prior strengthening or weight training programs.

Instrumentation: To evaluate the time to peak torque of the trunk flexors and extensors, we used the Biodex System 3 Multi-joint Testing and Rehabilitation isokinetic dynamometer (Biodex Medical System, Shirley, NY, USA). Measurements were carried in the concentric mode of muscle contraction at an angular velocity 60º/sec throughout a 70º range of motion (ROM). The device maintains a consistent velocity with accommodating resistance, allowing for accurate assessment of concentric muscle strength at 60º/sec angular velocity. Previous validation studies have demonstrated high test-retest reliability and validity for measurements of trunk muscle torque using this system, confirming its suitability for evaluating time to peak torque in trunk muscle groups [28].

Procedures: Prior to participation, each participant was thoroughly informed about the study's objectives and methodology. Written informed consent was obtained from all participants, ensuring their voluntary and informed participation in the research endeavor.

Setup and positioning: Using the Biodex Isokinetic Dynamometer system chair, the participants underwent testing in a sitting posture. Previous studies have indicated that this posture is more comfortable and allows greater ROM in both flexion and extension than the standing posture [29,30]. Therefore, the sitting posture was chosen as the optimal resting position for the testing.

For testing Trunk flexion and extension, Trunk seated compressed protocol was employed, ensuring isolation of trunk movement without involvement of pelvic and hip muscles. The pelvis and thighs were stabilized by straps. Two curved anterior leg pads were positioned to adjust the knee block position. Additionally, a lumbar support pad was placed against the lower lumbar spine [30]. The two anterior force application straps were aligned vertically and connected to a horizontal strap, positioned in line with the second intercostal cartilage on the anterior chest wall during flexion torque measurement. For extension torque measurement, the posterior force application padded roller bar was placed on the posterior trunk just distal to the spine of the scapula. The dynamometer arm axis was aligned at the intersection point of the mid-axillary line and the disc space between the 5^{th} lumbar and the 1^{st} sacral vertebrae (L5/S1) [31]. The tested trunk ROM for each participant was set at 50° flexion and 20° extension, resulting in an overall isokinetic testing range of 70° **(Figure 1).**

Figure (1): Testing position and stabilization.

Measurements of time to peak torque: Prior to the actual isokinetic testing procedures, each participant performed one practice session of three sub-maximal trunk flexion and extension repetitions to get accommodated with the specificity of the Biodex speed of movement and trunk ROM. Three practice sessions were performed. In each practice session, the participant performed five consecutive trunk flexion extension repetitions at the available trunk ROM. The participant was instructed to exert maximal force and velocity. Verbal encouragement was given during the testing procedure to maximize the participant's voluntary effort. The mean time to peak torques of trunk flexors and extensors for the three practice sessions were recorded. Each participant of both groups underwent the isokinetic testing twice with a six-week interval, during which the participants of the study group performed the beginners' core stability program.

Beginners' core stability program: Beginners' core stability program consists of three main core stability exercises; curl up, side-bridge, and bird dog. Before starting the program, the participants performed a warm-up exercise called "Cat-Camel", which involved flexing and extending the spine repeatedly. This exercise was done to reduce spine viscosity (internal resistance and friction) and free the nerve roots as they exit at their respective lumbar levels. The "Cat-Camel" motion was intended as a motion exercise not a stretch, so the emphasis was on motion rather than pushing at the end ranges of extension and flexion. Five to eight cycles were reported to be sufficient for reducing most viscous-frictional stresses [32].

In the curl-up exercise, the participant's hands were placed under the lumbar spine to preserve a neutral spine posture. The participant was instructed not to flatten the lumbar spine. The participant was asked to flex one knee with the other kept straight to lock the pelvis-lumbar spine and minimize the loss of the neutral lumbar posture. They lifted their head and upper shoulders off the floor, keeping the motion in the thoracic region and avoiding it in lumbar or cervical flexion. To increase difficulty, they lifted their elbows off the floor as well. The participant was asked to perform abdominal bracing (activating the abdominal muscles), and then curling up against the brace **(Figure 2).** The flexed posture was maintained for 7-8 seconds while breathing deeply and not holding the breath [32].

Figure (2): The curl-up exercise

The side-bridge exercise involved the following steps: The participant positioned himself on the right side with the right shoulder abducted and the upper arm was perpendicular to the ground and the forearm rested on the floor for support. The participant lifted his pelvis from the floor and held it in a straight line “plank” position. The duration of this posture was 7-8 seconds, during which the participant focused on stabilizing the pelvis and the rib cage through the abdominal bracing and deep breathing [32]. A more advanced variation of this exercise required the participant to place their upper leg-foot in front of the lower one to facilitate longitudinal rolling on the torso to challenge both the anterior and posterior portions of the abdominal wall **(Figure 3).**

Figure (3): The side-bridge exercise (Side plank)

The participant supported their body weight with forearms and toes on the floor, kept his elbow at 90° and his spine in a neutral position. The participant also activated the gluteal muscles and aligned the head leveled with the floor. The duration of this posture was also 7-8 seconds, and the participant had to breathe normally throughout the exercise while maintaining the abdominal brace. No compensatory motions such as excessive lumbar lordosis or sagging were allowed. The side-bridge exercise targeted the lateral and abdominal muscles (quadratus lumborum, and abdominal obliques), which are essential for optimal stability. The beginner’s level of this exercise involved bridging the torso between the elbows and knees. Once this was mastered and tolerated, the difficulty was increased by bridging using the elbows and feet **(Figure 4)** [32].

