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Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players

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The aim of this study was to examine the effect of a soccer (strength and technique) training program on kinematics and electromyographic (EMG) muscle activity during a instep kick. Ten amateur soccer players (aged 19.9 ± 0.4 years, body mass 74.8 ± 9.1 kg, height 177.4 ± 6.7 cm) constituted the experimental group (EG) whereas 10 players (age 21.6 ± 1.3 years, weight 71.5 ± 6.7 kg, height 175.2 ± 3.4 cm) served as controls (CG). The EG followed a 10-week soccer-specific training program combining strength and technique exercises. All participants performed an instep soccer kick using a two-step approach while three-dimensional data and EMG from six muscles of swinging and support legs were recorded prior to and after training. Maximum isometric leg press strength, 10-m sprint performance and maximum speed performance on a bicycle ergometer were also measured. Analysis of variance designs with repeated measures showed that the EG improved significantly ($P < 0.05$) maximum ball speed, the linear velocity of the foot, ankle and angular velocity of all joints during the final phase of the kick. Training had insignificant effects on EMG values, apart from an increase in the averaged EMG of the vastus medialis whereas maximum isometric strength and sprint times significantly improved after training ($P < 0.05$). The present results suggest that the application of the training programs using soccer-specific strength exercises would be particularly effective in improving of soccer kick performance.

Modern soccer requires a high level of physical conditioning throughout a competitive season. Therefore, one of the most important aims of training programs in the preparation (pre-season) period is to improve soccer-specific strength. Soccer-specific strength is a concept which is extensively used in training practice and can be defined as the ability of a soccer player to use muscle strength and power effectively and consistently within a game and a whole season (Bangsbo, 1994).

During a soccer game, each player performs several dynamic movements (headers, cutting, tackling, sprints, kicks) which require a very good level of muscle strength, power and endurance (Cabri et al., 1988; Bangsbo, 1994). Strength in its various forms (maximum and explosive strength, rate of force development) plays a critical role on performance of such skills (Cabri et al., 1988). Soccer practice suggests that a soccer player needs to develop a level of maximum strength and power, which is utilized effectively within the game (Buhrle, 1985).

The instep kick constitutes a basic element of a soccer game. It is multijoint activity which depends on various factors, such as the maximum strength and power of the muscles activated during the kick (De Proft et al., 1988a, b; Isokawa & Lees, 1988; Weineck, 1992; Lees & Nolan, 1998; Dorge et al., 1999), the timing and appropriate transfer of energy between segments that participate in the kick (Plagenhoef, 1971), the speed and angle of approach of the player to the ball (Isokawa & Lees, 1988; Opavsky, 1988) and the utilization of the stretch–shortening cycle characteristics by the muscles of the kicking leg (Weineck, 1992).

Many research studies on soccer kick emphasized the importance of maximum power of the lower limb muscles and the coordination between the agonist muscles (vastus lateralis and medialis, rectus femoris, tibialis anterior and m. iliopsoas) and the antagonists (gluteus maximus, biceps femoris and semitendinosus) during the kick (De Proft et al., 1988a, b; Isokawa & Lees, 1988; Lees & Nolan, 1998; Dorge et al., 1999). However, there have been very limited studies that examined the effects of soccer training programs on the above characteristics. Although knowledge of neuromuscular activity during a kick is important, the examination of how these characteristics are altered through training is practically more useful.

While soccer coaches apply various training programs to improve performance in the pre-season period, a few of those have been published in the literature. Some studies (De Proft et al., 1988a, b; Dutta & Subramanium, 2002) reported an increased soccer kick performance following the application of isokinetic strength training programs whereas others found the opposite (Aagaard et al., 1993; Trolle et al., 1993). It has been suggested that neural coordination should apparently be trained extensively in order to improve the kicking performance of elite soccer players (Aagaard et al., 1993).

Taina et al. (1993) reported that a training program consisting of soccer drills and movements significantly increase the speed of the ball of the instep kick. The application of soccer-specific strength training has been recommended. A limitation of this study was the absence of a control group (CG), whereas the training frequency was very low, one training session per week. Furthermore, the majority of previous studies measured maximal ball speed during a soccer kick to evaluate the efficiency of a training program. To our knowledge, there are no studies on muscle activity and joint kinematics following an application of a soccer-field training program. Such information could be used in the design of more effective soccer training programs. Therefore, the purpose of this study was to examine the changes in kinematic, electromyographic (EMG) and ground reaction force characteristics of the instep soccer kick following training program which aimed in improving strength and technique using soccer-specific exercises and drills.

