INTERNATIONAL SEVEN JOURNAL
OF MULTIDISCIPLINARY
ISSN: 2764-9547

RATE OF TORQUE DEVELOPMENT OF TRUNK MUSCLES IN WOMEN WITH DIFFERENT TRAINING BACKGROUNDS

TAXA DE DESENVOLVIMENTO DE TORQUE DOS MÚSCULOS DO TRONCO EM MULHERES COM DIFERENTES NÍVEIS DE TREINAMENTO

TASA DE DESARROLLO DEL TORQUE DE LOS MÚSCULOS DEL TRONCO EN MUJERES CON DIFERENTES NIVELES DE ENTRENAMIENTO

https://doi.org/10.56238/isevmjv5n2-037

Receipt of originals: 03/20/2026 **Acceptance for publication:** 04/20/2026

Mário Osvaldo Bertochi[1], Lucas Caetano Carlos[2], Leonardo Coelho Rabello de Lima[3], Renan Vieira Barreto[4], Mauro Gonçalves[5], Adalgiso Coscrato Cardozo[6]

ABSTRACT

Objectives: To compare the DTR of the trunk extensors and flexors of healthy individuals who practice training modalities with different movement patterns during trunk exercises such as Pilates, CrossFit and traditional resistance training.

Methods: Thirty-two volunteers aged 23.72 ± 3.4 years participated in the study and were allocated to one of four groups based on their training experience: Pilates, CrossFit. Participants included in the trained groups must have a history of practicing their respective modalities. Participants included in the CON group should not have exercised regularly in the last six months. Normality, homogeneity and sphericity tests were used. rate of torque development (RTD) and Isometric peak torque (IPT) values were compared between groups using one-way ANOVA followed by Bonferroni post-hoc tests. A significance level of $p < 0.05$ was adopted.

Results: No significant differences were found in age and body mass. Women with experience in CrossFit training have significantly greater IPT and RTD of trunk during isometric extension and flexion. Trunk flexion IPT was also significantly higher for participants who practiced CrossFit. RTD for trunk extension and flexion was not different between participants with experience in Pilates, traditional resistance training and those without experience with physical training. Furthermore, the CF group presented significantly higher RTD values in all time intervals analyzed.

Conclusion: The results obtained confirm that women who practice CrossFit training benefit from a greater capacity for rapid force production with the trunk flexors and extensors. Regular CrossFit practice results in superior RTD when compared to traditional resistance training, Pilates and a sedentary lifestyle in women. Maximum trunk strength is also greater for women who practice CrossFit.

[1] Master's degree. Universidade Estadual Paulista. E-mail: mobertochi@uol.com.br
Orcid: https://orcid.org/0009-0001-4205-8134
[2] Dr. Universidade Estadual Paulista. Orcid: https://orcid.org/000-0003-0907-5028
[3] Dr. Universidade de São Paulo. Orcid: https://orcid.org/0000-0003-4118-534X
[4] Dr. Universidade Estadual Paulista. Orcid: https://orcid.org/0000-0003-2734-4359
[5] Dr. Universidade Estadual Paulista. Orcid: https://orcid.org/0000-0002-4087-1113
[6] Dr. Universidade Estadual Paulista. Orcid: https://orcid.org/0000-0001-9462-0240

Keywords: Training. CrossFit. Pilates. Trunk Muscles.

RESUMO

Objetivos: Comparar a taxa de desenvolvimento de torque (RTD) dos músculos extensores e flexores do tronco em indivíduos saudáveis que praticam modalidades de treinamento com diferentes padrões de movimento durante exercícios para o tronco, como Pilates, CrossFit e treinamento resistido tradicional.

Métodos: Trinta e duas voluntárias, com idade média de 23,72 ± 3,4 anos, participaram do estudo e foram alocadas em um dos quatro grupos com base na experiência de treinamento: Pilates, CrossFit. As participantes incluídas nos grupos treinados deveriam ter histórico de prática em suas respectivas modalidades. As participantes incluídas no grupo controle (CON) não deveriam ter praticado exercícios regularmente nos últimos seis meses. Foram utilizados testes de normalidade, homogeneidade e esfericidade. Os valores de taxa de desenvolvimento de torque (RTD) e torque isométrico de pico (IPT) foram comparados entre os grupos por meio de ANOVA de uma via, seguida de testes post-hoc de Bonferroni. Adotou-se nível de significância de $p < 0,05$.

Resultados: Não foram encontradas diferenças significativas quanto à idade e massa corporal. Mulheres com experiência em treinamento CrossFit apresentaram valores significativamente maiores de IPT e RTD do tronco durante extensão e flexão isométricas. O IPT na flexão do tronco também foi significativamente maior para as participantes que praticavam CrossFit. A RTD para extensão e flexão do tronco não diferiu entre participantes com experiência em Pilates, treinamento resistido tradicional e aquelas sem experiência em treinamento físico. Além disso, o grupo CF apresentou valores significativamente maiores de RTD em todos os intervalos de tempo analisados.

