TITLE
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JOURNAL
Archives of Budo

DATE DEPOSITED
18 January 2023

This version available at
https://research.stmarys.ac.uk/id/eprint/5722/

Effect of strength training programs on front push kick dynamics and kinematics

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 28 May 2021; **Accepted:** 30 July 2021; **Published online:** 11 August 2021

AoBID: 14458

Abstract

Background and Study Aim: The general fitness requirements for any combat activity include the flexibility, speed, power, muscular endurance, aerobic capacity, muscular strength, agility, balance, coordination, and body composition. In addition, the development of these fitness component should support and not disrupt the development and practice of combat techniques The aim of this study was knowledge about the effects of two programs of strength training on front push kick dynamics and kinematics across different loading conditions (no-load up to 45kg of external load) in professional soldiers.

Material and Methods: Sixteen professional military personnel were randomized into two groups who performed an 8-week intervention program focused either on functional training with a core emphasis (FCE: 26.8 ±10.1 years, 84.2 ±5.4 kg, 181.1 ±6.4 cm) or traditional strength preparation (TSP: 26.8 ±10.1 years, 84.2 ±5.4 kg, 181.1 ±6.4 cm). Both groups performed 5 front push kicks into a force plate across 5 different loading conditions and forces and kinematics were measured.

Results: The main differences in the performance of the front push kicks after FCE were that impulse increased by 16% and the impact time of the front kicks were prolonged by 10% whereas after TSP the peak force was increased by 20% and the angular velocity of the knee by 13%. Both training programs promoted changes in the coordination of movement as quantified by principal component analysis.

Conclusions: The FCE should be included in training close combat to increase impulse of the front push kick and TSP should be included to increase the peak force and the angular velocity of the knee. The combination of FCE and TSP should be used in training as both could improve kicking performance.

Keywords: close combat, core training • Covid-19 pandemic • dynamic forces • home training • military personnel

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The study was approved by the Ethics Committee of the Faculty of Physical Education and Sport of Charles University, Prague (No. 234/2020)

Provenance & peer review: Not commissioned; externally peer-reviewed

Source of support: The research was supported by grant: UNCE/Hum/032

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Close combat – physical confrontation between two or more opponents at short-range involving weapons (knife, stick, firearms and other distance weapons).

Front push kick – kick executed by lifting the knee straight forward while pulling the foot to the hamstring and subsequently straightening the leg in front of the target area.

Dynamic forces – force generated at the start of contact or collision. In close combat, this is the peak force, impact force and impulse of a kick or punch as it hits the body or solid pad.

Kinematics – the scientific study of geometrically possible motion of a body or system of bodies motion.

Functional training with a core emphasis (FCE) - exercises focusing on strengthening the deep stabilization system with a specific focus on a particular sport or movement pattern.

Traditional strength preparation (TSP) – exercises that contribute to generally increase muscular strength, power, and speed.

Personal protective equipment (PPE) – protective clothing, helmets, thorax-protection system, or other equipment designed to reduce the likelihood of serious injury from the impact of small arms fire and fragments.

Load – the amount of something, usually weight, that a body part can deal with at one time.

INTRODUCTION

Military personnel and combat athletes in different fighting styles (kick-boxing, Muay Thai, free style wrestling, mixed martial arts, close combat) require extraordinary fitness levels [1-6] which are sustained by routine strength training. The general fitness requirements for any combat activity include the flexibility, speed, power, muscular endurance, aerobic capacity, muscular strength, agility, balance, coordination, and body composition [1]. In addition, the development of these fitness component should support and not disrupt the development and practice of combat techniques [7]. At the same time, the need for specific fitness training increases as the fighter's performance level improves. This is especially important for military personnel, who have to be able to move and fight while carrying personal protective equipment (PPE) [8] which can amount to as much as 58kg of external load [9].

The Covid-19 pandemic has presented unique challenges to military personnel and combat athletes alike. In particular, wide-spread national lockdowns have dramatically compromised access to traditional training facilities meaning that a large proportion of the fighting population has had to train at home with minimal equipment [10, 11]. An important question is whether it is possible to maintain or improve one's combat conditioning when restricted to home training with minimal equipment. Similarly, it is valuable to understand what approach to training is most effective in this scenario.

It has been shown that maximal and explosive strength training [12] and elastic resistance training [13] improved the velocity of a kick in taekwondo. However, it is unclear which dynamic indicators are improved by this approach. Other authors have stated that the training of muscular power [3], use of non-traditional equipment for strength training [5], or core training [6], can enhance the performance of combat athletes. Of particular interest to this study is that although a relationship between core strength and functional movements has been observed previously [14, 15], the influence of core training on front kick performance remains unclear. Similarly, traditional strength preparation (TSP) is often part of the training of combat athletes [4] and has been shown to generally improve the performance of the task with external load [16]. However, the influence of TSP on front kick performance also remains unclear.

Training of the deep stabilization system or core is popular to improve control of trunk movement and increase net force production in activities ranging from running to throwing [17]. The efficacy of this stems from the joint coupling effect, where motion of the distal segment is heavily influenced by the movement of the proximal segment [18] an effect which is typical in striking, throwing and kicking. However, although core training has been shown to increase functional performance, its effect on specific task techniques remains questionable. As the front kick requires a high degree of stability in trunk posture to maximize force generation, functional training with a core emphasis (FCE) seems to be a good training solution for performance improvement [19]. However, it might be expected that an improvement in kicking performance would also be achieved through TSP [20], and there is no clear evidence evaluating the relative efficacy of core exercises.

The magnitude of the kick impact is a function of the quantity of transferred momentum or energy [21], which is dependent on the level of motor skill and performance [22]. In this regard, it has been shown that the dynamics of the front kick is related to the isokinetic strength of the flexors/extensors and rotators of the hip [23] and the angular velocities of the hip and knee [7]. Therefore, a strengthening program focused on the improvement of kicking performance should include hip flexor/extensor and rotator exercises along with specific kicking movements [13].

Since there is a lack of evidence on how different training specifically affects kicking performance variables (e.g., dynamics, angular velocities, muscle strength), the aim of this study was knowledge about the effects of two programs of strength training on front push kick dynamics and kinematics across different loading conditions (no-load up to 45kg of external load) in professional soldiers.

Based on previous studies [13, 5, 6, 23], we hypothesized that the FCE would improve front push kick impact and hip and knee joint distal coupling, while the program based on TSP would improve the knee velocity, peak force and knee movement pattern across the different loading conditions.

MATERIAL AND METHODS

This quantitative study used a quasi-experimental cross-sectional design. Participants were randomly divided into FCE (Table 1) and TSP (Table 2) groups for 8 weeks of exercise and were pre and post tested for kicking performance (dynamics and kinematics) and isokinetic muscle strength. The kicking performance test consisted of the execution of five kicks using five randomly selected loading conditions, and the isokinetic testing was performed for hip and knee flexion and extension, and hip internal/external rotation.

Table 1. Training program for front kick with functional core emphasis (FCE).