Methods

Subjects

Twenty amateur soccer players volunteered to participate in this study after signing informed consent forms, approved by the University ethical committee. Ten subjects (aged 19.9 ± 0.4 years, body mass 74.8 ± 9.1 kg, height 177.4 ± 6.7 cm) constituted the experimental group (EG) while the remaining 10 (age 21.6 ± 1.3 years, weight 71.5 ± 6.7 kg, height 175.2 ± 3.4 cm) were the CG.

Experimental design

A randomized group design has been used. Testing measurements included the performance of maximal instep kicks, maximum leg press strength test, maximum cycling speed test and a 10-m sprint test. The EG then followed a 10-week training program with a training frequency of three times a week. The testing measurements were repeated after the end of the training period.

Training programme

The EG followed a 10-week training program with a frequency of 3 times a week. The first two weeks aimed to improve general strength and included 10 exercises of various muscle groups (push-ups, stretching of arms, abdominal and back muscle exercises, hip abduction, hip adduction, knee extension and flexion, and ankle plantarflexion–dorsiflexion exercises) against resistance provided either using portable equipment (rubber bands, ropes, barbells) or performed in pairs (Cometti, 1988; Weineck, 1992). Three sets × 15–20 repetitions for each exercise were performed. All training sessions were performed on soccer field.

In the following 2 weeks, the subjects performed six repetitions of three sets of soccer-specific exercises. Each set included five different exercises such as skipping over cones, jumping on one leg, jumping on both legs, jumping running forwards, backwards and to the side, jumping above obstacles and kicking the ball towards the goal post (Cometti, 1988).

The training program for weeks 5–10 aimed to improve the soccer-specific strength of the lower limbs and included (a) three sets × six instep kicks against the goal post taken within a time of 5 s (b) six simulated kicking actions with a 5 m run-up approach against resistance provided by a rubber band attached on the ankle of the swinging leg (c) 5- or 8-a side soccer games, with or without loads (wet ground, 5 kg dumb bells on each arms, carrying a player on they back) which lasted for 10 min and were repeated three times. (Cometti, 1988; Togari et al., 1988; Bangsbo, 1994) and (d) a series of modified exercise sequences, where external resistance was provided either by using a rubber band or another soccer player (Cometti, 1988). Particularly, there were three exercise sequences applied. The first included six simulated kicking movements against resistance of a rubber band, jumping above three obstacles, isometric exercise of the trunk with another player on the back in a semi-seated position for 6 s, four sideward jumps on a bench. The second sequence consisted of six leg extensions against the resistance of a rubber band, three simulated headers, isometric exercises of the ankle musculature, carrying another player on their backs for 6 s, kicking a ball at the goal post. The third sequence included six knee flexion repetitions against a resistance of a rubber band, four sideward jumps into a hop, three 5-m sprints and a soccer kick towards the goal post.

Testing measurements

Instep soccer kick

The participants of both teams executed an instep kick with a run up of two strides at a goal post using their preferred leg. Self-adhesive reflective markers were placed on both sides of the body on the fifth metatarsal, the ankle, knee, greater trochanter, shoulders, vertex of the head, 7th cervical vertebra, elbows, wrists. A standard 14-segment anthropometric model (Dempster, 1955) was used to model the body segments and to estimate the center of mass (CM).

A limitation of the present approach is that the calculation of the body CM could be affected by changes in muscle volume following training. We have used a standardized anthropometric model to calculate the center of body mass (CM) by changing the input parameters before and after training. Although any changes in body mass may have been reflected on the calculation of segmental masses and subsequently on the whole body CM, clearly this does not account for muscle volume changes because of training. The exact effect of training on muscle volume and CM requires composition analysis of each segment which could then be used for the determination of each individual segment's CM, and subsequently the whole body CM.

The three-dimensional (3-D) kinematics of the instep kick were measured using an Ariel Performance Analysis system (Ariel Dynamics Inc., San Diego, California, USA). Two Panasonic PV-900 (60 Hz; Panasonic, Osaka, Japan) video cameras were placed at angle of 90°. A calibration frame (1.80 × 1.80 × 1.80 m) was used to calibrate the measurement area.

The 3-D marker position data were estimated using direct linear transformation. The resulting displacement-time data of each marker were filtered using a second-degree Butterworth digital filter with zero-order phase lag (Winter, 1990). The cut-off frequencies were selected based on residual analysis and ranged from 6 to 12 Hz. To avoid any joint data distortion because of impact, a special procedure was followed. Particularly, ball impact point was specified within each data set. The curves were then smoothed in order to obtain a more close fit of the raw data curves over a specified small interval (around impact) of the sequence. Adjustment of the curves was achieved by permitting higher frequency variations in raw values. This resulted in smoothed curves that more closely fit the abrupt change in the raw data curves because of ball impact. From the smoothed angular displacement data, the hip, knee and the ankle angular position data were further analyzed. These data were used to calculate joint angular velocities using numerical differentiation (Winter, 1990).