Conclusão: Os resultados confirmam que mulheres que praticam CrossFit apresentam maior capacidade de produção rápida de força nos músculos flexores e extensores do tronco. A prática regular de CrossFit resulta em RTD superior quando comparada ao treinamento resistido tradicional, ao Pilates e ao estilo de vida sedentário em mulheres. A força máxima do tronco também é maior em mulheres que praticam CrossFit.

Palavras-chave: Treinamento. CrossFit. Pilates. Músculos do Tronco.

RESUMEN

Objetivos: Comparar la tasa de desarrollo de torque (RTD) de los músculos extensores y flexores del tronco en individuos sanos que practican modalidades de entrenamiento con diferentes patrones de movimiento durante ejercicios del tronco, como Pilates, CrossFit y entrenamiento de resistencia tradicional.

Métodos: Treinta y dos voluntarias, con edad media de 23,72 ± 3,4 años, participaron en el estudio y fueron asignadas a uno de cuatro grupos según su experiencia de entrenamiento: Pilates, CrossFit. Las participantes incluidas en los grupos entrenados debían tener antecedentes de práctica en sus respectivas modalidades. Las participantes incluidas en el grupo control (CON) no debían haber realizado ejercicio regularmente en los últimos seis meses. Se utilizaron pruebas de normalidad, homogeneidad y esfericidad. Los valores de tasa de desarrollo de torque (RTD) y torque isométrico máximo (IPT) se compararon entre los grupos mediante ANOVA de una vía,

seguida de pruebas post-hoc de Bonferroni. Se adoptó un nivel de significación de $p < 0,05$.

Resultados: No se encontraron diferencias significativas en la edad ni en la masa corporal. Las mujeres con experiencia en entrenamiento CrossFit presentaron valores significativamente mayores de IPT y RTD del tronco durante la extensión y flexión isométricas. El IPT en la flexión del tronco también fue significativamente mayor en las participantes que practicaban CrossFit. La RTD para la extensión y flexión del tronco no difirió entre participantes con experiencia en Pilates, entrenamiento de resistencia tradicional y aquellas sin experiencia en entrenamiento físico. Además, el grupo CF presentó valores significativamente más altos de RTD en todos los intervalos de tiempo analizados.

Conclusión: Los resultados confirman que las mujeres que practican CrossFit presentan una mayor capacidad de producción rápida de fuerza en los músculos flexores y extensores del tronco. La práctica regular de CrossFit da como resultado una RTD superior en comparación con el entrenamiento de resistencia tradicional, el Pilates y un estilo de vida sedentario en mujeres. La fuerza máxima del tronco también es mayor en las mujeres que practican CrossFit.

Palabras clave: Entrenamiento. CrossFit. Pilates. Músculos del Tronco.

1 INTRODUCTION

The American College of Sports Medicine recommends that healthy individuals exercise trunk muscles at least twice a week to improve spine stability and maintain mobility in daily activities[1]. The core complex consists of 29 pairs of muscles that act to stabilize the spine, pelvis, and hip during functional movements[2]. Trunk extensors and flexors (i.e., paravertebral, and abdominal muscles, respectively) have been proposed to be important components of the core complex[3].

The core complex depends on several components of physical fitness such as strength, flexibility, and coordination to allow for adequate functionality[4]. When one of these components is insufficiently stimulated, excessive loading can occur in the spine and limbs [5]. An important variable that should be highlighted among the physical components that are required for core functionality is the rate of torque development (RTD, i.e., the ability to generate force rapidly), which is calculated as the torque variation in a time interval comprising the onset of a contraction (30 to 300 milliseconds)[6]. This variable depends on properties[6,7], several factors like muscle mass, distribution of different fiber types, as well as motor unit firing[6,7].

Several studies analyzed RTD in different muscle groups, especially in athletes[8], elderly people[9,10] and individuals with chronic pain[11,12] and showed that the compromised capacity to develop rapid force negatively affects performance by impairing functional capacity and might also increase the incidence of injuries[13,14]. Compared to maximal voluntary contraction (MVC) peak torque, RTD has been shown to be more functional[15], specific and sensitive to chronic adaptations induced by exercise training[16]. The greater responsiveness to training observed for RTD appears to be related to the fact that most movements require contraction times of 50-250 ms, while the time required to develop maximal strength during a MVC is longer (i.e., approximately 500 ms)[17,18].

