



EFFECTS OF A CORRECTIVE EXERCISE PROGRAM ON TRUNK ENDURANCE, JUMPING PERFORMANCE AND REACTION TIME IN ADOLESCENT FENCERS: A RANDOMIZED CONTROLLED TRIAL

DÜZELTİCİ EGZERSİZ PROGRAMININ ADOLESAN ESKRİMCİLERDE GÖVDE DAYANIKLILIĞI, SIÇRAMA PERFORMANSI VE REAKSİYON ZAMANI ÜZERİNE ETKİSİ: RANOMİZE KONTROLLÜ ÇALIŞMA

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ABSTRACT

Objective: The aim of this study was to investigate the effects of an eight-week individualized Functional Corrective Training (FCT) program, developed using the Functional Movement Screen (FMS) Pro360 system, on trunk muscle endurance, jump performance, and reaction time in adolescent fencers.

Method: A randomized controlled single-blind design was employed. Twenty-two adolescent fencers (aged 10-19 years) were allocated into either the FCT group (n=11) or control group (n=11). Both groups continued regular training, but only the FCT group received a supervised, individualized exercise program based on FMS results. Pre- and post-intervention assessments included trunk endurance tests (McGill protocol), jump performance (Countermovement Jump and Single-Leg Jump), and visual reaction time via OptoJump, an optical measurement system that records jump height and reaction time.

Results: The FCT group demonstrated a significantly greater improvement in trunk extension endurance compared to the control group (p=0.008); while no between-group differences were observed for trunk flexion (p=0.114), right side bridge (p=0.575), or left side bridge (p=0.921). Both groups showed within-group improvements in squat jump (FCT: p=0.005; Control: p=0.004), dominant leg jump (FCT: p=0.008; Control: p=0.002), and reaction time (dominant: FCT p=0.014, Control p<0.001; non-dominant: FCT p=0.029, Control p=0.002). However, no significant between-group differences were found for jump or reaction time measures (p>0.05).

Conclusion: An eight-week individualized FCT program improved trunk extension endurance in adolescent fencers but did not lead to superior gains in jumping performance or reaction time compared to regular training alone. Further studies with larger samples and longer interventions are needed to determine the full potential of FCT programs in youth athletic development.

Key Words: Adolescent, Athletic Performance, Reaction Time

ÖZ

Amaç: Bu çalışmanın amacı, Fonksiyonel Hareket Taraması (FHT) Pro360 sistemi kullanılarak oluşturulan sekiz haftalık bireyselleştirilmiş Fonksiyonel Düzeltici Antrenman (FDA) programının, adolesan eskrimcilerde gövde kas dayanıklılığı, sıçrama performansı ve reaksiyon zamanı üzerindeki etkisini araştırmaktır.

Yöntem: RANOMİZE kontrollü, tek kör bir araştırma tasarlandı. 22 adolesan eskrimci (10-19 yaş aralığında), FDA grubu (n=11) ve kontrol grubu (n=11) olarak ikiye ayrıldı. Her iki grup da düzenli antrenman programlarına devam etti, yalnızca FDA grubu FHT sonuçlarına göre oluşturulan bireyselleştirilmiş, monitörize edilen egzersiz programına katıldı. Gövde dayanıklılığı testleri (McGill protokolü), OptoJump optik sistemi ile ölçülen sıçrama performansı (eller belde squat sıçraması, tek bacak sıçrama) ve görsel reaksiyon zamanı (sıçrama yüksekliği ve reaksiyon zamanı kaydedilerek) müdahale öncesi ve sonrasında değerlendirildi.

Bulgular: FDA grubunda gövde ekstansiyon dayanıklılığı, kontrol grubuna kıyasla anlamlı düzeyde arttı (p=0.008). Ancak gövde fleksiyonu (p=0.114), sağ yan köprü (p=0.575) ve sol yan köprü (p=0.921) için gruplar arasında anlamlı fark gözlenmedi. Her iki grupta da kendi içinde squat sıçramasında (FDA: p=0.005; Kontrol: p=0.004), dominant tek bacak sıçramasında (FDA: p=0.008; Kontrol: p=0.002) ve reaksiyon zamanında (dominant: FDA p=0.014, Kontrol p<0.001; non-dominant: FDA p=0.029, Kontrol p=0.002) performans artışı saptandı. Ancak sıçrama performansı ve reaksiyon zamanı ölçümlerinde gruplar arası anlamlı bir fark bulunmadı (p>0.05).