The EMG activity was recorded using an EMG interface module of the ARIEL system (Ariel Dynamics Inc.), sampling at 1000 Hz, a common mode rejection ratio greater than 100 db at 50/60 Hz, a measurement bandwidth ranging from 8 to 500 Hz and a gain of 400. Bipolar surface EMG electrodes (inter-electrode distance = 1 cm) with a pre-amplifier were placed on the rectus femoris, the vastus medialis, and long head of biceps femoris of the swinging leg and the rectus femoris, biceps femoris and medial head of the gastrocnemius of the support leg. These muscles were selected because they demonstrate high activity during a soccer kick (De Proft et al., 1988a, b; Dorge et al., 1999).

An electronic switch system was used to identify the start of the movement and ball impact using both video and EMG data. Particularly, the start of the movement triggered a LED visible on both cameras. Similarly, an electronic switch placed underneath the ball, triggered another LED indicating ball contact time. Signals of both switches were fed as separate channels and sampled with the EMG data at 1000 Hz. The ball signal and the LED signal initiated at the start of the movement were then used to identify the actual ball contact time. The video and EMG signals were then matched using cubic splines.

Maximum cycling speed and sprint tests

The bicycle ergometer MONARK (Vansbro, Sweden) ergomedic type (814 E, classe Á, din 32932) was used for the measurement of the maximum velocity on the ergo bike (TEmax) without any extra load. Particularly, following a standardized warm up with submaximal cycling, subjects were asked to cycle as fast and as hard they can until the recorded cycling speed could no longer increase.

Maximum 10-m sprint times were measured by two infrared photo-electric cells situated 10 meter apart and interfaced to a timing system (Saint Wien Digital Timer Press H5 K), with a time resolution of 0.01 s and a measurement error of ± 0.01 s.

Maximum isometric leg press strength

A leg press machine was used to perform the leg press measurements. Force signals were detected by a force transducer (sampling rate: 1000 Hz) and then amplified by a charge amplifier (Analog Devices Module, SB40). The dynamometer was calibrated using known weights prior to each testing session.

Maximal isometric force and force-time parameters of the bilateral leg extensor muscles (hip, knee, and ankle extensors) were measured in a sitting position, with the knee and hip angles 110° and 90°, respectively (180° = full extension). During maximum isometric effort a non-movable-back chair was supporting the trunk, while the subjects had their hands on the dynamometer grips. A Velcro belt was placed around the waist to stabilize the trunk. During testing, there was standardized verbal encouragement and visual feedback of the force–time curve.

Each subject performed three maximum voluntary contractions separated by a 3-min interval. The subjects were instructed to exert maximum effort as fast and hard as possible. The trial where the highest maximal force was exerted was further analyzed.

From the registered force–time curve, maximal isometric force (MVC) and two explosive force measures were determined during the maximum isometric effort. Particularly, MVC was defined as the highest value of force during each effort. Explosive force (F_{60}) was defined as the amount of force exerted during the first 60 ms of the contraction. Furthermore, the force developed during the first 100 ms of the contraction (F_{100}) was also estimated. MVC was also divided by subject body mass to yield relative strength.

Data analysis

Soccer kick

Kicking movement was divided into three phases (Luhtanen, 1988). Particularly, the first phase was defined from the start of the movement up to the contact of the support leg on the ground. The second phase started with the ground contact of the support leg up to the smallest knee angle of the pushing leg. The third phase started from the smallest knee angle of the swinging leg until ball impact.

Kinematic characteristics

From the recorded data the variables examined were the linear displacement and velocity of the CM, the linear displacement and velocity of the thigh, tibia and foot of both legs, the angular displacement and velocity of the hip, knee and ankle of both legs and the linear velocity of the ball.

EMG characteristics

The EMG data were collected during the three phases of the soccer kick. All EMG measurements were normalized by dividing the recorded data by the maximum EMG of each muscle during each kick. Furthermore, the normalized EMG data of each muscle were averaged across each phase of the soccer kick. Consequently, three EMG values (phases 1–3) for each muscle were used for further analysis.

Statistical analysis

Two-way analysis of variance (ANOVA) with repeated measures designs were used to examine the differences in each parameter, between the two groups, before and after the training period. Following significant interactions, simple effects have been applied to check the differences between pairs of means of one variable at the same level of the other variable. If significant, post-hoc Tukey tests were applied to examine significant differences between pairs of means. The level of significance was $P < 0.05$.