It has been consistently shown that executing training movements at high speed provides greater increments in RTD compared to training at slower speeds[19,20,21,22]. Young and Bilby[23] found that improvements in RTD were 46% greater for individuals who trained with fast-velocity contractions compared to those who trained with slow-velocity contraction after 7 weeks of half-squat training. However, some studies contradict these results, showing that strength training at slower speeds (including isometric training) also results in significant improvements in RTD[24,25].

Pilates and CrossFit figure among the practices that most outstandingly focus in strengthening trunk muscles. The principle of centralization is preconized as one of the bases of Pilates, requiring isometric contractions to stabilize the spine for more precise and safe movements[26]. CrossFit also relies in exercises often defined as great activators of core muscles, in addition to improving the individual's functional abilities[27]. Finally, traditional resistance training programs require an expressive amount of strengthening exercises for the whole body, including trunk muscles, and relies on several types of contractions and exercise regimens to develop muscle mass[28].

The present study aimed to compare the RTD of the trunk extensors and flexors of healthy individuals who practice training modalities with different movement patterns during trunk exercises such as Pilates, CrossFit and traditional resistance training. Our hypothesis was that RTD values would be greater in the participants who practice CrossFit when compared to those who practice Pilates, traditional resistance training, and those who are not engaged in any physical training programs.

2 METHODS

2.1 PARTICIPANTS

Thirty-two female volunteers aged 23.72 ± 3.4 participated in the study and were allocated to one of four groups based on their training experience: Pilates (PL, n = 8), CrossFit (CF, n = 8), traditional resistance training (RT, n = 8) and no systematic exercise training (control group, CON, n = 8). Participants signed an informed consent form to participate in the study. As inclusion criteria, participants included in the trained groups (PL, CF and RT) should have a history of practicing their respective modalities at least twice a week for a minimum of six months prior to the experiment[29,30]. Participants included in the CON group should not have exercised regularly in the last six months. The exclusion criterion was having a history of low back pain in the 6 months preceding the experiment. Participants who regularly practiced other training modalities besides those relevant for the study were also excluded. This study was evaluated and approved by the institutional Research Ethics Committee (CAAE: 30539514.6.0000.5465) and all procedures complied with the Declaration of Helsinki for research with humans.

2.2 EXPERIMENTAL DESIGN

The experimental design consisted of a transversal analysis in which we evaluated the impact of practicing different strength training modalities (Pilates, traditional resistance training, CrossFit and no training) in the RTD of the trunk extensors and flexors. After being recruited and allocated to their respective groups, the participants visited the laboratory twice: in the first visit physical evaluations were carried out and participants were familiarized with the isokinetic dynamometer. During the second visit, they performed the tests described below.

2.3 MAXIMAL VOLUNTARY ISOMETRIC CONTRACTIONS

RTD was assessed using an isokinetic dynamometer (System 4, Biodex Systems, USA) coupled to a specific device for trunk flexion and extension tests (Dual-position Back Ex/Flex Attachment) (Figure 1). The participants' lumbar and thoracic regions rested on the back of the chair, with the leg support fixed just below the lower edge of the patella, keeping both knees flexed at 90º. Fastening belts secured the hip, thighs, and the chest regions to the chair (Figure 1).

Figure 1

Positioning of the participants in the dual-position (trunk extension/flexion) attachment of the isokinetic dynamometer

Source: personal archive.

After being properly secured to the chair, participants performed submaximal isometric trunk flexions and extensions as a warm-up procedure. Then, participants performed a protocol comprising six five-second maximal voluntary isometric contractions consisting of three trunk flexions interspersed with three trunk extensions at 90º of trunk flexion and respecting a 30-second interval between consecutive contractions[31]. Participants were instructed to perform the contractions as quickly and forcefully as possible[32], after hearing a sound signal emitted by the computer. Torque data produced during contractions was recorded using a biological signal acquisition module coupled to the dynamometer (Noraxon, Phoenix, USA) with a capture frequency of 1,000 Hz.

2.4 DATA PROCESSING

The obtained torque data was analyzed with specific routines developed in a MATLAB environment (MATLAB 5, MathWorks, USA), and filtered with a fourth-order Butterworth filter with a cutoff frequency of 15 Hz. The contraction with the highest torque value was used for analyses of both trunk extension and flexion isometric peak torque and RTD. Isometric peak torque was considered as the greatest torque value obtained in the torque curve. RTD was determined as the inclination of the torque-time curve (Δ torque/Δ time) over time intervals of 0-30, 0-50, 0-100, 0-150, 0-200, 0-250 ms relative to the onset of the contraction[6]. Peak RTD was calculated as the greatest RTD value in 0-n intervals.