Sonuç: Antrenman programına ek olarak uygulanan 8 haftalık bireyselleştirilmiş FDA programı, adolesan eskrimcilerde gövde ekstansiyon dayanıklılığını artırdı, ancak sıçrama performansı ve reaksiyon zamanında bir fark oluşturmadı. FDA programlarının genç sporcuların gelişimindeki potansiyelini tam olarak ortaya koymak için daha büyük örneklem ve daha uzun müdahale sürelerine sahip araştırmalara ihtiyaç vardır.

Anahtar Kelimeler: Adolesan, Atletik Performans, Reaksiyon Zamanı

Article Info/Makale Bilgisi

Submitted/Yüklem tarihi: 01.12.2025, Revision requested/Revizyon isteği: 02.02.2026, Last revision received/Son düzenleme tarihi: 03.02.2026, Accepted/Kabul: 16.02.2026

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INTRODUCTION

Fencing is among the few sports that have been included in every Olympic Games [1]. It is a fast, high-intensity discipline that demands agility, strength, coordination and perceptual cognitive skills. Athletes must develop motor, technical and tactical skills while minimize the risk of injury [1,2]. The adolescent years are important for building correct functional movements. In this period, proper biomechanics, neuromuscular control, and identifying movement deficiencies can help long-term athletic development, minimize the risk of overuse injuries, and improve overall performance [3-5].

The Functional Movement Screen (FMS) and Functional Corrective Training (FCT) were developed by Cook et al. [6]. FMS is a seven-item instrument designed to analyse key functional movement patterns. FMS assesses mobility and stability and identifies asymmetries and poor movement patterns. Each task receives a score between 0 and 3, with 0 assigned if pain occurs during the movement and 3 given for a correctly performed action. The highest possible FMS score is 21, and values under 14 have been linked to a greater risk of injury [6-7]. Functional Corrective Training exercise protocols are applied according to FMS results in terms of improving movement quality and minimizing incidence of injury [6-8].

Studies have often investigated the effect of Functional Corrective Training exercises on FMS scores; however there has been less investigation on performance and these studies have reported conflicting results regarding whether corrective exercises improve performance or not [3,9,10].

To the authors' knowledge, no study to date has investigated the effects of FCT exercises on performance in adolescent fencers. Fencing requires explosive lunges, rapid changes in direction, and sustained en garde positions, all of which demand optimal mobility, stability, and neuromuscular control [1,11]. Core stability and lower limb strength are also particularly critical for maintaining postural control and executing explosive lunges [12]. Additionally, asymmetrical movement patterns in fencing may lead to muscular imbalances, relative weakness or reduced mobility [13]. We hypothesize that an eight-week individualized Functional Corrective Training program, integrated into regular fencing sessions, will lead to significant improvements in trunk muscle endurance, jumping performance, and visual reaction time in adolescent fencers compared to regular training alone. The aim of this study is to examine the effect of the Functional Corrective Training exercises on trunk endurance, jumping performance and reaction time in adolescent fencers.

METHOD

Study Design and Participants

This research employed a randomized controlled single-blind design. Participants were randomly allocated to one of the two groups (Exercise or control) using block randomization (block size of 4) with a computer-generated random table of numbers created via Microsoft Excel's random number generator function. This randomization was performed by an individual uninvolved in the recruitment and measurements (a research coordinator not affiliated with the study team) to minimize bias. Sequentially numbered index cards with the randomized allocation were prepared and placed in opaque, sealed envelopes to secure allocation concealment.