Tri-set	Exercises	Repetition	Recovery	Sets	Tempo
	Session A				
1	Hip internal rotation with knee flexion	10 R, 10 L	60s	2	2212
	Single leg front plank	8 R, 8 L			2122
	Side lying hip adduction	10 R, 10 L			2112
2	Hip external rotation with knee flexion	10 R, 10 L	60s	2	2221
	Glute bridge single leg progression	8 R, 8 L			2221
	Side plank hip abduction	10 R, 10 L			2112
3	Single leg deadlift	8 R, 8 L	60s	2	2121
	Half kneeling foot raise	8 R, 8 L			1222
	Contralateral limb raises	10 R, 10 L			2122
4	Lying leg raises	10 R, 10 L	60s	2	2121
	Hip rotation with a pelvis turn	10 R, 10 L			2211
	Mountain climbing plank	10			2121
	Session B				
1	Side plank with legs forwards	8 R, 8 L	60s	2	2121
	Lying straight one leg raise	8 R, 8 L			2212
	Fire hydrant	8 R, 8 L			2122
2	Transverse lunge to single arm row with powerband	8 R, 8 L	60s	2	1111
	Superman	8 R, 8 L			2122
	Single leg bridge with powerband	8 R, 8 L			2122
3	One arm press with rotation with powerband	8 R, 8 L	60s	2	1222
	Single leg deadlift with powerband	8 R, 8 L			2121
	Clamshells (hip side-lying with powerband)	8 R, 8 L			2112
4	Knee tuck crunches	10 R, 10 L	60s	2	2121
	Cross crunches	20			2121
	Bird dog	8 R, 8 L			2212

R right lower limb exercise, **L** left lower limb exercise. Tempo of exercise is in the order of eccentric, isometric, concentric and initial phase of the movement.

Table 2. Training program for front kick using regular strength exercises (TSP).

Di-set	Exercises	Repetitions	Recovery	Sets	Tempo
Session A					
1	Forward leg hip swings	12	60s	3	1010
	Squat jumps with forward lean	8 R, 8 L			21X1
2	Plyometric lunges	10	60s	3	12X0
	Kick with powerbands	8 R, 8 L			1210
3	Step up with knee raise	8 R, 8 L	60s	3	10X0
	Inverted kick with powerband	12			22X2
4	Tip toe squats	12	60s	3	2101
	Back lunge	10			2111
Session B					
1	One leg squat	5 R, 5 L	60s	3	31X1
	Standing glute kickbacks	8 R, 8 L			2111
2	Donkey kick	8 R, 8 L	60s	3	1021
	Eccentric calf raise	10			2111
3	Standing knee raise with powerband	10 R, 10 L	60s	3	2121
	Romanian deadlift with powerband	12			3112
4	Sumo squat	12	60s	3	2121
	Lateral-band steps	8 R, 8 L			1111

R right lower limb exercise, **L** left lower limb exercise. Tempo of exercise is in the order of eccentric, isometric, concentric and initial phase of the movement.

The research was approved by the Ethics Committee of the Faculty of Physical Education and Sport of Charles University, Prague (No. 234/2020. 6. January 2021).

Participants

Sixteen male professional soldiers (26.8 ±10.1 years, 84.2 ±5.4 kg, 181.1 ±6.4 cm) with training experience in physical training and front kicking were randomized and divided into an FCE group (n = 8, 31.8 ±7.4 years, 86.9 ±4.4 kg, 179.8 ±5.4 cm) and a TSP group (n = 8, 22.5 ±2 years, 81.7 ±6.1 kg, 182.4 ±6.3 cm). The participants were highly familiar with the experimental protocol and all testing procedures, and they attended two familiarization sessions prior to testing. In addition, they were instructed not to perform any physically demanding activity three days prior to the testing day. All the soldiers were healthy for the duration of the experiment. Exclusion criteria were traumatic injuries affecting performance or musculoskeletal injury within 3 months of the start of the study. All participants gave written informed consent before the start of the experimental testing. The study was conducted in accordance with the Declaration of Helsinki.

Testing protocol

All measurements of kicking were completed in a single laboratory visit. Data acquisition was conducted under identical environmental conditions (temperature: 22 ±1C; relative humidity: 40 ±5%) and equipment was calibrated before measuring. During the familiarization session the optimal distance from the force plate for each participant was measured – these individualized distances were then recorded and used to ensure the same starting position for each kick. Isokinetic testing was performed 1-2 hours after the kicking protocol.

Each testing session took approximately 40 minutes. Before testing, participants completed a 10-minute dynamic warm-up and then executed a sequence of five kicks of progressively increasing intensity to get used to the feeling of kicking against the force plate. All front push kicks began with a front-facing posture and were executed such that the foot made contact at a height equivalent to their midsection [21, 24, 23]. Each participant was asked to execute five of their best kicks by aiming for the maximum velocity of movement and maximum impact force on the force plate. The order of testing conditions was randomized. Participants executed a single set of five front kicks with bare feet (NL); five front kicks with military boots of 2 kg and a 3 kg rifle (WL1); five front push kicks with military boots, rifle, and a 10 kg ballistic vest (WL2); five front kicks with military boots, rifle, ballistic vest, and a 15 kg backpack (WL3); and five front push kicks with military boots, rifle, ballistic vest, and a 30 kg backpack (WL4). Between each kick participants were given 30 s of rest and between each set of five front push kicks 3 min of rest was taken [7]. All five recorded front kicks in each set were analysed.

Training program

Both groups performed training programs consisting of two different training sessions, 3 times a week, where the two different sessions were alternated (Table 1A, 1B; Table 2A, 2B). All training sessions took approximately 30 minutes. For FCE, the subjects performed three exercises in one set and for TSP two exercises in one set without rest between exercises. A 60 s rest interval was taken after the set. Both training programs were performed with their own body weight or a powerband as resistance. Both groups were instructed to avoid any additional resistance training during the study.

Kicking performance

Kicking performance was analysed by inverse dynamics from a triaxial force plate (Kistler 9281, Winterthur. Switzerland) mounted horizontally on the wall using an anchor construction. The kicking target area was marked with a 600 mm × 400 mm rectangle covered with industrial strength vinyl (tatami 200 mm), and the target area and kicking distance was individually adjusted [21, 24, 7]. The force plate was synchronized with a 3D optical motion capture system using Qualisys Track Manager (Qualisys Track Manager 2.10, Qualisys AB, Göteborg, Sweden) and recorded at a minimum sampling rate of 1000 Hz.

The main outcomes were the force-time curve, peak force (F_{peak}), net impulse (I_{net}) and impact force (F_i). F_{peak} was calculated as the maximum value of the 2ms sliding mean net force from all three axes (x, y, z). I_{net} was calculated according to Equation 1 by summing the net force over the contact period (t_0 -t_1).

$$\overrightarrow{I_{net}} = \int_{t_0}^{t_1} F(t)dt \qquad \text{(Equation 1)}$$

and F_i was calculated as I_{net} from initial contact to the time of the F_{peak} divided by the time to reach F_{peak}.

Kinematics

Three-dimensional kinematic data were collected using a six-camera motion analysis system Qualisys (Qualisys AB, Göteborg, Sweden) sampling at 200 Hz, where the retro-reflective markers were placed on the subject's acromioclavicular joints, anterior superior iliac spine (ASIS), lateral epicondyle, lateral malleoli and on the force plate's corners. The angular displacements of the hip, knee and ankle in the sagittal plane were calculated from the raw marker positions and analysed as angle-time curves. The velocity of each marker was calculated and used to identify the peak velocity of the ankle and foot (Vankle), knee (Vknee), hip (Vhip) and shoulder (Vshoulder). In addition, the angular velocity of the hip (AVhip) and knee (AVknee) joints was computed as the change in angular displacement and the peak angular velocity was used for comparative analyses.

Isokinetic strength testing

Isokinetic strength testing of the kicking prime movers was performed using a standard dynamometer (Humac Norm; CSMi Stoughton, MA, USA). After calibration and individual warm-up, participants were positioned on the isokinetic dynamometer for the assessment of the muscle's maximal strength according to the manufacturer's instructions. The test parameters were peak moments of concentric hip flexion and extension at 120°/s, and knee flexion and extension at 60°/s of the kicking dominant limb; and peak moments of concentric and eccentric hip external and internal rotation at 30°·s^{-1} of the non-dominant lower limb (stance limb during kicking).