2.5 STATISTICAL ANALYSIS

Data normality was confirmed by the Shapiro-Wilk's test. The assumptions of homogeneity and sphericity were confirmed by the Levene's and Mauchly's tests, respectively. RTD and isometric peak torque values were compared between groups using one-way ANOVA followed by Bonferroni's post-hoc tests. The significance level of $p < 0.05$ was adopted. All statistical tests were performed using a statistical analyses software (SPSS 18, IBM, USA).

Cohen's d was calculated by dividing the difference between the means by the pooled standard deviation of both conditions for the dependent variables. Effect sizes (ES) < 0.2, 0.2-0.5, and > 0.5 were interpreted as trivial, small, medium, and large, respectively[33]. Data is presented as mean ± standard deviation (SD), unless otherwise stated.

3 RESULTS

No significant differences in age and body mass were found between groups. Body fat percentage was similar between groups except for the RT group, which presented a lower percentage of fat mass ($p < 0.01$) compared to the CON group. Data regarding participants' characteristics are shown in Table 1.

Table 1

Participant's characteristics

Group	Age (year)	Body mass (kg)	Body fat (%)
Resistance trained (RT)	22.9 ± 4.3	54.5 ± 4.9	14.9 ± 2.6*
CrossFit (CF)	24.6 ± 3.9	60.9 ± 7.1	18.6 ± 4.4
Pilates (PL)	25.1 ± 3.9	57.1 ± 3.4	16.8 ± 2.6
Physically inactive (CON)	22.2 ± 1.8	58.7 ± 4.9	21.1 ± 3.8

*Significantly different ($p < 0.05$) than CON group.

Significant effects of groups were evident for IPT during trunk extension and flexion. Post hoc analyses showed that trunk extension IPT was greater ($p < 0.05$) for CF compared to RT (ES: 1.25) and CON (ES: 1.98). Trunk flexion IPT was greater ($p < 0.05$) for CF compared to CON (ES: 2.12). IPT values during trunk extension and flexion are presented in Table 2.

Table 2

Isometric peak torque (IPT) during maximal voluntary isometric trunk extension and flexion

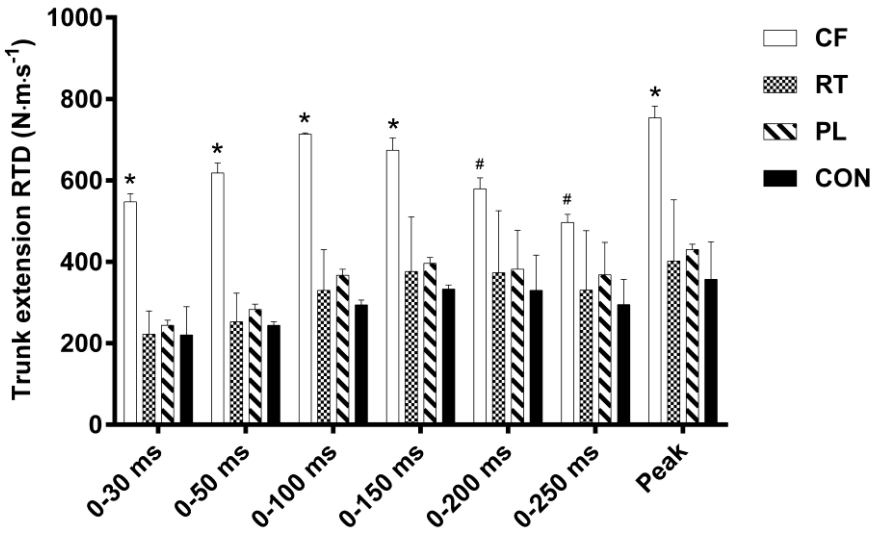
Group	Trunk Extension IPT (N.m)	Trunk Flexion IPT (N.m)
Resistance trained (RT)	167.7 ± 31.6	97.8 ± 11.5
CrossFit (CF)	227.2 ± 59.1*	118.8 ± 25.9#
Pilates (PL)	180.2 ± 28.8	98.7 ± 24.9
Physically inactive (CON)	139.0 ± 22.0	77.6 ± 9.3

*Significantly greater (p<0,05) than RT and CON. #Significantly greater (p<0,05) than CON.