The study was conducted in adolescents aged 10 to 19 years, as defined by the World Health Organization. Inclusion criteria were as follows: i) practicing fencing for at least three years, ii) age between 10 and 19, iii) no pain in any body part. Exclusion criteria are as follows: i) prior sports injury and rehabilitation during the past six months, ii) following a different exercise program besides what is followed in athletes sports club. Forty-seven fencers were volunteered, but fifteen were excluded due to the age criteria. The study began with thirty-two fencers divided into exercise (n=16) and control groups (n=16). In the FCT group, five participants were excluded due to not attending sessions regularly

(n=2), quitting the sport (n=1), and not completing assessments after treatment (n=2). In the control group, five participants were excluded for not attending sessions regularly (n=4), and not completing assessments (n=1). The study concluded with twenty-two participants (11 each group). Figure 1 shows the flowchart of the participants. The participants reported no adverse effects incident associated with the interventions conducted during the study. Following the initial measurements, the FCT group performed structured exercise program for 8 weeks. The control group did not take part in the 8-week intervention. Training and match routines were same for both groups during the study period. After eight weeks, same assessment procedures were repeated. Two physiotherapists, expertise in musculoskeletal and sports injury rehabilitation more than ten years, conducted the assessments. These assessors were unaware of group allocations.

Outcome Measures

Functional Movement Screen: Seven-test protocol developed by Cook et al. were followed (6). The assessment was performed by an FMS level 2 certified expert. Assessments included (1) deep squat, (2) hurdle step, (3) inclined lunge, (4) shoulder mobility, (5) active straight-leg raise, (6) trunk stability push-up, and (7) rotary stability. Each test was repeated three times, and movement quality was scored on a scale from 0 to 3, following the standard FMS scoring system: 3=optimal movement pattern, 2=movement performed with compensation, 1=inability to complete the movement, and 0=pain during the test. An FMS kit was used for tests. Standardized instructions and a demonstration were applied before each test. If a participant reported pain during any movement, testing was stopped for that specific movement, and a score of 0 was assigned. All test scores were added together to generate a final score, which could reach up to 21 points. The functional movement screen has been detailed in prior studies [6,7].

Trunk Muscle Endurance: Isometric trunk muscle endurance tests defined by McGill and colleagues were used. These tests include extension, flexion and side plank assessments, all demonstrated excellent test-retest reliability [14,15]. To assess the endurance of the trunk extensor muscles, participants were positioned prone with their lower limbs strapped to the bed, while their upper body extended over the edge of the bed, which was elevated approximately 25 cm above the floor. Prior to test, participants relaxed their upper bodies on the floor. At the beginning of the test, they crossed their arms over their chest, put their hands on opposing shoulders, and elevated their upper body until their back was parallel to the ground. Participants were asked to hold the horizontal posture for the maximum duration possible. Time to fatigue was measured in seconds with a stopwatch. To evaluate the endurance of the anterior trunk muscles (flexors), participants sat on the bed with their trunk supported at a 60° incline, their hips and knees flexed to 90°. Their arms were crossed over the chest, hands put on opposite shoulders. The assessment began once the support was taken, and participants maintained the posture for as long as they could. Endurance duration was measured until participants could no longer maintain the 60° trunk angle. To evaluate lateral trunk muscle endurance, a bilateral side plank test was applied. Participants were positioned in a lateral plank posture on a 2.5 cm-thick exercise mat, with their legs fully extended. Participants lifted their hips off the mat to stay straight alignment from head to toe, with their feet and one elbow as the support points. The arm not involved in support was crossed over the chest, with the hand resting on the opposite shoulder. The test ended when the subject could no longer hold the required position. During all assessments, participants were encouraged to hold the position for the maximum duration possible. A standardized two-minute rest period was given between tests to prevent muscular fatigue.

Jump and Reaction Time Performance: The Countermovement Jump (CMJ) and the Single-Leg Jump (SLJ) tests were performed to assess lower-limb explosive power using the OptoJump Next system (Microgate, Italy); a validated optical measurement device that records

jump height based on flight time [16]. For the CMJ test participants stood upright with feet shoulder-width apart in the OptoJump measurement area, keeping their hands on their hips. Participants performed a quick downward movement (eccentric phase) by flexing their knees and hips, which was immediately followed by a maximal vertical jump (concentric phase) without stopping. Participants were asked to fully extend their knees, hips, and ankles at take-off and to land both feet inside the OptoJump measurement area. The OptoJump system automatically recorded jump height (cm). SLJ test was applied to assess unilateral lower-limb power. The test was performed separately for each leg, starting with the dominant leg. Participants stood on one leg with hands placed on their hips. Athletes performed a maximal vertical jump using only the tested leg while maintaining balance upon landing. The take-off and landing had to be on the same leg. If additional step or loss of balance occurred, the teste were repeated. Athletes did three trials for CMJ and SLJ tests, with a 30-second rest period between jumps to minimize fatigue. The highest jump height was noted for the analysis. A familiarization trial was allowed before testing, and standardized verbal encouragement was provided.