Figure (4): The prone-bridge exercise (plank)

In the bird-dog exercise, the participant assumed a quadruped position on the hands and knees and braced the abdominal wall. While maintaining a mid-range/neutral curve of the lumbar spine, the participant raised the right arm and left leg (opposite upper and lower limbs) in line with the trunk. The participant was instructed to prevent any rocking of the pelvis or spine (excessive transverse or coronal plane motion). The exercise was maintained for 7-8 seconds while breathing deeply and not holding the breath **(Figure 5).** The bird dog exercise challenges the back extensors of both the lumbar and thoracic regions. Only one half of these muscles are challenged at a time by lifting the alternate arm and leg. This reduces the spine load to about a half of that produced during traditional spine extension exercises [32].

Figure (5): The bird-dog exercise

The participant followed a beginner’s core stability program for six weeks, with three sessions per week. The program had three phases of two weeks each, with increasing frequency of exercise once, twice, and thrice per day in the first, second and third phases respectively. Each session involved 15 repetitions per exercise [32]. Participants were instructed to avoid performing the core stability exercises within the first hour after waking due to elevated hydrostatic pressure within the spinal discs during this period [33]. Additionally, participants were instructed to maintain bracing techniques throughout all the conducted exercises. This bracing maneuver involves simultaneous activation of all abdominal and back muscles.

Statistical analysis: Descriptive statistics (means and standard deviations) were calculated for all variables using standard statistical procedures. Normality of data distribution was assessed with Shapiro-Wilks and Kolmogorov-Smirnoff tests. The t-test was conducted for comparing subject characteristics between both groups. Mixed MANOVA was employed for comparing time to peak torque between pre- and post-treatment conditions within and between groups. Statistical significance was set at $p < 0.05$ for all statistical tests. All statistical analyses were performed using the statistical package for social studies (SPSS) version 19 for Windows (IBM SPSS, Chicago, IL, USA).

RESULTS

Normality of data distribution: The Shapiro-Wilk and Kolmogorov-Smirnoff test confirmed that all dependent variables in both groups exhibited normal distribution ($p > 0.05$).

Subject characteristics: **Table 1** presents the mean ± SD for age, weight, and height of both groups. There was no significant difference in these characteristics between the study and control groups (all $p > 0.05$).

Table (1): Mean age, weight, and height of study and control groups:

	Study group	**Control group**	**t-value**	**p-value**
Age (years)	20.7±2.4	20.3±0.61	0.69	0.46*
Weight (kg)	66.5±12.1	68.57±12.2	0.47	0.63*
Height (cm)	166.7±7.8	164.28 ±7.59	0.9	0.37*

$\bar{X}$, Mean; SD, standard deviation; p-value, level of significance; * Nonsignificant.

Time to peak torque: Mixed MANOVA showed significant interaction of time x group (*F = 182.23, p = 0.0001*), a significant group effect (*F = 32.28, p = 0.0001*), and a significant time effect (*F = 210.88, p = 0.0001*).

Between- Group Comparisons: There was no significant difference between study group and control group in time to peak torque of extensors and flexors pre-treatment ($p > 0.05$). However, post-treatment comparisons revealed a marked decrease in time to peak torque for both extensors and flexors within the study group relative to the control group ($p < 0.0001$) **(Table 2, figure 6).**

Within- Group Comparisons: Notably, the study group exhibited a significant reduction in time to peak torque of both extensors and flexors following the intervention ($p = 0.0001$), whereas the control group displayed no significant pre-post treatment difference in time to peak torque of either muscle group ($p < 0.05$) **(Table 2, figure 6).**

Table (2): Mean time to peak torque pre and post treatment of study and control groups:

	Pretest			Post test				
	Study group	Control g.		Study g.	Contro l g.		Within study g.	Within control g.
Time to peak t. (msec)	$\bar{X}$ ±SD	$\bar{X}$±SD	P-value	$\bar{X}$±SD	$\bar{X}$±SD	P-value	P-value	P-value
Extensors	537.22±59.68	555.33±73.08	0.43*	286.33 ±44.48	539.66 ±67.73	0.001**	0.0001**	0.3*
Flexors	600±54.12	628.66±95.08	0.28*	315.22 ±53.06	621.46 ±91.61	0.0001**	0.0001**	0.55*

$\bar{X}$, Mean; SD, standard deviation; p-value, level of significance; * Nonsignificant; ** Significant.