A significant effect of groups was evident for RTD measured at different times as well as peak RTD (0-30: p = 0.017, F = 12; 0-50: p = 0.030, F = 11; 0-100: p = 0.004, F = 8.2; 0-150: p = 0.001, F = 5.4; 0-200: p = 0.031, F = 3.4; 0-250: p = 0.032, F = 3.4; Peak: p = 0.001, F = 7.8). Post hoc analyses showed that RTD was greater for CF compared to CON at all intervals during both trunk flexion (p < 0.05; ES: 0-30 = 15.1; 0-50 = 1.8; 0-100 = 3.6; 0-150 = 15.3; 0-200 = 3.5; 0-250 = 3.4; peak = 4) and extension (p < 0.05; ES: 0-30 = 6.4; 0-50 = 20.6; 0-100 = 5.3; 0-150 = 15.2; 0-200 = 5.1; 0-250 =4.3; peak = 5.8). When compared to PL, RTD values for the CF group were higher for trunk extension at 0-30 ms (p < 0.001; ES = 18.3), 0-50 ms (p < 0.01; ES = 17.3), 0-100 ms (P <0.05; ES = 32), 0-150 ms (p < 0.05; ES = 18.8) and peak (p < 0.01; ES = 14.3); and trunk flexion at 0-30, 0-50, 0-150, 0-200, 0-250 ms and peak (p < 0.05; ES = 2.6, 2.3, 14.1, 14.7, 2.6 and 11.1, respectively). Regarding the RT group, CF showed greater trunk extension RFD values higher at 0-30 ms (p < 0.001; ES = 7.6), 0-50 ms (p < 0.001; ES = 6.9), 0-100 ms (p < 0.01; ES = 5.4), 0-150 (p < 0.05; ES = 3) and peak (p < 0.01; ES = 3.2) with no significant differences for trunk flexion RTD. (Figures 2 and 3).

Figure 2

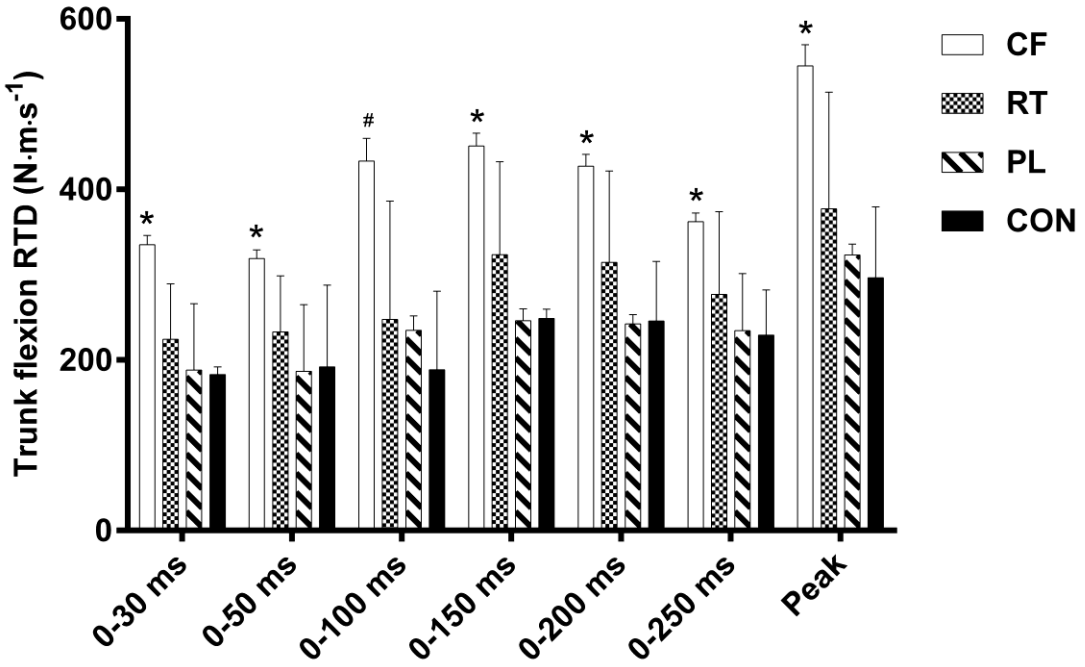
Rate of torque development (RTD) during maximal voluntary isometric trunk extension.



CF: CrossFit group; RT: traditional resistance training group; PL: pilates group; CON: control group. *Significantly greater (p<0,05) compared to all other groups. #Significantly greater (p<0,05) than CON.

Figure 3

Rate of torque development (RTD) during maximal voluntary isometric trunk flexion.



CF: CrossFit group; RT: traditional resistance training group; PL: pilates group; CON: control group. *Significantly greater ($p<0,05$) than PL and CON. #Significantly greater ($p<0,05$) than CON.

4 DISCUSSION

This study aimed to compare the capacity to produce force rapidly with trunk muscles, measured as RTD, between women with experience in three different strength training modalities as well as physically inactive women. The obtained results showed that women with experience in CrossFit training have significantly higher isometric trunk extension and flexion IPT and RTD compared to women with no experience with exercise training. Trunk flexion IPT was also significantly greater for participants who practiced CrossFit compared to those who practiced traditional resistance training. Curiously, trunk extension and flexion RTD were not different between participants with experience in Pilates, traditional resistance training, and no experience with exercise training. Furthermore, CF group presented significantly higher RTD values at all analyzed time intervals (30, 50, 100, 150, 200 and 250 ms) when compared with the other groups, confirming our initial hypothesis. These data confirm that women who are engaged in CrossFit training benefit from greater capacity to produce rapid strength with the trunk flexors and extensors, even when compared to women who practice other strength training modalities.