Reaction time for the dominant and non-dominant sides was measured using an optical stimulus. The athlete placed the foot of the tested side between the OptoJump sensor bars while keeping the other leg outside. Athletes faced towards a computer screen. When a red circle on the screen turned green at a random moment, the athlete lifted their foot. The stimulus was performed three times, and the shortest reaction time was recorded [17].

FMS assessments were conducted across three consecutive days for scheduling purposes; however, each participant completed the FMS in a single session on one day. Performance-related tests were conducted on a separate day. All performance-related tests, including trunk muscle endurance, jumping, and reaction time, were conducted on a single day. To reduce potential order effects, the sequence of performance tests was randomized for each participant using a computer-generated randomization list. To minimize fatigue and its potential impact on test results, a standardized 5-minute rest interval was given between each test. Additionally, participants were asked whether they felt recovered before heading to the next test.

Exercise Intervention

Individualized corrective exercise programs were created using FMS Pro 360 software, a subscription-based platform offered by Functional Movement Systems (www.functionalmovement.com). The FMS scores were provided for each participant, and the software generated an 8-week FCT program, based on the FMS algorithm, to specifically target the patterns associated with the identified restrictions. The FCT program was started with a focus on enhancing mobility, motor control, and stability, before moving on to more advanced movements [18]. Based on FMS results, the software prescribed 15 to 20 exercises for each participant. Exercises progressively advanced on a weekly basis. To ensure the exercises were performed regularly and correctly, the FCT program was delivered three times per week under the supervision of a physiotherapist and trainer at the start of training sessions and three days per week as a home program. The exercise progression was structured on a weekly basis, an example of an outlined program in the supplementary materials. Adherence to the home program was monitored via daily reminders and follow-up messages delivered through a dedicated WhatsApp group; participants were asked to confirm completion of each session.

Ethical Approval

The research complied with the ethical standards of the 1964 Helsinki Declaration and obtained permission from the Ethics Committee of Gülhane Scientific Research University of Health Sciences (date: 24.04.2024, decision number: 2024-227). Written informed consent was obtained from all participants, and the study was registered on ClinicalTrials.gov with the ID NCT06927778.

Statistical Analysis

The G*Power software package (G*Power, Version 3.1.9.4, Franz Faul, University of Kiel, Germany) was used to determine the sample size. A pilot study was conducted with 3 participants in each group. The data were analysed using a two-way mixed ANOVA to assess changes in the squat jump variable, which was the primary outcome. The eta squared and effect size (f) were found to be 0.092 and 0.318, respectively. It was calculated that a total sample of 32 subjects (16 per group) would be necessary to achieve 95% power with a 0.05 type I error rate.

The analyses and calculations were performed using a statistical analysis program (IBM SPSS Statistics for Windows, Version 25.0, IBM Corp., Armonk, New York, USA). A p -value below 0.05 was accepted as statistically significant. The histogram, skewness and kurtosis coefficients, Shapiro-Wilk test, coefficient of variation analysis, and detrended normal Q-Q plots were employed to assess the normality of the values. Normally distributed values were expressed as mean and standard deviation, but non-normally distributed variables were given as median and interquartile range. Ordinal variables were given as counts and percentages. The chi-square test or Fischer exact test was used to compare categorical variables. For inter-group comparisons of continuous variables, the independent-sample t -test was used where the assumption of bivariate normality was accepted, while the Mann-Whitney U test was implemented in other cases. For intra-group comparisons of continuous variables, the paired-sample t -test was employed where a bivariate normal distribution was present, but the Wilcoxon signed-rank test was applied in situations of non-normal distribution.