Hip flexion and extension were tested in the supine position with the dynamometer lever arm aligned with the axis of the femur's greater trochanter and with a maximum range of motion of 120° of hip flexion. Participants performed four consecutive maximal concentric repetitions with a 90 s rest interval between the tested velocities. The internal and external hip rotators were tested in the supine position with the knee extended. Each participant performed two maximal repetitions of the concentric and eccentric muscle actions in two sets. The dynamometer was set up to perform the concentric internal and external hip rotation in antagonist action first, followed by the eccentric internal and external hip rotation with a 90 s rest interval. Hip rotation range of motion was determined by the individual's capacity with a minimum range of 35° of internal and external hip rotation.

Knee flexors and extensor were tested in the seated position according to standard operating procedures with the hips at 90°, and subjects were secured around the pelvis and torso with two belts. The non-tested limb was placed in a relaxed neutral seated position with the knee hanging off the chair's end, supported by a footrest. The dynamometer lever arm was aligned with the tibia of the tested leg and was attached three centimetres above the ankle. The axis of rotation was aligned with the knee joint. Each subject performed three warm-up trials at 50% of maximal effort and two sets of three repetitions of reciprocal concentric and eccentric knee flexion with a 90 second rest intervals between the sets.

Statistical analysis

Comparative and descriptive analyses were performed using Statistica 13.5 (Tibco Software Inc., Palo Alto, USA), and Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA), with the alpha level for significance set at ≤0.05. Confidence intervals of the intraclass correlation coefficient using a two-way mixed-effect model (ICC) [25], were used to calculate the intra-rater reliability of the kicking dynamics and kinematics and the Shapiro-Wilks test was used to check for data normality separately for both groups. Comparisons were performed using a Friedman's ANOVA (kick dynamics or kinematics × load × time) separately for both groups. Wilcoxon's signed-rank test was used to compare between pre and post-test for isokinetic strength, dynamics, and the kinematics of the front kick separately for both groups and between groups. *Cohen's d* was used for effect size, where d = 0.2, 0.5 and 0.8 correspond to small, medium, and large effects, respectively [26].

The coordination of kicking performance was analysed using principal component analysis (PCA) in MATLAB® (MatLab, Natic, MA, USA, R2019b for academic use) following the example of our previous work [27, 28]. Firstly, each kick was divided into three phases – pre-contact, contact and post contact. Secondly, the time series of hip and knee angles and contact force were normalized to the average phase lengths of the training group (FCE or TSP) and test period (pre or post-test). All loading conditions were analysed together. Thirdly, we spline interpolated the knee and hip angles and the contact force in order to create time-series at regular intervals of 0.01s. Lastly, we performed separate PCA for each training group and test period. In addition, we entered both the hip and knee angles for each training group and test period into the same PCA in order to analyse the coupling of knee and hip movements.

The main outputs of the PCA analysis that were of interest were the variability explained by each principal component (PC), the time-series of the scores of each PC and the loading coefficients which describe the transformation of the raw data to the new coordinate system described by the PCs. In our results below we present the PC scores multiplied by the mean loading coefficient plus or minus 1 standard deviation.

RESULTS

Due to the violation of the normal distribution for some variables (Table 2) and the small number of subjects, non-parametric methods of data processing were used for comparison. The dynamic (Table 3) and kinematic (Table 4) indicators showed good to excellent reliability according to the ICC values (Table 2), and there was no correlation of dynamic indicators with the height or mass of the participants. There were differences in dynamic (Table 3) and kinematic (Table 4) values in some pre and post-tests between groups. Isokinetic strength of the hip flexors at 120°/s was decreased for FCE and hip extensor strength at 120°/s increased after TSP. All other strength results remained the same after both programs (Table 5).

Differences in kick dynamics and kinematics after functional training with core emphasis

Differences in kick dynamics after FCE were found for I_{net} and impact time (Table 3). Friedman's test revealed that there were differences between loads for I_{net} kick for pre and post-test (p≤0.001), where Wilcoxon's test showed that the I_{net} after FCE was higher with NL, and WL1-4 than before training program (p = 0.049, d = 0.51; p = 0.011, d = 0.81; p = 0.011, d = 1.36; p = 0.011, d = 1.35; and p = 0.017, d = 1.50; respectively; Figure 1). The average improvement in I_{net} after FCE without load (NL) and with a small load (WL1) was 17.8 N.s, and with higher loads (WL2-4) was 37.8 N.s. In addition, for all loading conditions, the participants achieved a longer impact time (p = 0.036, d = 1.01; p = 0.011, d = 1.50; p = 0.017, d = 1.49; p = 0.017, d = 0.68; and p = 0.012, d = 0.97; respectively; Figure 1).

Table 2. Interrater reliability of the individual kicks and normal distribution in groups FCE and TSP.