Results

Kinematic characteristics

CM

The ANOVA results indicated significant interaction (Time × EG) effects on the horizontal linear displa-

Table 1. Mean (± standard deviation), CM, LD (cm) and velocity (m/s) of the experimental and control groups before and after training

Variables	Experimental group		Control group	
	Before	After	Before	After
1st phase				
Horizontal LD of CM	32.70 ± 10.1	52.71 ± 10.7*	33.3 ± 20.10	39.40 ± 18.11
Vertical LD of CM	95.70 ± 4.90	95.11 ± 4.41	98.12 ± 6.71	96.42 ± 5.21
Horizontal LV of CM	3.12 ± 0.30	4.04 ± 0.23*	3.32 ± 1.20	3.39 ± 1.2
Vertical LV of CM	– 0.67 ± 0.50	– 0.68 ± 0.21	– 0.45 ± 0.21	– 0.47 ± 0.31
2nd phase				
Horizontal LD of CM	48.20 ± 11.1	69.01 ± 14.31*	50.31 ± 24.0	59.51 ± 15.01
Vertical LD of CM	92.80 ± 4.40	92.31 ± 5.11	94.90 ± 6.61	93.11 ± 5.21
Horizontal LV of CM	3.74 ± 1.00	3.42 ± 0.60	3.33 ± 0.50	3.44 ± 0.50
Vertical LV of CM	– 0.47 ± 0.5	– 0.13 ± 0.31	– 0.04 ± 0.51	– 0.08 ± 0.51
3rd phase				
Horizontal LD of CM	63.50 ± 17.0	90.6 ± 8.60*	66.71 ± 26.0	75.63 ± 19.17
Vertical LD of CM	94.50 ± 4.80	94.0 ± 5.60	97.92 ± 8.01	95.90 ± 6.41
Horizontal LV of CM	3.06 ± 1.18	2.93 ± 0.63	2.39 ± 1.01	2.67 ± 0.79
Vertical LV of CM	0.74 ± 0.50	1.08 ± 0.72	0.81 ± 0.51	0.84 ± 0.51

*significantly different compared with the pre-training value at $P<0.05$.
LD, linear displacement; LV, linear velocity; CM, center of mass.

cement of the CM for all phases of the movement (Table 1, $P<0.05$). Particularly, the post-training values for the EG significantly increased compared with pre-training values ($P<0.05$). The results also showed a significant increase of horizontal CM velocity following training (Table 1, $P<0.05$). In contrast, training effects on vertical displacement and velocity of the CM were insignificant (Table 1, $P>0.05$).

Ball speed

There was a significant interaction effect on ball speed (Fig. 1, $P<0.05$). Post-hoc Tukey tests indicated that the EG significantly increased ball speed followed the training program.

Linear segmental kinematics

The linear velocity of the foot during the 1st, 2nd and the 3rd phase of the kick (Fig. 2) for the EG was significantly lower compared with pre-training value ($P<0.05$). Similarly, the linear velocity of the ankle during the 1st and 3rd phase significantly decreased after training for the EG (Fig. 2, $P>0.05$). The opposite was observed for the 2nd phase value. No other significant effects on linear velocity values of the hip and knee were observed (Fig. 3, $P>0.05$).

Angular kinematics

The training group demonstrated a lower ankle angular velocity after training ($P<0.05$). Similarly, the knee angular velocity during the 1st phase of the kick significantly decreased following training (Table 2, $P<0.05$). No other significant differences in the angular velocity values were found ($P>0.05$).

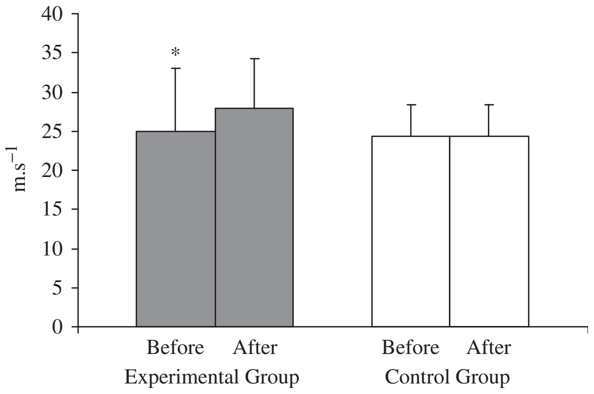

Fig. 1. Maximal (mean ± SD) ball speed during the instep soccer kick in the experimental (EG) and control (CG) groups before and after the training period (*significantly different compared with pre-training value).