RESULTS

Forty-seven fencers from sports clubs enrolled, but fifteen were not taken in the sample because of their age categories. The study began with thirty-two fencers randomly divided into exercise ($n=16$) and control groups ($n=16$) randomly. In the exercise group, five participants were excluded due to not attending treatment sessions regularly because of personal causes ($n=2$), quitting the sport ($n=1$), and not completing assessments after treatment ($n=2$). In the control group, five participants were excluded due to not being involved in treatment sessions regularly due to personal causes ($n=4$), and not completing assessments after treatment ($n=1$). Consequently, the study concluded with twenty-two individuals (11 from each group). Figure 1 illustrates the flowchart diagram of the participants. No participants reported any adverse effects linked to the interventions or to the assessment procedures.

Demographic and Sport-Related Characteristics

The groups did not differ in demographic variables (age, gender, BMI) or sport-related characteristics (fencer type, years of participation, FMS scores) ($p > 0.05$). (Table 1). Table 2 compares the changes in outcomes from baseline to post-intervention across groups and Table 3 provides a comparison of group outcomes at baseline and post-intervention. Baseline performance measures did not differ between the two groups ($p > 0.05$) (Table 3).

Trunk Muscle Endurance

After the eight-week intervention, trunk extension endurance ($p=0.009$) and right-side bridge endurance ($p=0.003$) improved in the FCT group. However, trunk flexion endurance ($p=0.379$) and left side bridge endurance ($p=0.154$) showed no changes. In the control group, trunk extension endurance also improved ($p=0.031$), but there were no differences in trunk flexion endurance ($p=0.072$), right-side bridge endurance ($p=0.082$), or left-side bridge endurance ($p=0.074$) (Table 3). The increase in trunk extension endurance in the FCT group was greater than in the control group after the intervention ($p=0.008$). However, there were no differences for trunk flexion ($p=0.114$) and for right and left side bridge endurance ($p=0.575$ and $p=0.921$, respectively) (Table 2).

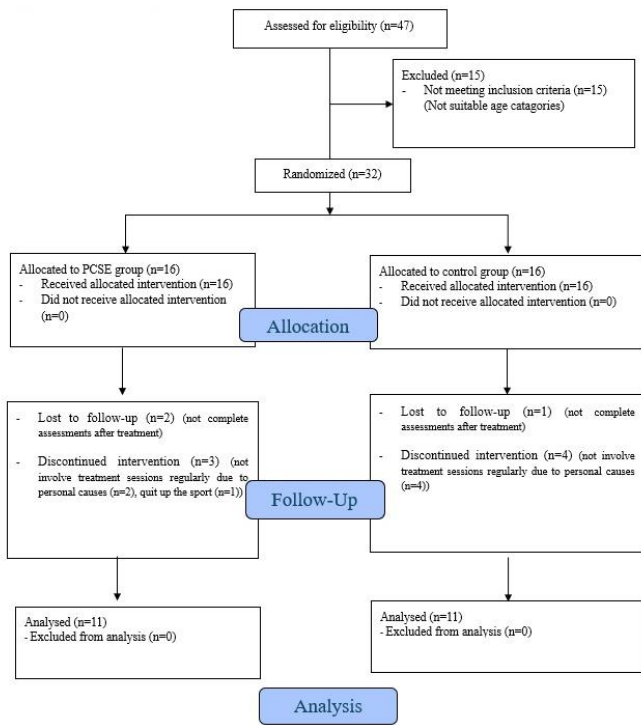


Figure 1. The flowchart of the participants

Jump and Reaction Performance

The height of the squat jump in the FCT group showed improvement after the 6-week intervention ($p=0.005$), as did the dominant leg jump ($p=0.008$). However, the non-dominant leg jump height did not exhibit any changes ($p=0.074$). In the control group, there were also increases in jump heights; the squat jump ($p=0.004$), dominant leg jump ($p=0.002$), and non-dominant leg jump ($p<0.001$) all demonstrated improvements. Additionally, reaction times for the dominant and non-dominant legs decreased in both the FCT group ($p=0.014$ and $p=0.029$) and the control group ($p<0.001$ and $p=0.002$) (Table 3). The 8-week intervention did not result in any significant differences in squat jump performance between-group ($p=0.944$), dominant leg jump ($p=0.725$), non-dominant leg jump ($p=0.647$), dominant leg reaction time ($p=0.192$), and non-dominant leg reaction time ($p=0.972$) (Table 2).