Variable		NL ICC$_{CI}$	NL SW	WL1 ICC$_{CI}$	WL1 SW	WL2 ICC$_{CI}$	WL2 SW	WL3 ICC$_{CI}$	WL3 SW	WL4 ICC$_{CI}$	WL4 SW
Intraclass correlation coefficient and Shapiro-Wilk tests of kicks dynamics (group FCE)											
Peak Force (N)	Pre	0.81-0.98	0.283	0.39-0.95	0.338	0.71-0.98	0.875	0.46-0.96	0.108	0.52-0.96	0.683
	Post	0.79-0.98	0.555	0.77-0.98	0.804	0.93-0.99	0.695	0.92-0.99	0.231	0.82-0.99	0.696
Time to reach PF (s)	Pre	0.62-0.97	0.267	0.51-0.96	0.121	0.53-0.96	0.405	0.62-0.97	0.314	0.83-0.96	0.771
	Post	0.59-0.97	0.637	0.29-0.94	0.369	0.30-.094	0.487	0.56-0.96	0.558	0.43-0.95	0.848
Impact time (s)	Pre	0.35-0.96	0.435	0.34-0.96	0.069	0.27-0.94	0.512	0.53-0.96	0.605	0.41-0.95	0.253
	Post	0.43-0.95	0.277	0.37-0.95	0.706	0.65-0.97	0.516	0.37-0.95	0.401	0.77-0.98	0.187
Impulse (N·s)	Pre	0.93-0.99	0.877	0.89-0.99	0.143	0.75-0.98	0.945	0.52-0.96	0.098	0.75-0.98	0.431
	Post	0.92-0.99	0.052	0.77-0.98	0.719	0.89-0.99	0.575	0.76-0.98	0.493	0.87-0.99	0.657
Impact Force (N)	Pre	0.75-0.98	0.526	0.39-0.95	0.284	0.54-0.96	0.963	0.45-0.96	0.888	0.49-0.96	0.975
	Post	0.59-0.97	0.683	0.67-0.97	0.599	0.88-0.99	0.885	0.93-0.99	0.429	0.79-0.98	0.882
Intraclass correlation coefficient and Shapiro-Wilk tests of kicks dynamics (group TSP)											
Peak Force (N)	Pre	0.87-0.99	0.446	0.41-0.95	0.677	0.93-0.99	0.063	0.92-0.99	0.203	0.82-0.99	0.068
	Post	0.84-0.99	0.542	0.62-0.92	0.408	0.31-0.94	0.447	0.52-0.96	0.445	0.38-0.95	0.244
Time to reach PF (s)	Pre	0.77-0.99	0.133	0.29-0.94	0.131	0.30-0.94	**0.007**	0.56-0.96	0.978	0.26-0.90	0.935
	Post	0.32-0.94	0.066	0.41-0.97	0.513	0.57-0.97	0.725	0.42-0.95	0.392	0.49-0.96	0.664
Impact time (s)	Pre	0.79-0.99	0.380	0.37-0.95	0.554	0.65-0.97	0.314	0.37-0.95	0.994	0.78-0.98	0.665
	Post	0.88-0.99	0.346	0.86-0.99	0.922	0.68-0.97	0.378	0.78-0.98	0.275	0.81-0.98	0.973
Impulse (N·s)	Pre	0.96-0.99	0.540	0.77-0.98	0.223	0.89-0.99	0.185	0.76-0.98	0.498	0.96-0.99	0.425
	Post	0.92-0.99	0.755	0.96-0.99	0.426	0.86-0.99	0.637	0.76-0.98	0.995	0.77-0.98	0.243
Impact Force (N)	Pre	0.88-0.99	0.718	0.67-0.97	0.118	0.88-0.99	0.155	0.93-0.99	0.266	0.21-0.93	0.218
	Post	0.64-0.97	0.143	0.82-0.91	0.393	0.11-0.93	0.557	0.11-0.91	0.322	0.30-0.94	0.657
Intraclass correlation coefficient and Shapiro-Wilk tests of kicks kinematics (group FCE)											
V_{ankle} (m/s)	Pre	0.83-0.99	0.571	0.44-0.96	0.937	0.61-0.98	0.596	0.61-0.97	0.976	0.70-0.98	0.543
	Post	0.85-0.99	0.253	0.84-0.99	0.765	0.29-0.92	0.086	0.85-0.99	0.433	0.85-0.99	0.199
V_{knee} (m/s)	Pre	0.58-0.93	0.483	0.91-0.97	0.558	0.84-0.99	0.217	0.85-0.99	0.681	0.97-0.99	0.209
	Post	0.88-0.99	0.934	0.27-0.90	0.258	0.75-0.98	0.656	0.87-0.99	0.885	0.80-0.98	0.494
V_{hip} (m/s)	Pre	0.75-0.93	0.604	0.81-0.99	0.480	0.59-0.98	0.244	0.88-0.99	0.111	0.71-0.98	0.374
	Post	0.96-0.99	0.067	0.79-0.98	**0.039**	0.95-0.99	0.503	0.72-0.98	0.680	0.73-0.98	0.503
$V_{shoulder}$ (m/s)	Pre	0.66-0.98	0.458	0.88-0.99	0.504	0.26-0.95	0.202	0.92-0.99	0.358	0.92-0.99	0.823
	Post	0.93-0.99	0.248	0.92-0.99	0.428	0.92-0.99	0.658	0.81-0.99	0.132	0.89-0.99	**0.012**
AV_{knee} (rad/s)	Pre	0.41-0.97	0.064	0.28-0.93	**0.023**	0.85-0.99	0.256	0.27-0-98	**0.015**	0.55-0.98	0.811
	Post	0.93-0.99	0.874	0.75-0.98	0.073	0.94-0.99	0.366	0.56-0.96	0.47	0.26-0.95	0.193
AV_{hip} (rad/s)	Pre	0.88-0.99	0.261	0.48-0.98	**0.036**	0.71-0.99	0.891	0.28-0.99	0.211	0.79-0.99	0.574
	Post	0.88-0.99	0.980	0.81-0.99	0.563	0.96-0.99	0.387	0.52-0.97	0.169	0.21-0.95	0.056
Intraclass correlation coefficient and Shapiro-Wilk tests of kicks kinematics (group TSP)											
V_{ankle} (m/s)	Pre	0.42-0.93	0.997	0.70-0.98	0.133	0.79-0.99	0.624	0.91-0.99	0.774	0.90-0.99	0.188
	Post	0.63-0.97	0.560	0.38-0.93	**0.002**	0.88-0.99	0.888	0.87-0.99	0.985	0.87-0.99	0.742
V_{knee} (m/s)	Pre	0.82-0.99	0.050	0.87-0.99	0.750	0.91-0.99	0.170	0.89-0.99	0.125	0.89-0.99	0.261
	Post	0.67-0.97	0.736	0.89-0.99	**0.041**	0.88-0.99	0.312	0.78-0.99	0.580	0.85-0.99	0.956

Intraclass correlation coefficient and Shapiro-Wilk tests of kicks dynamics (group FCE)											
V_{hip} (m/s)	Pre	0.86-0.99	0.081	0.55-0.90	0.219	0.81-0.98	0.535	0.81-0.98	0.485	0.95-0.99	0.628
	Post	0.76-0.98	0.175	0.85-0.99	0.853	0.88-0.99	0.279	0.94-0.97	0.094	0.89-0.99	0.111
$V_{shoulder}$ (m/s)	Pre	0.67-0.97	0.781	0.48-0.96	0.487	0.87-0.99	0.324	0.53-0.96	0.798	0.92-0.99	**0.009**
	Post	0.41-0.95	0.186	0.78-0.98	0.913	0.52-0.96	0.482	0.37-0.89	0.358	0.52-0.96	0.107
AV_{knee} (rad/s)	Pre	0.78-0.99	0.171	0.44-0.95	0.911	0.82-0.99	0.725	0.29-0.97	0.868	0.81-0.99	0.096
	Post	0.31-0.92	0.570	0.23-0.96	0.426	0.43-0.97	0.575	0.65-0.99	1.000	0.33-0.95	0.913
AV_{hip} (rad/s)	Pre	0.91-0.99	0.099	0.79-0.99	**0.026**	0.90-0.99	**0.021**	0.89-0.99	0.225	0.93-0.99	**0.021**
	Post	0.27-0.93	0.793	0.81-0.99	0.393	0.25-0.96	0.896	0.37-0.99	0.333	0.67-0.99	0.828

Abbreviations: **ICC_{CI}** confidence interval for mean interclass correlation coefficient**; SW** Shapiro-Wilk test; **M1** measurement before training program; **M2** measurement after training program; **NL** no loads; **WL1** 5kg (military boots 2 kg and rifle 3 kg); **WL2** 15kg (military boots 2 kg, rifle 3 kg and ballistic vest 10 kg); **WL3** 30kg (2 kg military boots, rifle 3 kg ballistic vest 10 kg and backpack 15kg); **WL4** 45kg (2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 30kg). Bold values represent not normal distribution $p \geq 0.05$.

Table 3. Kick dynamics for the two groups.