EMG

The group EMG values for each group and experimental session are presented in Table 3. There was a significant interaction effect ($P<0.05$) on mean EMG value of vastus medialis of the swinging leg during phase 3. Post-hoc Tukey comparisons indicated that the EG vastus medialis EMG significantly increased following training. No other significant effects were found.

Maximum strength, cycling speed and sprint times

The results of this study indicated that the training group significantly increased its maximum isometric strength, relative force, explosive strength and rate of force development (Table 4, $P<0.05$).

In contrast, there was a non-significant interaction effect on maximum cycling speed (Fig. 4) whereas

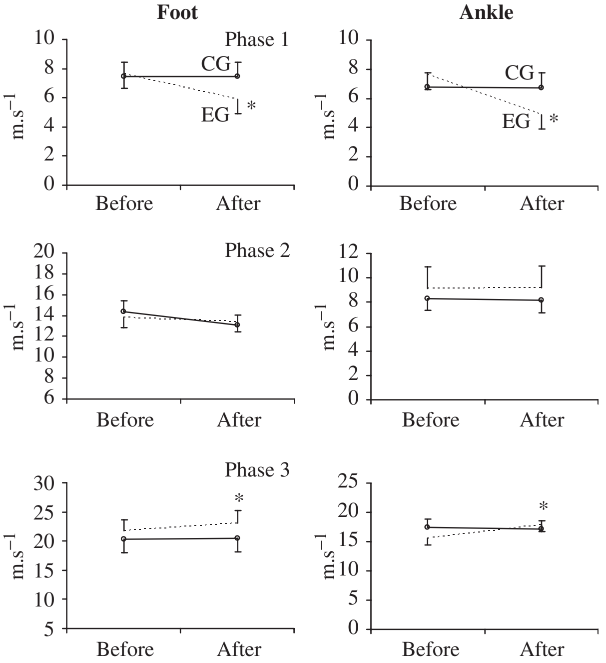

Fig. 2. Segmental linear velocity (m/s) of the swinging foot and ankle of the experimental (dotted line) and control groups (straight line) before and after training (*experimental group post-training value significantly different compared with the pre-training value at $P<0.05$; error bars indicate standard deviation; EG, experimental group; CG, control group).

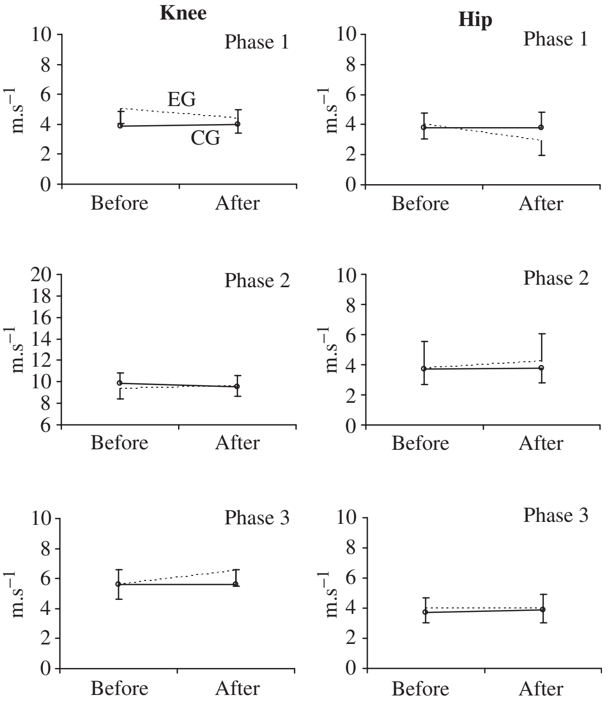

Fig. 3. Segmental linear velocity (m/s) of the swinging hip and knee of the experimental group (dotted line) and control group (straight line) before and after training (error bars indicate standard deviation. EG, experimental group; CG, control group).

maximum 10-m sprint times were significantly affected ($P>0.05$). Post-hoc Tukey multiple comparisons indicated that the sprint time significantly declined following training in the EG but not for CG ($P<0.05$).

Discussion

The main finding of this study is that a combined strength and kicking coordination training program applied resulted in a significant increase in ball speed and some kinematic parameters of the soccer kick whereas performance in maximum strength, cycling speed and 10-m sprint test also improved.