DISCUSSION

This study investigated the effects of an eight-week individually tailored Functional Corrective Training (FCT) program on trunk endurance, jumping performance, and reaction time in adolescent fencers. The results indicated that the tailored FCT program did not demonstrate superior effects on any of these parameters except trunk extension endurance.

Movement quality is taught to be a key to enhanced athletic performance [19]. We hypothesized that with two groups having similar FMS scores, the FCT exercise intervention would improve neuromuscular control and movement quality, leading to better performance relative to the control group. In line with this, earlier research has yielded conflicting results regarding the effects of neuromuscular training and FCT exercise programs on athletic performance [9,20-22]. Our study found no such effects in adolescent fencers. However, we did not reassess the FMS scores; therefore, we cannot conclude that any improvement in FMS occurred without corresponding performance changes. Changes in FMS scores were not the focus of this study. We assessed FMS scores to ensure the two groups were similar and to develop a structured FCT exercise program using a software-based approach. However, previous literature indicates that FCT enhances FMS, implying possible advantages for physical fitness [5,22,23].

Table 1. Comparison of demographic and sport-related characteristics of groups

Variables	FCT Group (n:11)	Control Group (n:11)	p
Age (years, M (IQR))	14.00 (2.00)	13.00 (2.00)	0.797 ^a
BMI (kg/m ² , X±SD)	25.80±3.03	27.34±3.46	0.131 ^b
Gender (n (%))			
Female	3 (27.3)	4 (36.4)	0.392 ^c
Male	8 (72.7)	7 (63.6)	
Fencer type (n (%))			
Flore	4 (36.4)	6 (54.5)	0.999 ^d
Epee	7 (63.6)	5 (45.5)	
Sport years (M (IQR))	5.00 (3.00)	5.00 (2.00)	0.748 ^a
FMS Score (X±SD)	11.55±1.87	13.00±2.05	0.130 ^b

FCT:Dynamic Neuromuscular Stabilization, M:Median, IQR:Interquartile range, X:Mean, SD:Standard Deviation, BMI:Body Mass Index, n:Number, %:Percentage, ^aMann-Whitney U test, ^bIndependent samples t-test, ^cPearson Chi Square, ^dFisher's Exact Test

Table 2. Comparison of the changes in trunk muscle endurance, jump, and reaction performance from baseline to post-intervention between groups

Variables	FCT Group (n:11) X±SD, M (IQR)	Control Group (n:11) X±SD, M (IQR)	p
Trunk Muscle Endurance (sec)			
Trunk flexion	15.0 (18.25)	10.00 (11.50)	0.114 ^b
Trunk extension	12.0 (19.50)	6.50 (7.50)	0.008^{b*}
Right side bridge	7.50 (9.50)	7.50 (18.25)	0.575 ^b
Left side bridge	6.50 (20.75)	6.50 (19.0)	0.921 ^b
Jump Performance (cm)			
Squat jump	5.75 (6.37)	5.75 (8.10)	0.944 ^b
Right leg jump	2.65 (5.71)	3.55 (5.85)	0.725 ^b
Left leg jump	3.60 (5.22)	3.80 (3.37)	0.647 ^b
Reaction Performance (sec)			
Right leg	-0.05 (0.08)	-0.08 (0.08)	0.192 ^b
Left leg	-0.05 (0.15)	-0.06 (0.02)	0.972 ^b

FCT:Dynamic Neuromuscular Stabilization, M:Median, IQR:Interquartile range, X:Mean, SD:Standard Deviation, n:Number, sec:Second, cm:Centimeter, ^{*} $p<0.05$, ^aIndependent sample t-test, ^bMann-Whitney U test

Trunk extension endurance was the only parameter that improved in the FCT group following intervention. Trunk extension plays an important role in fencing, particularly in executing dynamic movements like lunges. When a fencer recovers from a lunge, he or she uses trunk extension and hamstrings to pull himself or herself back [24,25]. Strong trunk extensors support stability and power transfer from the lower to the upper body, improving the effectiveness of attacks and defences. To our knowledge no study that applies the FCT program based on the FMS pro360 web system and specifically investigates trunk extension endurance in fencers exists. There is only one study that applied an individualised FCT exercise program using the software and compared the effect on physical performance. In this study, a 4-week intervention that developed by the FMS pro360 system based on individual FMS scores was applied. Changes in Army Physical Fitness test battery results were investigated.