Robust evidence supports the strengthening trunk muscles[1,34], while performance in such tests is frequently reported to be associated with quality of life and control of lower back pain[35]. However, the role of rapid force development of trunk muscles and its association with exercise performance and quality of life are still unclear.

The data obtained in the present study suggests that maximal trunk extension and flexion strength, assessed as maximal isometric peak torque, is not different between untrained individuals and those who practice traditional resistance training and Pilates. Moreover, participants in the CrossFit group exhibited greater maximal trunk flexion strength compared to those in the traditional resistance training group. It would be expected that individuals who engage in any type of strength training regimens present better trunk strength than those who are sedentary, which was not the case in the present study. The similarities between trunk extension and flexion IPT between the ST/PL and the CON groups could be due to specific set configurations within these modalities. It has been widely accepted that heavy loads are required to improve maximal strength[36], and many CrossFit exercises apply such specific stress to the trunk extensors and flexors while it may not be the case for Pilates and traditional resistance training exercises.

It is well accepted that RTD is positively influenced by resistance training. Recent evidence indicates an important influence of movement velocity on isometric RTD adaptations, with fast exercise movements being more advantageous than slow movements[37]. Besides actual velocity of the movement, the intention to produce force rapidly during exercises is also considered a key feature of successful training interventions designed to improve RTD[37]. Among the exercise modalities investigated in this study, CrossFit is the one that involves a greater amount of explosive whole-body movements which clearly depend on a rapid recruitment of trunk muscles for force transfer and spine stabilization[38]. Opposingly, there is a tendency for adopting slow muscle actions during traditional resistance training to supposedly provide greater activation of targeted muscles[39], although existing evidence indicate that slow muscle contractions may not be more effective than fast muscle contractions in promoting positive neuromuscular adaptations[40]. Some authors suggest that the lack of increase (or reduction) in RFD after traditional strength training might result from the slow movement speeds during this training modality[19]. Based on the results obtained in the present study, this appears to also be the case for Pilates.

The benefits of Pilates for the core complex are well documented, especially when variables such as strength and flexibility are observed[26]. During Pilates training sessions the respiratory pattern must be continuously controlled to provide satisfactory trunk stabilization[41]. Consequently, Pilates movements are widely known to be performed with slow and controlled contraction velocities. This appears to explain the lack of differences in trunk muscle RTD observed between the PL and CON groups in the present study.

The choice of exercises focused on the core complex in each training modality may have an important influence in trunk muscles requirement. In traditional resistance training programs, core complex muscles are frequently strengthened through isolated exercises focusing on developing tension in target trunk muscles (e.g., rectus abdominis and obliques). During the execution of whole-body exercises, core complex muscles act as a kinetic link between the upper and lower extremities, allowing the transfer of torque and angular momentum between these structures[42]. A combination of isolated and whole-body exercises during traditional strength training sessions results in an accumulation of stimuli to core complex that culminate in the strengthening of this complex. However, the velocity of the contractions performed during traditional strength training does not appear to improve rapid force production of the trunk flexors and extensors as evidenced by the lack of significant differences in the RTD of these muscles between resistance trained and untrained women in this study. The similar RTD values observed for the RT, PL and CON groups in the present study are supported by the exercise training principle of specificity[36], which proposes that the adaptations to exercise training are specific to a plethora of variables inherent to the training protocol, with movement velocity being one of them.

Since it has been initially studied, in the 1970s [43], RTD has been considered an important functional marker due to its association with daily activities[44,45]. The ability to produce a rapid increase in contractile strength during the initial phase of a voluntary contraction (0-300 ms) is vital not only for athletes, but also for older adults who need to neutralize sudden disturbances in postural balance [46,10]. RTD also appears to improve functional capacity and reduce pain[47,12]. However, few studies investigated RTD in trunk muscles. Rossi[48], showed that asymptomatic individuals have greater capacity to generate strength, and extend the trunk more quickly, when compared to subjects with chronic low back pain.

Although none of our participants reported lower back pain, when comparing our data with those of Rossi[48], only the CF group showed greater trunk extension RTD compared to untrained individuals and resistance- and Pilates-trained individuals, while trunk extension RTD values for these groups were similar to those presented by people with lower back pain[48]. This suggests that the capacity to produce strength rapidly does not appear to be associated with the incidence of lower back pain, as none of the individuals recruited for the present study reported lower back pain and trunk muscle RTD was different between groups. Furthermore, if health and quality of life are to be considered, it is important to notice that increased trunk RTD can result in quicker postural adjustments during daily activities, which could prevent falls and unexpected incidents.