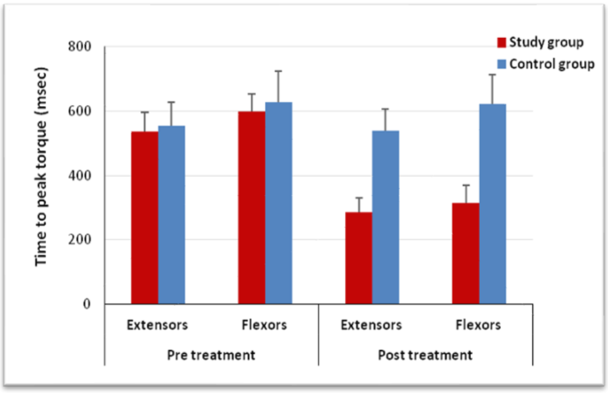

Figure (6): Mean time to peak torque pre- and post-treatment of the study and control groups.

DISCUSSION

Recent years have witnessed a surge of interest in core stability exercises (CSEs). While their impact on trunk muscle strength has been well-documented, their influence on time to peak

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torque, a crucial metric of muscle performance, remains largely unexplored. Time to peak torque is a measure of the time taken for a muscle to generate maximal torque reflecting its functional capacity rapid force production [34]. This study aimed to bridge this research gap by investigating the effect of CSEs on trunk muscle time to peak torque.

Our findings reveal a significant decrease in time to peak torque for both trunk flexors and extensors after six weeks of CSE intervention. This improvement can be attributed to enhanced muscle activation patterns induced by these exercises. CSEs have been shown to reverse pain-related reorganization in the motor cortex [35], optimize muscle behavior, and retrain the vital function of local trunk muscles for optimal spinal stability [36].

These findings suggest that CSEs transcend mere muscle strengthening, acting instead as neuromuscular facilitators. The improved ability to control the core aligns with the observations of Miyake et al. [37]. Similarly, Lee et al. [38] demonstrated the effectiveness of the 7-week CSE program in reducing muscle stiffness and enhancing erector spinae muscle contraction velocity through improved neuromuscular control.

Further supporting the efficacy of CSEs, Puntumetakul et al. [39] reported significant pain reduction and deeper abdominal muscle activation in patients with lumbar instability following a 10-week CSE program compared to conventional treatment. Their subsequent study comparing CSEs to strengthening trunk exercises (STEs) revealed comparable improvements in balance and pain, but with CSEs leading to greater deep abdominal muscle activation in chronic low back pain patients with lumbar instability.

Aly et al. [40] also emphasized the effectiveness of CSEs, demonstrating significant improvements in trunk and hip muscle strength, particularly hip extensors, and adductors, within a 6-week timeframe. This underscores their potential for enhancing overall trunk and hip muscle performance. Harridge et al. [41] further elaborated on the underlying mechanisms, suggesting that CSEs elicit greater motor unit recruitment and firing rates, ultimately leading to heightened muscle activation. In the same context, Hlaing et al. [42] reported that CSEs are optimal treatments for patients with subacute non-specific low back pain (NSLBP), improving proprioception, balance, and percentage change of muscle thickness while reducing functional disability and fear of movement.

Furthermore, Aziz et al. [43] reported superior pain management, trunk control, and balance when using Physio-ball based CSEs compared to floor mat exercises. This aligns with Cosio-Lima et al. [44] findings, where 5-week physio-ball CSEs significantly improved myoelectric activities of trunk muscles. They attributed this to neuroadaptations elicited by unstable surfaces, leading to early gains in stability and proprioception. These adaptations include more efficient neural recruitment patterns, increased nervous system activation, improved synchronization of motor units, and a lowering of neural inhibitory reflexes [45].

The observed time to peak torque improvements may also be attributed to the associated improved strength of trunk muscles. Lehman (2006) [46] highlighted the ability of common CSEs (curl up, bird dog, side bridge) to adequately strengthen all trunk muscles responsible for maintaining a strong and stable spine without exceeding safe loading thresholds. This reinforces the role of CSEs in strengthening the core musculature, which plays a pivotal role in both stability and lumbar posture control [47].

Kim et al. [48] further explored the impact of CSEs on muscle size. They found that both stabilization training combined with dynamic and dynamic-static resistance training led to increased paravertebral muscle cross-sectional area. This suggests the necessity of both stabilization exercises and lumbar resistance training for optimal paravertebral muscle restoration. Finally, Moon et al. [49] compared the effects of CSEs and lumbar dynamic strengthening exercises on patients with chronic low back pain. Both interventions led to improvements in pain and lumbar extensor strength, with CSEs demonstrating greater efficacy in extensor strengthening and functional improvement.

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While our study offers valuable insights, limitations exist. The small sample size and inclusion of healthy individuals restrict generalizability. Additionally, the lack of electromyography measurement prevents definitive identification of the activated muscles. Further research incorporating electromyography with larger and more diverse populations is warranted to further elucidate the mechanisms and broader implications of CSEs.

CONCLUSION

The findings of this study suggest that core stability exercises have the potential to significantly enhance trunk muscle performance by reducing the time to peak torque of both trunk flexors and extensors. This improved neuromuscular response, reflected in the decrease in time to peak torque in the study group, warrants further investigation and inclusion of core stability training in the exercise programs aiming to optimize both neuromuscular adaptations and overall fitness.

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