Table 3. Comparison of trunk muscle endurance, jump, and reaction performance of the groups at baseline and post-intervention

Variables	FCT Group (n:11)		Control Group (n:11)		P ¹	P ²	P ³
	Baseline X±SD, M (IQR)	After the intervention X±SD, M (IQR)	Baseline X±SD, M (IQR)	After the intervention X±SD, M (IQR)			
Trunk Muscle Endurance (sec)							
Trunk flexion	46.27±31.19	54.90±29.85	39.72±19.86	46.09±19.07	0.564 ^c	0.379 ^a	0.072 ^a
Trunk extension	27.00±15.77	46.27±31.19	34.45±19.04	38.81±17.72	0.329 ^c	0.009^{a*}	0.031^{a*}
Right side bridge	20.63±8.59	27.72±8.93	20.00 (36.00)	25.00 (27.00)	0.223 ^d	0.003^{a*}	0.082 ^b
Left side bridge	19.00 (8.00)	28.00 (15.00)	20.00 (16.00)	22.00 (26.00)	0.981 ^d	0.154 ^b	0.074 ^b
Jump Performance (cm)							
Squat jump	25.30 (14.65)	31.10 (7.25)	25.31±3.41	31.58±5.39	0.973 ^d	0.005^{b*}	0.004^{a*}
Right leg jump	13.05±4.25	16.32±2.56	13.25±4.00	16.88±4.27	0.892 ^c	0.008^{a*}	0.002^{a*}
Left leg jump	11.45 (6.90)	13.60 (3.33)	11.96±3.70	15.63±3.37	0.809 ^d	0.074 ^b	<0.001^{a*}
Reaction Performance (sec)							
Right leg	0.46 (0.06)	0.42 (0.06)	0.51±0.06	0.41±0.03	0.223 ^d	0.014^{b*}	<0.001^{a*}
Left leg	0.48±0.09	0.42±0.04	0.48±0.05	0.41±0.04	0.998 ^c	0.029^{a*}	0.002^{a*}

FCT: Dynamic Neuromuscular Stabilization, M: Median, IQR: Interquartile range, X: Mean, SD: Standard Deviation, n: Number, sec: Second, cm: Centimeter, p¹: Baseline comparison of groups, p²: Baseline and after intervention comparison of FCT group, p³: Baseline and after intervention comparison of control group, *p<0.05, ^aPaired Sample T Test, ^bWilcoxon Signed Rank Test, ^cIndependent samples t-test, ^dMann-Whitney U test

This test battery includes sit-ups and push ups tests that require trunk strength and control. No significant changes were found between control and FCT exercise groups [22]. Due to the lack of studies, it is not possible to conclude the effectiveness of the software-based tailored FCT programme on trunk extension endurance or trunk control. Future studies are needed to address the unresolved questions and improve our understanding of this topic.

To our knowledge, only Stanek et al. and Basar et al. used the FMS Pro360 web-based system as an intervention, with Stanek et al. specifically investigating the effect of the FCT program on physical performance [18,22]. The duration and outcomes of these interventions varied notably. Stanek et al. conducted an 8-week program and reported improvements in stability measures, though no significant changes in mobility were observed. In contrast, Basar et al. applied a shorter, 4-week program and did not report any significant improvements in physical performance outcomes. Our study also applied an 8-week web-based FCT intervention. Improvements were only shown in trunk extension. Given this limited effect, it is not possible to generalize the efficacy of web-based FCT interventions based on our findings alone. While a few other studies did not use the FMS Pro360, they applied very similar FCT exercise programs [20,21]. The FCT programs, including the one used in the present study, followed a consistent sequence: flexibility training, static motor control, dynamic motor control, and strength. These investigations have produced conflicting evidence on how effective FCT interventions are. Several factors may cause for these inconsistencies, including the use of different physical performance tests, variations in participants' initial FMS levels, lack of supervision during training, and inconsistencies in assessment procedures or assessors across studies.