Soccer kick kinematics

The displacement and velocity of the CM during the kick is indicative of the stability of the player's position during the kick. Following training, the position and velocity of the CM in the horizontal direction increased (Table 1). This indicates that position of the body was such that the CM was much forward throughout the shot. In contrast, the vertical position of the CM remained unchanged which indicates that the EG moved faster to the ball after training. These changes appeared to be greater in the EG after the special soccer training and they possible display an adaptation in the kicking movement.

One of the most important indicators of a successful soccer kick is the speed of the ball. In the present study, training caused a significant increase in ball speed (Fig. 1). This clearly indicates that combined strength and kicking coordination training improves soccer kick performance. This is in agreement with some studies which applied resistance training (De Proft et al., 1988a, b) or soccer-specific strength training programs (Taina et al., 1993) and found increased ball speed during the kick. However, differences in type of program applied make comparisons between different studies difficult.

Ball speed is the result of a several segmental actions of the body during the kick. As such, the training program applied in the present study must have caused alterations in some kinematic parameters, which may have cumulatively or individually contributed to a higher ball speed value after training. Indeed, our results showed that the EG had an increased linear velocity of the ankle and foot in the final phase of the kick (Fig. 2) which may contributed to the higher ball speed observed in the EG after training. However, the linear velocity of the knee and hip as well as other segments was unaffected (Fig. 3).

One of the main mechanisms, which enhance soccer kick performance, is the action of the thigh

Table 2. Mean (± standard deviation) angular velocities of the swinging leg (rad/s), of the experimental and control groups before and after training

Variables	Experimental group		Control group	
	Before	After	Before	After
1st phase				
Ankle	−10.31 ± 7.8	−3.21 ± 9.7*	−9.02 ± 4.2	−8.98 ± 4.2
Knee	−11.68 ± 3.3	−5.06 ± 6.9*	−10.16 ± 2.3	−10.03 ± 2.3
Hip	4.23 ± 5.4	−0.46 ± 7.1	2.75 ± 6.0	2.90 ± 6.0
2nd phase				
Ankle	−8.85 ± 7.2	−3.21 ± 1.9*	−12.84 ± 6.2	−7.07 ± 5.7
Knee	−2.54 ± 1.4	−1.01 ± 2.1	−1.55 ± 1.7	−1.64 ± 1.5
Hip	−5.99 ± 5.4	−2.4 ± 3.7	−3.72 ± 9.4	−3.64 ± 6.3
3rd phase				
Ankle	15.26 ± 3.3	16.8 ± 1.3*	14.4 ± 3.2	13.8 ± 2.4
Knee	26.5 ± 4.3	32.7 ± 2.7*	24.5 ± 9.8	24.5 ± 9.6
Hip	6.3 ± 3.5	8.1 ± 3.2*	5.5 ± 3.5	5.9 ± 3.6

*Significantly different compared with the pre-training value at $P<0.05$.

Table 3. Mean (± standard deviation) normalized EMG values of the experimental and control groups before and after training

Variables	Experimental group		Control group	
	Before	After	Before	After
Support leg – phase 1 (%)				
Rectus femoris	45.4 ± 18.4	47.9 ± 14.3	43.1 ± 21.3	47.4 ± 23.5
Gastrocnemius	62.1 ± 16.2	62.1 ± 14.1	61.5 ± 20.2	63.2 ± 21.9
Biceps femoris	59.7 ± 22.3	64.8 ± 18.3	59.7 ± 20.0	60.4 ± 13.9
Support leg – phase 2 (%)				
Rectus femoris	67.3 ± 11	66.5 ± 10.1	55.9 ± 10.4	64.3 ± 16.8
Gastrocnemius	42.1 ± 17	53.2 ± 17	62.1 ± 15.3	64.1 ± 20.9
Biceps femoris	55.2 ± 11	71.4 ± 18.5	68.5 ± 23.1	62.8 ± 24.1
Support leg – phase 3 (%)				
Rectus femoris	62.4 ± 12.4	63.4 ± 12.8	58.8 ± 11.2	63.1 ± 16.0
Gastrocnemius	45.2 ± 15.2	56.2 ± 13.0	63.3 ± 15.1	64.1 ± 20.5
Biceps femoris	64.9 ± 10,3	71.1 ± 15.8	69.5 ± 24.0	63.3 ± 24.7
Swinging leg – phase 1 (%)				
Rectus femoris	47.8 ± 17.4	51.0 ± 16.8	54.6 ± 14.5	45.8 ± 23.1
Biceps femoris	38.9 ± 23.9	50,0 ± 17.7	36,7 ± 13.8	43.9 ± 23.6
Vastus medialis	33.1 ± 13.7	40.8 ± 14.4	36.9 ± 11.3	34.9 ± 16.6
Swinging leg – phase 2 (%)				
Rectus femoris	85.5 ± 20.5	78.6 ± 10.8	73.1 ± 20.4	67.5 ± 44.4
Biceps femoris	40.1 ± 20.3	39.8 ± 14.3	40.3 ± 24.0	36.1 ± 25.1
Vastus medialis	66.9 ± 16.5	70.4 ± 18.2	75.0 ± 19.5	75.3 ± 26.8
Swinging leg – phase 3 (%)				
Rectus femoris	59.1 ± 27.5	63.8 ± 11.2	46.1 ± 13.2	55.3 ± 17.1
Biceps femoris	54.1 ± 27.2	53.6 ± 24.5	52.6 ± 16.1	48.7 ± 16.4
Vastus medialis	54.4 ± 14.0	70.8 ± 15.6*	62.8 ± 15.2	50.8 ± 16.0