Variable	Session	No load (NL) Median	No load (NL) 25th-75th percentile	Load 5kg (WL1) Median	Load 5kg (WL1) 25th-75th percentile	Load 15kg (WL2) Median	Load 15kg (WL2) 25th-75th percentile	Load 30kg (WL3) Median	Load 30kg (WL3) 25th-75th percentile	Load 45kg (WL4) Median	Load 45kg (WL4) 25th-75th percentile
Kicking dynamics of the functional with core emphasis training group											
Peak Force (N)	Pre-test	4865*	3785–6049	4747	4494–5488	5005	4215–5318	4855	4705–5029	4593	4083–4658
	Post-test	6028*†	4882–7106	**4780†**	4062–5799	4732†	4021–5857	5054	3800–5945	**4245†**	3779–4699
Time to reach PF (s)	Pre-test	0.011	0.009–0.014	0.009	0.006–0.013	**0.007***	0.006–0.009	0.008	0.007–0.01	**0.008***	0.007–0.01
	Post-test	0.011	0.01–0.012	0.011	0.009–0.012	**0.011***	0.01–0.013	0.011	0.009–0.011	**0.011***	0.009–0.012
Impact time (s)	Pre-test	**0.119*†**	0.111–0.124	**0.135*†**	0.122–0.14	**0.148***	0.14–0.161	**0.173***	0.161–0.187	**0.181***	0.163–0.185
	Post-test	**0.127*†**	0.124–0.136	**0.148***	0.141–0.157	**0.170***	0.156–0.183	**0.184***	0.175–0.201	**0.200***	0.182–0.237
Impulse (N·s)	Pre-test	**146.4*†**	123.2–165.7	**171.6*†**	137.8–186.8	**179.3*†**	161.5–196.3	**196.9*†**	185.8–202.9	**204.0***	196.5–212.6
	Post-test	**170.8*†**	142.9–177.3	**182.7*†**	164.3–205	**220.3***	201.1–234.7	**225.7***	206.6–247.8	**247.7***	232.2–281.1
Impact Force (N)	Pre-test	**2674***	1977–3013	3181	2927–3761	3131	2924–3452	3259	3053–3456	2984	2817–3072
	Post-test	**3042***	2446–3401	3140	2568–3737	3141	2576–3451	3268	2370–3477	2659†	2309–2836
Kicking dynamics of the traditional strength preparation training group											
Peak Force (N)	Pre-test	5085	4209–6655	**5443***	4907–5879	5163	4784–6825	**5254***	4464–6304	5283	4476–5996
	Post-test	**7018†**	5608–8183	**6058*†**	5776–6831	**6306†**	5304–6454	**6390***	5292–6674	**5584†**	5137–5990
Time reach PF (s)	Pre-test	0.011	0.008–0.014	**0.008***	0.006–0.011	0.008	0.006–0.01	**0.009***	0.007–0.01	**0.009***	0.007–0.01
	Post-test	0.011	0.008–0.011	**0.010***	0.009–0.012	0.011	0.01–0.012	**0.011***	0.01–0.013	**0.012***	0.011–0.014
Impact time (s)	Pre-test	**0.145†**	0.138–0.149	**0.144†**	0.135–0.165	0.170	0.145–0.18	0.184	0.164–0.201	0.203	0.186–0.215
	Post-test	**0.148†**	0.131–0.184	0.154	0.133–0.168	0.160	0.145–0.18	0.175	0.163–0.215	0.203	0.18–0.214
Impulse (N·s)	Pre-test	**193.7†**	158.8–220.1	**203.5†**	192.9–236.8	**231.6†**	206.8–271.5	**238.7†**	209.4–286	240.5	222.4–314.7
	Post-test	**198.0†**	175.3–219	**205.5†**	187.9–223.4	229.1	216.9–256.1	243.3	223.2–261	261.2	239.9–283
Impact Force (N)	Pre-test	2989	2319–3613	3474	3131–3973	3444	3371–4275	**3415***	3027–3929	3173	2986–3794
	Post-test	3797	2940–4141	3811	3397–4145	3654	3328–4103	**3822***	3300–4253	3295†	3117–3789

Values are expressed as median and 25th to 75th percentile; *significant differences between pre and post-test, $p \leq 0.05$; † Significant difference between groups $p < 0.05$. Abbreviations: **Pre** measurement before training program; **Post** measurement after training program; **NL** no loads; **WL1** 5kg - military boots 2 kg and rifle 3 kg; **WL2** 15kg military boots 2 kg, rifle 3 kg and ballistic vest 10 kg; **WL3** 30kg 2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 15kg; **WL4** 45kg 2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 30kg

Table 4. Kick kinematics for the two groups.

Variable	Session	No load (NL)		Load 5kg (WL1)		Load 15kg (WL2)		Load 30kg (WL3)		Load 45kg (WL4)	
Kicking kinematics of the functional with core emphasis training group											
		Median	25th-75th percentile	Median	25th-75th percentile	Median	25th-75th percentile	Median	25th-75th percentile	Median	25th-75th percentile
V_{ankle} (m/s)	Pre-test	**7.694†**	6.438–9.155	**7.726†**	7.234–8.307	**7.794†**	7.019–8.932	**7.974†**	7.375–8.272	**8.077***	7.009–8.84
	Post-test	**7.449†**	6.951–7.844	**7.445†**	6.226–7.775	**7.096†**	6.695–7.588	**7.881†**	6.767–8.214	**7.365*†**	6.283–7.748
V_{knee} (m/s)	Pre-test	**4.857†**	4.534–5.261	**4.764†**	4.253–5.442	**4.649†**	4.215–5.407	**4.457†**	4.082–4.973	**4.713*†**	3.619–5.311
	Post-test	**4.976†**	4.604–5.55	**4.925†**	4.794–5.214	**4.900†**	4.547–5.158	**5.070**	4.616–5.532	**4.957*†**	4.428–5.278
V_{hip} (m/s)	Pre-test	2.208	1.944–2.639	2.125	1.749–2.352	**2.048***	1.668–2.195	**1.542*†**	1.273–1.927	**1.556†**	1.333–1.648
	Post-test	2.428	1.71–2.597	2.014	1.768–2.401	**2.127***	1.805–2.39	**1.954***	1.571–2.118	1.622	1.525–1.902
$V_{shoulder}$ (m/s)	Pre-test	**1.356†**	1.132–1.491	**1.308†**	1.175–1.525	1.300	1.015–1.418	**1.156†**	0.944–1.325	**1.070†**	0.841–1.187
	Post-test	1.381	1.129–1.802	1.511	1.035–1.575	**1.289†**	1.098–1.35	1.271	1.052–1.415	1.251	0.981–1.329
AV_{knee} (rad/s)	Pre-test	885.2	819.5–989.1	865.3	837.1–957.4	921.6	851.6–964.6	891.5	867.9–937.3	948.6	896.1–1005.7
	Post-test	909.6	798.8–1016.3	821.2	790.1–945.9	865.7	725.5–1100.2	**951.1†**	868.6–1015.7	913.4	773.7–1016.4
AV_{hip} (rad/s)	Pre-test	503.8	450.5–573.4	500.9	466.2–615.9	514.5	456.6–572.9	468.6	424–481.1	**488.8†**	404.5–522.9
	Post-test	518.3	443.9–613.4	491.3	443.1–562.1	478.6	435.4–552.6	**439.5†**	414.4–486.3	451.2	381.9–506.7
Kicking kinematics of the traditional strength preparation training group											
V_{ankle} (m/s)	Pre-test	**9.290†**	8.81–10.03	**9.800†**	8.69–10.375	**9.820†**	8.75–10.42	**10.190†**	8.485–11.245	9.530	8.19–10.95
	Post-test	**9.940†**	9.19–10.35	**9.035†**	8.675–9.63	**9.590†**	8.575–9.865	**9.190†**	8.6–9.905	**9.445†**	8.305–9.845
V_{knee} (m/s)	Pre-test	**5.585*†**	5.13–5.74	**5.675†**	5.3–5.865	**5.995†**	5.485–6.115	**5.970†**	5.105–6.16	**5.895†**	5.2–6.025
	Post-test	**6.005*†**	5.735–6.35	**5.700†**	5.555–6.015	**5.955†**	5.565–6.235	6.050	5.71–6.16	**5.990†**	5.67–6.265
V_{hip} (m/s)	Pre-test	2.305	1.91–2.855	2.420	2.005–2.555	2.325	1.905–2.5	**2.075†**	1.835–2.39	**1.945†**	1.655–2.225
	Post-test	2.180	2–2.58	2.185	1.945–2.515	2.100	1.87–2.475	**1.725†**	1.57–2.345	1.690	1.58–2.205
$V_{shoulder}$ (m/s)	Pre-test	**1.575†**	1.405–1.645	**1.650†**	1.445–1.795	1.550	1.395–1.825	1.405	1.325–1.53	**1.415†**	1.225–1.475
	Post-test	1.610	1.485–1.77	1.625	1.47–1.84	**1.515†**	1.385–1.815	1.400	1.3–1.645	1.275	1.215–1.395
AV_{knee} (rad/s)	Pre-test	950.6	679.4–1046.5	904.3	855.6–966.2	**986.4***	890.6–1058.9	**968.9***	856.4–1039	**913.7***	827.4–984.4
	Post-test	1020.4	923.1–1093.5	1029.6	894.1–1110	**1059.8***	996.4–1140.3	**1108*†**	1011.3–1224.9	**1005.2***	955.9–1073.5
AV_{hip} (rad/s)	Pre-test	644.6	586.9–665	674.9	601.9–710.2	656.9	614.8–703.5	599.3	555.6–647.4	**603.5†**	578.8–638.1
	Post-test	600.7	559.6–652	608.1	535.9–688	587.1	538.2–647.5	**596.5†**	539.8–620.9	547.8	498.6–596.2

Values are expressed as median and 25th to 75th percentile; *significant differences between pre and post-test $p \le 0.05$; † Significant difference between groups $p < 0.05$. Abbreviations: **Pre** measurement before training program; **Post** measurement after training program; **NL** no loads; **WL1** 5kg - military boots 2 kg and rifle 3 kg; **WL2** 15kg military boots 2 kg, rifle 3 kg and ballistic vest 10 kg; **WL3** 30kg 2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 15kg; **WL4** 45kg 2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 30kg

The overall average increase in impact time after FCE was 10%. Peak force was only increased for the NL condition (p = 0.012, d = 0.89).