In fencing, strength and explosive power are very important because of the dynamic and high-intensity aspects of the sport [1]. Jump tests are commonly used to assess lower limb strength, power, and dynamic control. In this study, both double-leg and single-leg vertical jump tests (for the dominant and non-dominant legs separately) were applied to evaluate jumping performance. Following the 8-week intervention, no significant improvement was found in explosive power as measured

by the double-leg jump test and single-leg jump. To our knowledge, only Zhang et al. investigated the effect of the FCT program on explosive power. Long jump performance was compared before and after the 6-week FCT program. No improvement was observed [21]. One possible reason might be that FCT emphasizes neuromuscular control, postural stability, and movement quality. However, it may not provide sufficient load or intensity to lead adaptations in maximal power output. Additionally, the duration and frequency of the program may not have been sufficient to show improvements in explosive tasks. However, because the existing conclusions rely on only two studies, additional research is necessary to more clearly determine the potential effects of FCT on explosive performance.

An athlete's ability to react to various stimuli is a vital factor for success, especially in combat sports like fencing [26]. Visual reaction time (the speed and accuracy with which a fencer responds to visual cues) plays an important role in anticipating opponents' actions, executing precise attacks, and reacting swiftly to defensive situations. We hypothesized that improvements in movement efficiency and neuromuscular control would enhance reaction time. However, no significant improvement was shown in this study. There are conflicting results about whether functional training improves reaction time or not and these studies typically did not incorporate FMS-guided protocols [27,28]. Although these programs differ from traditional resistance training by incorporating multijoint and multiplanar exercises, they still do not align with our specific approach. Only one previous study has investigated the effects of an FMS-guided exercise program focused on movement quality and reported improvements in reaction time [29]. These findings highlight the need for further research to clarify the potential benefits of FMS-based interventions on reaction time in sport-specific contexts. It should be stated that the control group also demonstrated significant within-group improvements in jump performance and reaction time his suggests that the athletes' ongoing regular fencing training and match routines constituted a potent stimulus for neuromuscular adaptation over the 8-week period. Because both groups continued the same training and match routines during the study, the absence of between-group differences might also be interpreted in the context of training program that may already have been sufficient to improve power-related and reactive outcomes.

Limitations

There are several limitations of this study. First, we did not reassess the FMS scores post-intervention; therefore, it is unclear whether improvements in movement quality occurred independently of performance outcomes. Second, due to dropouts during the study, the final sample size was relatively small, and this may reduce the generalizability of the outcomes. Third, the intervention period of eight weeks may have been insufficient, especially in adolescent athletes who may require longer training durations for significant adaptations. Lastly, the case loss rate during the follow-up period was significantly higher than anticipated. This may be attributed to the demographic characteristics of the population we included. Our sample consisted of high school-aged children, and since we applied an eight-week follow-up, some participants had to take breaks from training due to their class schedules and exams. Those who did not meet our criteria for regular exercise were excluded from the study.

CONCLUSION

In conclusion, the eight-week individualized FCT program improved trunk extension endurance in adolescent fencers; however, it did not demonstrate superior improvements in jumping performance or reaction time compared with regular fencing training alone. Clinically, coaches and physiotherapists may consider FCT as an adjunct to support trunk endurance, but additional power- and speed-specific training elements are likely required when the primary goal is to enhance explosive performance and reaction time.

Ethical Approval: 2024/2024-227 *Gülhane Scientific Research Ethics Committee*

Conflict of Interest: *The authors have no conflicts of interest to declare.*

Funding: *None.*

Acknowledgements: *None.*

Author Contribution: *Concept: SBU,OM,SA,AA; Design: SBU,OM,SA,AA; Data collecting: SBU,OM,SA; Statistical analysis: SBU,OM; Literature review: SBU,OM,SA; Writing: SBU,OM; Critical review: SBU,OM,AA.*

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