*Significantly different compared with the pre-training value at $P<0.05$.

EMG, electromyography.

Table 4. Mean (± standard deviation) values of the experimental and control groups before and after training during maximum bilateral strength test

Variable	Experimental group		Control group	
	Before	After	Before	After
MVC (N)	2039.2 ± 431.4	2323.1 ± 568.8*	1854.4 ± 225.3	1952 ± 319.7
MVC/BW	2.79 ± 0.5	3.18 ± 0.5*	2.67 ± 0.5	2.81 ± 0.5
F_{100} (N)	1181 ± 173	1384 ± 273*	1158 ± 132	1189 ± 138
F_{60} (N)	677.8 ± 140.2	875 ± 176.5*	574.8 ± 109.8	548.3 ± 203

*Significantly different compared with the pre-training value at $P<0.05$.

MVC, maximum isometric force; MVC/BW, maximum force divided by body weight; F_{100}, maximum force value during the first 100 ms of the contraction; F_{60}, Maximum force value during the first 60 ms of the contraction.

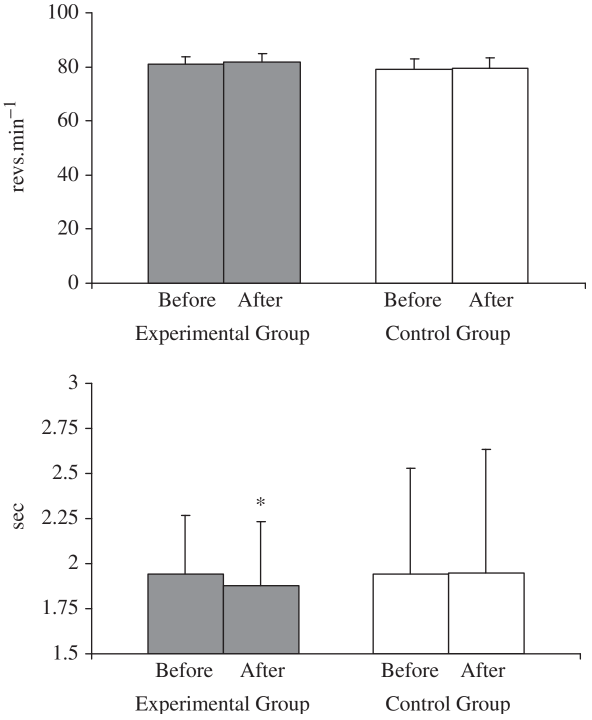

Fig. 4. Maximal (mean ± SD) cycling speed (upper graph) and 10-m sprint times (lower graph) in the experimental (EG) and control (CG) groups before and after the training period (*significantly different compared with pre-training value).

which slows down or reverses its motion prior to full knee extension is reached (Lees & Nolan, 1998). It has been suggested that deceleration of the thigh is mainly determined by movement of the shank whereas shank acceleration is caused by a moment exerted around the knee as well as a motion dependent moment arising from the thigh angular velocity (Sorensen et al., 1996; Dorge et al., 2002). The decline of linear velocity values during phase 1 of the kick after training (Fig. 2) and the increase of only distal segment (foot) and ankle velocity (Fig. 2) and all angular velocities (Table 2) during phase 3 indicate that shank acceleration was much higher and faster in the EG after training. In practical terms, this is indicative of a more ‘‘powerful’’ shot following training.