5 CONCLUSION

Regular CrossFit practice results in superior RTD when compared with traditional resistance training, Pilates and sedentary life style in women. Maximal trunk strength is also greater for women who practice CrossFit compared to those who practice traditional resistance training and those who are sedentary. This may be directly related to the principles and exercises of the modality, characterized by fast, intense, and free movements, which seems to the best strategy to improve trunk rate of torque development.

REFERENCES

Thompson, W. R., Gordon, N. F., & Pescatello, L. S. (2010). ACSM's guidelines for exercise testing and prescription (8th ed.). Lippincott, Williams & Wilkins.

Akuthota, V., Ferreiro, A., Moore, T., & Fredericson, M. (2008). Core stability exercise principles. Current Sports Medicine Reports, 7, 39–44.

Gottschall, J. S., Mills, J., & Hastings, B. (2013). Integration core exercises elicit greater muscle activation than isolation exercises. Journal of Strength and Conditioning Research, 27, 590–596.

Waldhelm, A., & Li, L. (2012). Endurance tests are the most reliable core stability related measurements. Journal of Sport and Health Science, 1, 121–128.

Panjabi, M. M. (1992). The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. Journal of Spinal Disorders and Techniques, 5, 383–389.

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, N. P., & Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. Journal of Applied Physiology, 93, 1318–1326.

Corvino, R. B. (2008). Taxa de desenvolvimento de força em diferentes velocidades de contrações musculares. Revista Brasileira de Medicina do Esporte, 15, 428–431.

Ishoi, L., et al. (2019). The influence of hamstring muscle peak torque and rate of torque development for sprinting performance in football players: A cross-sectional study. International Journal of Sports Physiology and Performance, 14, 665–673.

Pereira, M. P., & Goncalves, M. (2011). Muscular coactivation (CA) around the knee reduces power production in elderly women. Archives of Gerontology and Geriatrics, 52, 317–321.

Gurjão, A. L. D., et al. (2012). Effect of strength training on rate of force development in older women. Research Quarterly for Exercise and Sport, 83, 268–275.

Rossi, D. M. (2013). Análise eletromiográfica e dinamométrica do tronco de jovens com e sem dor lombar crônica inespecífica [Trabalho acadêmico]. Unesp. http://hdl.handle.net/11449/99069

Andersen, L. L., et al. (2009). Effect of contrasting physical exercise interventions on rapid force capacity of chronically painful muscles. Journal of Applied Physiology, 107, 1413–1419.

Opar, D. A., et al. (2013). Rate of torque and electromyographic development during anticipated eccentric contraction is lower in previously strained hamstrings. American Journal of Sports Medicine, 41, 116–125.

Buckthorpe, M., & Roi, G. S. (2017). The time has come to incorporate a greater focus on rate of force development training in the sports injury rehabilitation process. Muscles, Ligaments and Tendons Journal, 7, 435–441.

Angelozzi, M., et al. (2012). Rate of force development as an adjunctive outcome measure for return-to-sport decisions after anterior cruciate ligament reconstruction. Journal of Orthopaedic & Sports Physical Therapy, 42, 772–780.

Penailillo, L., Blazevich, A., Numazawa, H., & Nosaka, K. (2015). Rate of force development as a measure of muscle damage. Scandinavian Journal of Medicine & Science in Sports, 25, 417–427.

De Haan, A., Gerrits, K. H. L., & De Ruiter, C. J. (2008). Counterpoint: The interpolated twitch does not provide a valid measure of the voluntary activation of muscle. Journal of Applied Physiology.

Miller, M., Downham, J., & Lexell, D. Y. (1999). Superimposed single impulse and pulse train electrical stimulation: A quantitative assessment during submaximal isometric knee extension in young healthy men. Muscle & Nerve, 22, 1038–1046.

Tillin, N. A., & Folland, J. P. (2014). Maximal and explosive strength training elicit distinct neuromuscular adaptations, specific to the training stimulus. European Journal of Applied Physiology, 114, 365–374.

Oliveira, F. B., Rizatto, G. F., & Denadai, B. S. (2013). Are early and late rate of force development differently influenced by fast-velocity resistance training? Clinical Physiology and Functional Imaging, 33, 282–287.

Alegre, L. M., et al. (2006). Effects of dynamic resistance training on fascicle length and isometric strength. Journal of Sports Sciences, 24, 501–508.

Hakkinen, K., Alen, M., & Komi, P. V. (1985). Changes in isometric force and relaxation time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. Acta Physiologica Scandinavica, 125, 573–585.