In terms of the kinematics, the greatest difference was found in V_{hip} (Table 4). Friedman's test revealed that there were differences between loads in V_{hip} of the kick for pre and post-tests ($p \le 0.001$), where Wilcoxon's test showed that the V_{hip} after FCE was greater in WL2-3 than before training (p = 0.017, d = 0.43; and p = 0.017, d = 0.90, respectively).

Differences in kick dynamics and kinematics after traditional strength preparation

The largest improvement was seen in the peak force (Table 3) where the participants achieved higher values in all loading conditions. Friedman's test revealed that there were differences between loads in peak force of the kick for pre and post-test (p = 0.043), where Wilcoxon's test showed that the peak force after TSP was significantly higher in WL1 and WL3 than before training program (p = 0.025, d = 1.19; p = 0.05, d = 0.79; Figure 1). The greatest improvement in peak

Table 5. Isokinetic net moment during hip external and internal rotation, hip and knee flexion, and extension.

Peak moment (N·m)		Group 1 (FCE)				Group 2 (TSP)			
	Session	Mean ± SD	CI_{Lower}	CI_{Upper}	KS	Mean ± SD	CI_{Lower}	CI_{Upper}	KS
External Hip Rotation Con 30°·s	Pre	49 ± 11	40	59	0.20	45 ± 6	40	50	0.2
	Post	42 ± 3†	40	45	0.13	49 ± 7†	43	55	0.2
Internal Hip Rotation Con 30°·s	Pre	47 ± 11	37	56	0.2	42 ± 6	36	48	0.2
	Post	41 ± 5	37	45	0.2	46 ± 13	35	57	0.2
External Hip Rotation Ecc 30°·s	Pre	54 ± 14	42	66	0.2	54 ± 10	47	63	0.2
	Post	46 ± 9†	39	53	0.09	58 ± 8†	44	66	0.083
Internal Hip Rotation Ecc 30°·s	Pre	51 ± 9	43	58	0.2	50 ± 9	43	58	0.2
	Post	45 ± 7†	38	51	0.05	55 ± 13†	44	66	0.2
Knee flexion Con 60°·s	Pre	109 ± 24	89	129	0.2	99 ± 21	81	116	0.2
	Post	92 ± 16	79	106	0.2	106 ± 22	88	124	0.017
Knee extension Con 60°·s	Pre	197 ± 30	172	222	0.19	194 ± 23	175	214	0.2
	Post	165 ± 31	139	192	0.2	185 ± 34	157	214	0.2
Hip flexion Con 120°·s	Pre	166 ± 21*	148	183	0.04	151 ± 29	127	175	0.2
	Post	146 ± 15*	133	159	0.02	157 ± 31	131	183	0.2
Hip extension Con 120°·s	Pre	239 ± 63	186	291	0.09	214 ± 30*	189	239	0.2
	Post	211 ± 43	176	247	0.12	258 ± 67*	202	314	0.2

Con concentric; **ECC** eccentric; **SD** standard deviation; **KS** Kolmogorov-Smirnov test; **CI** confidence interval, * Significant difference between pre and post-test in one group $p<0.05$; † Significant difference between groups $p<0.05$. The hip rotators are reported in the preferred standing lower limb, Hip and knee flexion, and extension is reported in preferred kicking

force after TSP was for NL (1993 N) whereas the smallest improvement was with load WL4 (301 N). The overall average improvement in F_{peak} after TSP was 20%. In addition, the time to reach peak force for WL1, and WL3-4 was also increased after training (p = 0.012, d = 0.83; p = 0.05, d = 1.0; and p = 0.017, d = 1.46, respectively).

The greatest differences in the kinematics were found in AV_{knee} (Table 4). Friedman's test revealed that there were differences between loads in AV_{knee} of the kick for pre and post-test (p = 0.002), where Wilcoxon's test revealed significant differences for WL2-4 (p = 0.025, d = 0.60; p = 0.012, d = 1.18; and p = 0.036, d = 1.07, respectively; Figure 1). The overall average improvement in AV_{knee} after TSP was 13%

The effect of training on movement variability

The first principal component (PC1) was able to describe over 80% of the variation in the force-time curve in all cases, over 90% of the variation in hip angle, and over 79.6% of the variation in knee angle (Figure 2). The variation in force explained by PC1 increased for the FCE group (by 8.0%) but decreased for the TSP group (by 5.7%). There was a small decrease in the amount of variation explained by PC1 for the hip and knee angle (1.7% and 0.4% respectively) after FCE, but an increase in the explained variation for TSP (hip 2.3%; knee 6.8%; Figure 2).

When both hip and knee angles were entered into the same PCA, PC1 was hip-like in all cases, whereas PC2 was knee-like (Figure 3). The variance explained by PC1 decreased for FCE (by 3.3%) but increased marginally for TSP (by 0.8%). The variance explained by PC2 increased for both interventions.

DISCUSSION

The present project investigated the use of two training programs to improve front push kicking performance. In particular, we studied the effects of core and dynamic exercise training programs with Czech professional soldiers who usually train in close combat twice a week. According to our results, both training programs were able to promote positive changes in front push kicking performance. The FCE training program improved