Performance of a soccer kick utilizes the stretch–shortening cycle characteristics of the involved muscles, especially the knee extensors (Bober et al., 1987). Particularly, it has been noted that in mature kicking action the thigh is brought forward while the knee is still flexing. This action serves to stretch the extensor muscles of the thigh before they are required to shorten so that they are able to aid in the generation of large end-point speed (Bober et al., 1987). The reduction of the ankle and foot velocities during the middle phase of the kick (Table 2) and the subsequent increase of their velocity at the terminal kicking phase after training may be the result of an altered stretched–shortening cycle of the involved musculature. Furthermore, the significant increase of knee angular velocity during phase 3 of the kick in the EG also demonstrates the effectiveness of the training program applied, as this variable is considered as a good indicator of a successful shot (Lees & Nolan, 1998).

EMG

The present results indicated that the training program did not significantly affect the activation patterns of the muscles examined (Table 3). The only exception was the EMG activity of vastus medialis muscles during phase 3 of the kick which increased significantly in the EG following training (Table 3). In this phase, the knee extends because of the rapid movement of the tibia towards the ball. Since vastus medialis is particularly active during the terminal phases of knee extension (Sheehy et al., 1998), its higher activation in the EG may therefore indicate a higher force produced in this phase. However, the vastus medialis is only a component of the knee extensor muscle group whose contribution to knee extension muscle torque is unclear. Therefore, the practical significance of this increase is not clear. Furthermore, the insignificant changes in the recorded EMGs of the rest muscles examined clearly indicate that the magnitude of the motor unit activation of the examined muscles did not significantly change because of training. This suggests that the changes in kicking kinematics and ball speed mentioned above are not because of a general alteration of muscle activity of the muscles examined.

A limitation of the present study is that EMG data have been normalized relative to the maximal EMG value during the kick. Because of the nature of the EMG methodology and signal, it is likely that training effects on EMG data may affect the magnitude of both the reference value and the value during the kick. Although such approach has been used in the past to express EMG data (Kellis, 1998; Viitasalo et al., 1998), it is clear that presence or absence of differences in EMG magnitude after training may be because of normalization process itself. Normalisation relative to EMG value during maximum voluntary isometric effort could overcome such limitations, although clearly it is likely that training would also affect strength capacity and EMG activity during MVC as well.

Maximum strength and speed test performance

The training group improved significantly the performance during the maximal strength and sprint tests (Table 4; Fig. 2). This further emphasizes the importance of soccer-in-field training exercises in improving muscle strength and speed variables. Although soccer kick performance is not linearly related to performance in each of the laboratory tests applied, the general improvement of soccer players in the above strength and sprint tests could have been an important factor in the alterations in soccer kick kinematics after training. Similar changes have been observed by other studies using applied soccer training programs (Taina et al., 1993). Further, De Proft et al. (1988a, b) and Dutta and Subramanium (2002) showed that the application isokinetic strength training programs increases soccer kick performance. In contrast, other studies using resistance training have reported the opposite (Aagaard et al., 1993; Trolle et al., 1993). The main difference between the previous studies with the present program was that we used soccer-specific strength exercises as compared with isolated isokinetic or isokinetic strength training programs applied by previous investigators (De Proft et al., 1988a, b; Aagaard et al., 1993; Trolle et al., 1993). This lack of transfer from gain in muscle force and power into enhanced functional performance was attributed to the fact that a successful soccer kick depends on a precisely coordinated action of the leg muscles rather than on isolated muscle strength (Aagaard et al., 1993). The results of the present study confirm these results and suggest that the use of combined strength and technique training improves neural coordination and kicking performance of soccer players (Aagaard et al., 1993).

To summarize, taking into consideration all kinematic, EMG and physical conditioning tests, several factors can be identified which may have contributed to the increase in ball speed of the soccer kick in the EG. First, it appears that the subjects performed the final phases of the movement much quicker with a significant increase in velocity of the foot and ankle. The observation that muscle EMGs did not generally increase in the EG in combination with the increase of absolute strength and speed values, indicates that changes in kinematics and ball speed of soccer kick were not the result of higher activation of the main muscles involved, but partly because of an increased amount of muscle force produced per motor unit. Other factors which may also have contributed to the increased ball speed of the soccer kick, may be a better and quicker movement and transfer of energy between segments (Tsaousidis & Zatsiorsky, 1996).

Perspectives

Although the game of soccer is a very popular game, there has been very little information regarding the structure and efficiency of soccer strength training programs. The present study presented a training program in detail that can be applied as part of the pre-season training of soccer players. It appears that the present program improved significantly various parameters of physical conditioning (speed, strength) and most importantly these improvements have been transferred to soccer kick performance in terms of ball speed as well as technique. These results extend previous suggestions that the more specific the training program to the sport action, the more efficient. Therefore, the application of soccer-specific strength and skill training programs as part of pre-season training of soccer players is recommended.

Key words: Soccer kick, training program, biomechanics, electromyography, technique.

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