Young, W. B., & Bilby, G. E. (1993). The effect of voluntary effort to influence speed of contraction on strength, muscular power, and hypertrophy development. Journal of Strength and Conditioning Research, 7, 172–178.

Hakkinen, K., et al. (1998). Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. Journal of Applied Physiology, 84, 1341–1349.

Blazevich, A. J., Horne, S., Cannavan, D., Coleman, D. R., & Aagaard, P. (2008). Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. Muscle & Nerve, 38, 1133–1046.

Byrnes, K., Wu, P. J., & Whillier, S. (2018). Is Pilates an effective rehabilitation tool? A systematic review. Journal of Bodywork and Movement Therapies, 22, 192–202.

Glassman, G. (2009). What is CrossFit? CrossFit Journal. http://journal.crossfit.com/2009/11/what-is-crossfit.tpl

American College of Sports Medicine. (2009). Progression models in resistance training for healthy adults. Medicine & Science in Sports & Exercise, 41, 687–708.

Vieira, F. T. D., Faria, L. M., Wittmann, J. I., Teixeira, W., & Nogueira, L. A. C. (2013). The influence of Pilates method in quality of life of practitioners. Journal of Bodywork and Movement Therapies, 17, 483–487.

Paine, M. J., Uptgraft, M. J., & Wylie, M. R. (2010). CrossFit study. Command and General Staff College.

Gruther, W., et al. (2009). Diagnostic accuracy and reliability of muscle strength and endurance measurements in patients with chronic low back pain. Journal of Rehabilitation Medicine, 41, 613–619.

Sahaly, R., Vandewalle, H., Driss, T., & Monod, D. H. (2001). Maximal voluntary force and rate of force development in humans – importance of instruction. European Journal of Applied Physiology, 85, 345–350.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum.

Kumar, T., Kumar, S., Nezamuddin, M., & Sharma, V. P. (2015). Efficacy of core muscle strengthening exercise in chronic low back pain patients. Journal of Back and Musculoskeletal Rehabilitation, 28, 699–707.

Russ, D. W., Amano, S., Law, T. D., Thomas, J. S., & Clark, B. C. (2021). Multiple measures of muscle function influence Sorensen test performance in individuals with recurrent low back pain. Journal of Back and Musculoskeletal Rehabilitation, 34, 137–147.

Fleck, S. J., & Kraemer, W. J. (2014). Designing resistance training programs (4th ed.). Human Kinetics.

Blazevich, A. J., Wilson, C. J., Alcaraz, P. E., & Rubio-Arias, J. A. (2020). Effects of resistance training movement pattern and velocity on isometric muscular rate of force development: A systematic review with meta-analysis and meta-regression. Sports Medicine, 50, 943–963.

Claudino, J. G., et al. (2018). CrossFit overview: Systematic review and meta-analysis. Sports Medicine - Open, 4, 2–14.

Panhan, A. C., et al. (2021). Core muscle activation during Pilates exercises on the Wunda chair. Journal of Bodywork and Movement Therapies, 25, 165–169.

Schoenfeld, B. J., Ogborn, D. I., & Krieger, J. W. (2015). Effect of repetition duration during resistance training on muscle hypertrophy: A systematic review and meta-analysis. Sports Medicine, 45, 511–585.

Cancelliero-Gaiad, K. M., Ike, D., Pantoni, C. B. F., Borghi-Silva, A., & Costa, D. (2014). Respiratory pattern of diaphragmatic breathing and pilates breathing in COPD subjects. Brazilian Journal of Physical Therapy, 18, 291–299.

Behm, D. G., Drinkwater, E. J., Willardson, J. M., & Cowley, P. M. (2010). The use of instability to train the core musculature. Applied Physiology, Nutrition, and Metabolism, 35, 91–108.

Thorstensson, A., Grimby, G., & Karlsson, J. (1976). Force-velocity relations and fiber composition in human knee extensor muscles. Journal of Applied Physiology, 40, 12–16.

Maffiuletti, N. A., Bizzini, M., Widler, K., & Munzinger, U. (2010). Asymmetry in quadriceps rate of force development as a functional outcome measure in TKA. Clinical Orthopaedics and Related Research, 1, 191–198.

Tillin, N. A., Pain, M. T. G., & Folland, J. (2013). Explosive force production during isometric squats correlates with athletic performance in rugby union players. Journal of Sports Sciences, 31, 66–76.

Suetta, C., et al. (2004). Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. Journal of Applied Physiology, 97, 1954–1961.

Crockett, K., et al. (2013). The relationship of knee-extensor strength and rate of torque development to sit-to-stand performance in older adults. Physiotherapy Canada, 65, 229–235.

Rossi, D. M., et al. (2017). Rate of force development and muscle activation of trunk muscles in women with and without low back pain: A case-control study. Physical Therapy in Sport, 26, 41–48.