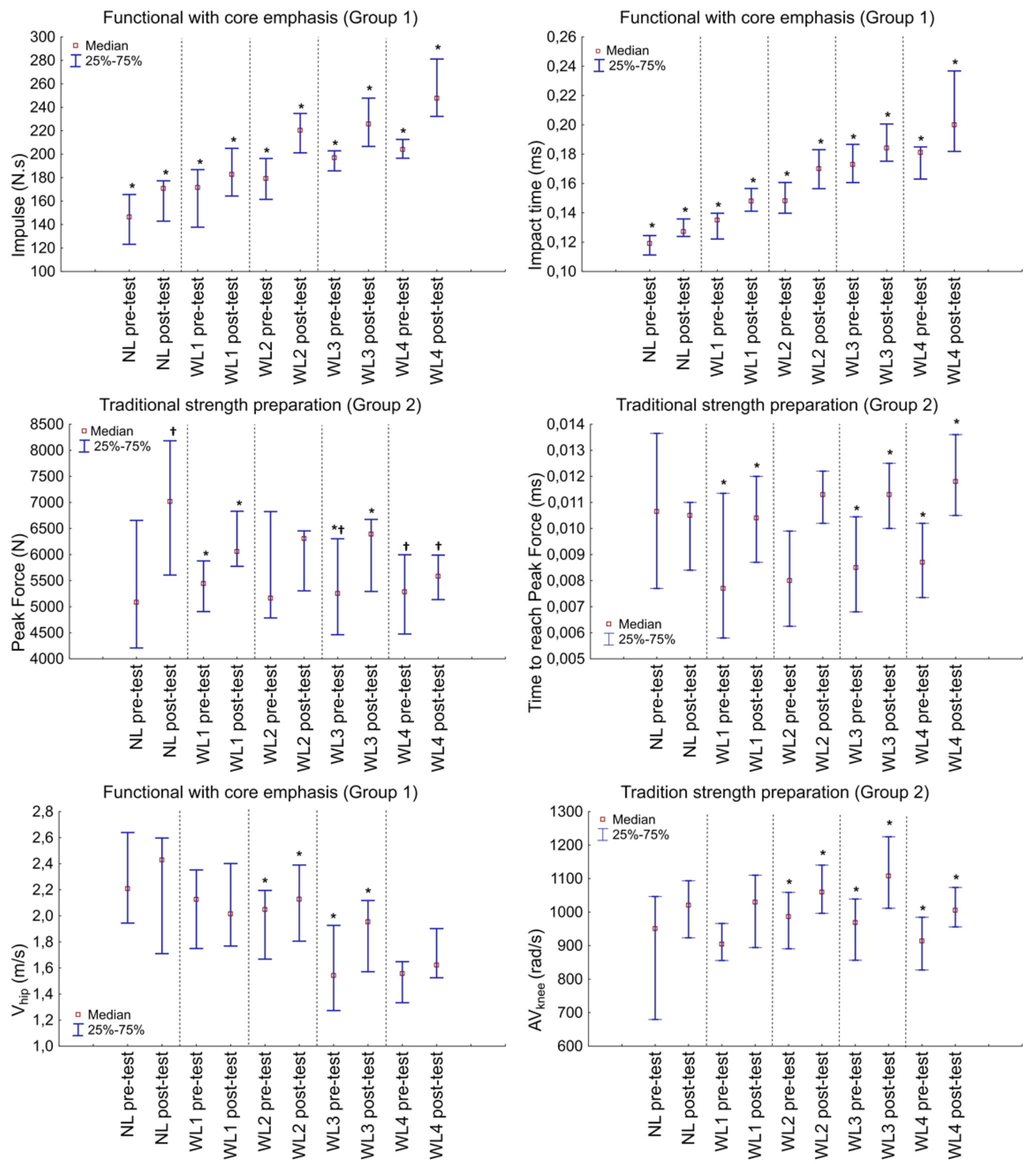

Figure 1. Selected changes in kick performance for the two training programs.

Abbreviations: **AV_{knee}** Angular velocity of then knee; **NL** no load; **WL1** 5kg (military boots 2 kg and rifle 3 kg); **WL2** 15kg (military boots 2 kg, rifle 3 kg and ballistic vest 10 kg); **WL3** 30kg (2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 15kg); **WL4** 45kg (2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 30kg); **WL4** 45kg (2 kg military boots, rifle 3 kg, ballistic vest 10 kg and backpack 30kg);

*significant differences between pre and post-test, *p*≤0.05; **†** significant differences between Peak force with NL post-test and other Peak Force of the front push kicks, *p*≤0.05

impulse and prolonged impact time, and the TSP training program increased peak force and AV_{knee} across all the loading conditions.

FCE training program and kick dynamics and kinematics

The principal goal of core exercise is to improve the coordination and stabilization of body segments throughout the entire kinetic chain. In this study, the core training program was comprised of exercises that target specific muscles, specific joints [15], and coactivity of antagonist trunk muscles [29] while maintaining the movement pattern specificity of the front kick. The improvement in kicking I_{net} after FCE was seen despite no change in isokinetic strength (Table 5). This might suggest that the FCE group was able to use a more efficient kicking

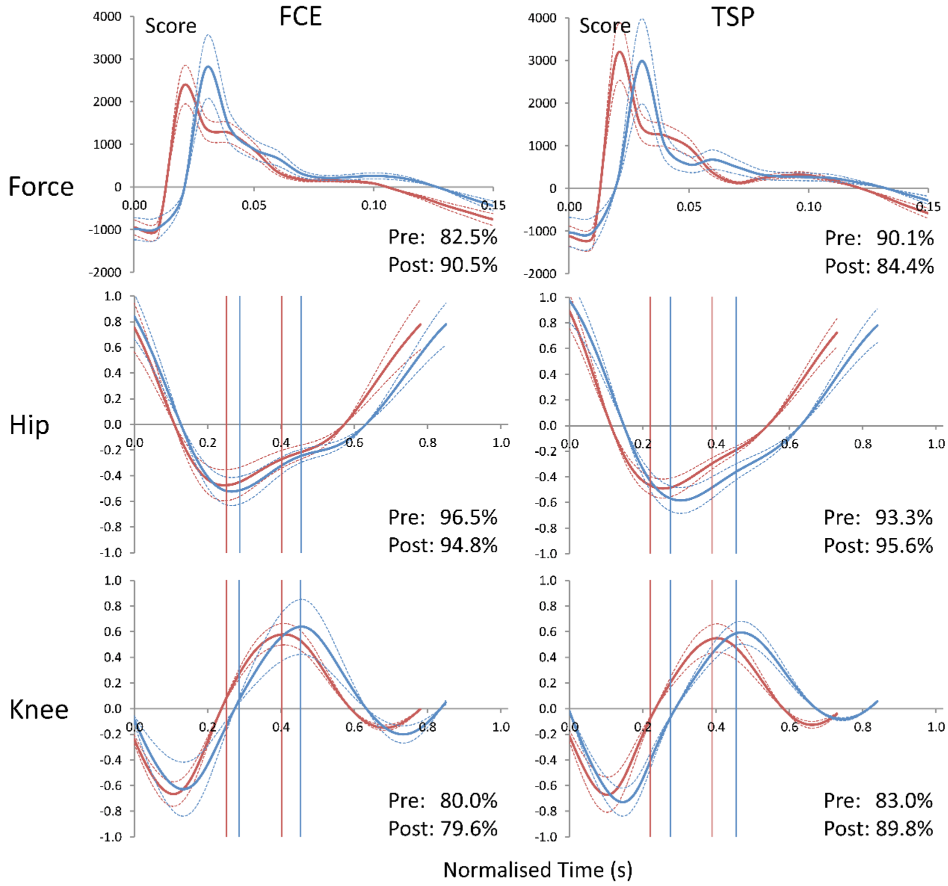

Figure 2. Scores for the first principal component of the front push kick before (red) and after (blue) functional core (FCE) and traditional strength training (TSP).
Percentages represent the amount of variation described by the first principal component. Dotted lines indicate 1 standard deviation from the mean. Vertical lines for hip and knee represent the period of contact with the force plate during the kick.

strategy [30] in which increased stability might support the feedforward movement of the kick with a positive impact on the total I_{net} transferred to the target. This effect of FCE training is quite evident since the increased I_{net} was seen for all loading conditions.

Our I_{net} results are in agreement with a previous study [31, 8], where increased I_{net} and a longer impact time was observed with increasing carried load. After the FCE program, the I_{net} values were approximately 16 to 48 N.s higher (Table 4). In addition, the impact time was similar to previous studies 0.166 to 0.212 s [7] and 0.150 to 0.166 s [8] and was increased after FCE (Table 3) which is consistent with the increased I_{net}.

Kinematics changes after FCE were found in the velocity of the individual segments, with higher values of V_{knee} and V_{hip}, and lower AV_{ankle} under loaded conditions. This might be due to increased stability of the subjects' stance during the front push kick allowing a greater use of the muscles of the pelvis to increase the velocity of the hip and consequently the knee. On the contrary, the velocity of the ankle was lower. When comparing V_{ankle}, V_{knee}, and V_{hip} with the TSP group we found that V_{hip} was lower and V_{ankle} was higher after TSP (both groups increased V_{knee}). On the one hand, movement of the knee can be related to better technical execution of the front push kick as the first phase of the kick is characterized by the acceleration of the knee up to its highest position [32, 33]. On the other hand, a higher velocity of the knee with a lower velocity of the hip is typically to a lower level of skill execution in sub-elite individuals [7]. However, FCE does seem to be effective to increase both V_{hip} and V_{knee} in loaded conditions, which is the desired improvement of kicking technique.

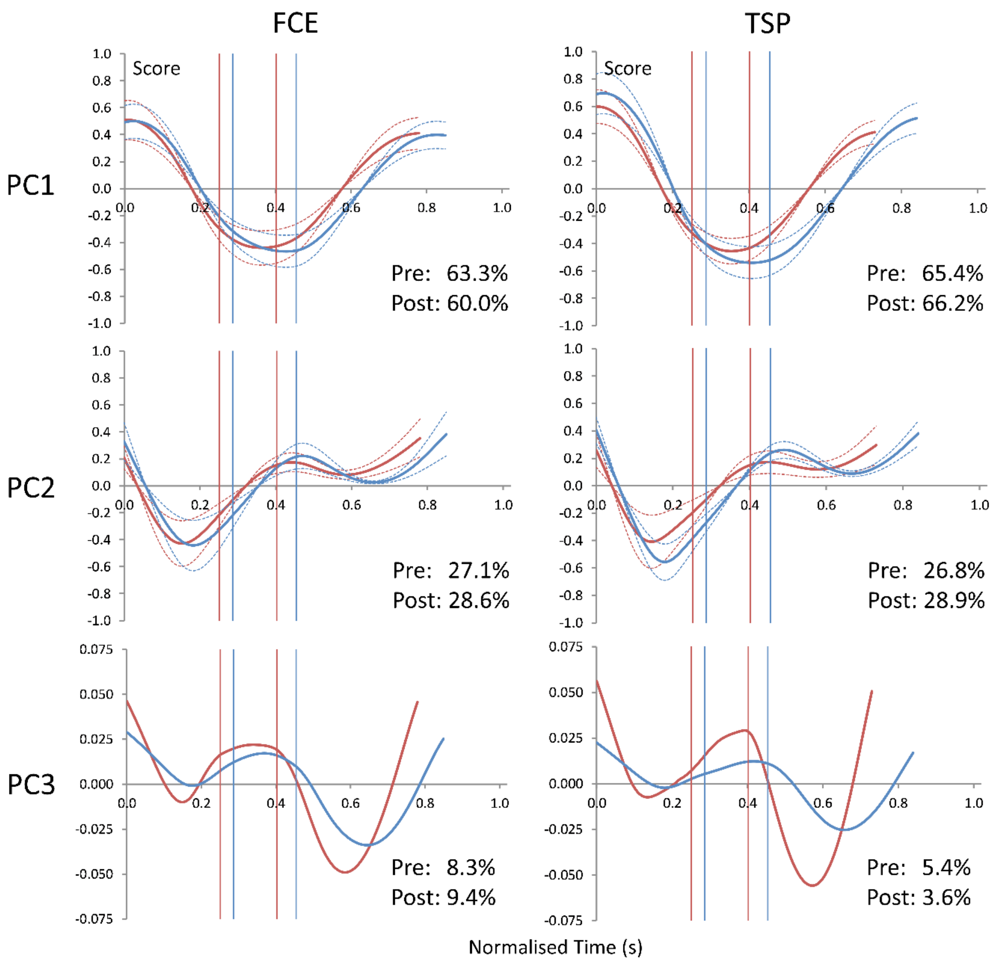

Figure 3. The principal component analysis (PCA) of the hip and knee joint coupling pattern (both hip and knee angles entered into the same PCA) during front push kicking before and after functional core (FCE) and traditional strength training (TSP).
Percentages represent the amount of variation described by the first principal component. Dotted lines indicate 1 standard deviation from the mean. Vertical lines represent the period of contact with the force plate during the kick. PCx is the xth principal component.

TSP training program and kick dynamics and kinematics

Although the TSP group had higher F_{peak} than FCE during pre-testing (5085 versus 4865 N in no load condition), they were able to significantly increase F_{peak} to an average of 7018 N. This result is in the upper range of previously reported peak force values for taekwondo and martial arts athletes (1.17 to 7.79 kN) [21, 24] and above the range 5201 to 5604 N that has been reported in other studies of military personnel [34, 8, 7].

The TSP group increased AV_{knee} and V_{knee} without the increasing the speed of the hip which is consistent with the increased F_{peak} without increased I_{net}. This might mean that the additional force might contribute to increased recoil rather than being directed into the target. However, although we did not observe an increased V_{hip}, we did see some positive changes in the hip angle-time curve throughout the whole movement (described in the joint coupling results above). Overall, we can state that TSP targeting specific muscles, specific joints and their antagonists [29] did have the effect of improving kicking dynamics and thus TSP has the potential to improve kicking performance.

The effect of training on movement variability

The outcome of the PCA was notably different for the two training programs. For the FCE training group the amount of variation in the force expression explained by PC1 increased, which we interpret as representing a decrease in the variability of the force expression. In contrast, the variation explained by PC1 for hip and knee angle decreased for FCE. The reverse pattern was seen for TSP – there was less variability in knee and hip angles, but more variability in force expression. A similar trend was found when considering the coupling of knee and hip angles. We found that around twice the variability in joint angles was explained by hip angle (PC1) than by knee angle (PC2). We interpret this as indicating that the movement is hip driven. However, for FCE the movement became less hip dominant, whereas for TSP it became more hip dominant.

Although the change in coordination that was seen for FCE and TSP may seem strange it is consistent with the contemporary ideas in motor control [35, 36] that is, more variation in movement (hip and knee angles), can lead to more precision in outcome (force expression). In the case of FCE, there was an increase in movement variability that led to decreased variation in force expression, whereas for TCP there was a decrease in movement variability that led to an increase in the variation in force expression. One explanation may be that an increase in core stability in kicking specific positions that was promoted by FCE may have permitted this greater variation in movement kinematics. Conversely, although strength capacities may have been improved by TSP, these did not translate into greater movement variability due to a lack of core control. Of course, this discussion is speculative, and there is an important caveat. That is, the results here relate to a relatively short-term intervention and are not necessarily reflective of the long-term outcome. For instance, TSP might cause a reduction in movement variability as the athlete learns to use their increased strength capacity, and this variability might return with further practice. Such a process would also be consistent with the proposed ‘freeing’ and ‘freezing’ of degrees of freedom that can take place during skill acquisition [35].

This study has some methodological limitations. Ideally, studies that compare training programs should be conducted with a cross-over design and random assignment of subjects. However, the effect of Covid-19 meant that only 16 subjects completed the study, and it was not possible to conduct a cross-over study. Nevertheless, we believe that due to the sufficient accuracy of the measuring equipment and the repeated number of kicks with good to high intra-rater reliability, strict guidance of training units by an army instructor, and the rigor of the data analysis that it is possible to take the results as reliable.

CONCLUSIONS

The results of this study demonstrate that combat athletes can still improve their combat conditioning even when training facilities are limited. FCE could promote increased stability is sustained when performing a kick prolonging impact time and increasing the impulse when the foot hits a fixed target. TSP could result in a higher angular velocity of the knee and an increase in peak force when hitting a fixed target. Although each program (TSP, FCE) leads to specific kinematic changes, both programs seem beneficial to front push kicking performance and should be combined in block periods.

HIGHLIGHTS

Military personnel and combat athletes should practice FCE and TSP not only to improve impulse, peak force, and angular velocity, respectively, of the front push kick but also to maintain kicking performance during equipment restrictions which restrict routine practice.

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Cite this article as: Vagner M, Cleather D, Kubovy P et al. Effect of strength training programs on front push kick dynamics and kinematics. Arch Budo 2021; 17: ???