Research article

Effects of combined foot/ankle electromyostimulation and resistance training on the in-shoe plantar pressure patterns during sprint in young athletes

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Abstract

Several studies have already reported that specific foot/ankle muscle reinforcement strategies induced strength and joint position sense performance enhancement. Nevertheless the effects of such protocols on sprint performance and plantar loading distribution have not been addressed yet. The objective of the study is to investigate the influence of a 5-wk foot/ankle strength training program on plantar loading characteristics during sprinting in adolescent males. Sixteen adolescent male athletes of a national training academy were randomly assigned to either a combined foot/ankle electromyostimulation and resistance training (FAST) or a control (C) group. FAST consisted of foot medial arch and extrinsic ankle muscles reinforcement exercises, whereas C maintained their usual training routine. Before and after training, in-shoe loading patterns were measured during 30-m running sprints using pressure sensitive insoles (right foot) and divided into nine regions for analysis. Although sprint times remained unchanged in both groups from pre- to post- training (3.90 ± 0.32 vs. 3.98 ± 0.46 s in FAST and 3.83 ± 0.42 vs. 3.81 ± 0.44 s in C), changes in force and pressure appeared from heel to forefoot between FAST and C. In FAST, mean pressure and force increased in the lateral heel area from pre- to post- training (67.1 ± 44.1 vs. 82.9 ± 28.6 kPa [$p = 0.06$]; 25.5 ± 17.8 vs. 34.1 ± 14.3 N [$p = 0.05$]) and did not change in the medial forefoot (151.0 ± 23.2 vs. 146.1 ± 30.0 kPa; 142.1 ± 29.4 vs. 136.0 ± 33.8; NS). Mean area increased in FAST under the lateral heel from pre- to post- (4.5 ± 1.3 vs. 5.7 ± 1.6 cm^2 [$p < 0.05$]) and remained unchanged in C (5.5 ± 2.8 vs. 5.0 ± 3.0 cm^2). FAST program induced significant promising lateral and unwanted posterior transfer of the plantar loads without affecting significantly sprinting performance.

Key words: Track and field, medial arch, reinforcement, injury prevention.

Introduction

During the ground contact phase of sprint running, a proximal-to-distal timing in the generation of peak extensor power occurs from the hip to the ankle (Johnson and Buckley, 2001). In addition to the hip and knee extensors' contribution, the foot/ankle complex plays an important part in leg stiffness regulation (Kuitunen et al., 2002; Weyand et al., 2010). Therefore, to enable efficient propulsion, the foot/ankle muscles must: 1/ be strong enough to stabilize the foot during the stance phase and therefore adjust the underlying surface (Cote et al., 2005); and 2/ allow and facilitate an efficient recoil-reuse of the elastic energy by the elastic materials (Achilles tendon, plantar fascia) (Alexander, 1992).

During the stance phase in sprinting, foot plantar pressure distribution is firstly characterized by the highest peaks under the medial and central forefoot, hallux and toes. This was shown in our recent comparison in plantar patterns between training shoes and racing spikes in young sprinters where we found a globally higher load under forefoot and toes with significantly more marked maximum force and mean pressure when wearing spikes (Fourchet et al., 2007). Eils et al. (2004) reported similar results regarding 1st and 2nd ray relative loads in subjects performing sprint when wearing soccer shoes and regardless of the surface. The findings of Queen et al. (2007) also confirmed these results with a significant higher force time integral under the medial forefoot area during the acceleration phase of sprinting when compared with other tasks such as side cuts or crossover cuts. Nevertheless, it is also known that during sprinting, the loads under the midfoot are higher than during low speed running or walking (Hennig and Milani, 1995). At the same time, forces must be much faster attenuated: in roughly one-third the time as compared to walking (Novachek, 1998). This suggests a considerable collapsing of the longitudinal arch of the foot due to the high forces acting on the foot (Alexander, 1992). A strong active support (in addition to the action of the passive structures) is needed in order to control this flattening. The muscles involved in this process are not only the extrinsic foot/ankle muscles (*e.g.* Gastrocnemius and soleus, posterior tibialis (Kitaoka et al., 1997), flexor hallucis longus, peroneus longus and brevis), but also the intrinsic foot muscles at the medial longitudinal arch (MLA) level (*e.g.* abductor hallucis and flexor digitorum brevis) (Ferris et al., 1995; Fiolkowski et al., 2003; Johnson and Buckley, 2001; Mann, 1981; Sherman, 1999). Thus weakness or fatigue of the aforementioned muscles may lead to a higher risk of injury due to overload under certain foot regions: heads of first, second and third metatarsal bones in relation with triceps surae failure (Weist et al., 2004) or MLA in relation with MLA muscles or posterior tibialis deficiency (Fiolkowski et al., 2003; Kitaoka et al., 1997). This relative overload mechanism might lead to stress reaction injuries (e.g. plantar fasciitis, first and second metatarsal stress fractures, metatarsalgia, posterior tibialis tendonitis, or shin splints) (Cornwall and McPoil, 1999; Cote et al., 2005; Robbins and Hanna, 1987). Foot and ankle problems have been reported as the second most common musculoskeletal problem in prebubertal and circumpubertal athletes next to acute injury (Stanish, 1995).

Other studies have already reported that specific foot/ankle muscle strengthening induced performance enhancement in terms of strength (Feltner et al., 1994)

and joint position sense (Docherty et al., 1998). Recent results also showed that neuromuscular electromyostimulation reinforcement (NMES) of MLA muscles may decrease the navicular drop (Fourchet et al., 2009) and induced a lateral displacement of anterior maximal pressure point of the stimulated foot (e.g. inversion) in standing position (Gaillet et al., 2004). To our knowledge, only these two former studies used NMES of the intrinsic foot muscles despite that NMES is now widely used for strength training or rehabilitation of lower limbs muscles in athletes (Maffiuletti, 2010; Paillard, 2008).

It was demonstrated that an NMES long-term program was not systematically needed in order to obtain substantial effect on muscle fibres and that a limited dose of NMES may be sufficient for inducing significant changes on muscles strength, i.e. a short-term NMES program (3 sessions per week during 3 weeks) on knee extensors significantly enhanced isokinetic strength (Brocherie et al., 2005) and 12 sessions of approximately 12 min of NMES on ankle plantar flexors and knee extensors enhanced the jumping performance (Malatesta et al., 2003). In addition, Gaillet et al. (2004) reported that a single 20 min NMES session of the abductor hallucis muscle in the foot induced immediate specific changes in baropodogram indices, some of which persisted 2 months later. Finally, it was important to assess the efficiency of a protocol usable in the "real world" with young athletes. Therefore the aim of this study was to evaluate the effects of a brief foot/ankle strength training (FAST) program combining NMES of the MLA short intrinsic muscles and resistance strength training of the foot/ankle extrinsic muscles on sprint performance and on related plantar loading characteristics in teenage athletes.

Methods

Design
The study was carried out in a national training centre in Middle-East and consisted of a randomized clinical trial involving young track and field athletes.

Participants
A total of sixteen adolescent male athletes from a national sports institute were tested. All the subjects volunteered to participate in the study and signed an informed consent form. The study, which was approved by the local research ethics committee, conformed to the recommendations of the Declaration of Helsinki. During the 5 weeks experimental period, the athletes were instructed to continue their regular athletics training as they had done for the 6 months prior to commencement of the study. Briefly, every subject had been training in the Track and Field academy program on a regular basis, defined as averaging at least 9 sessions per week. No subject withdrew because of injury or adverse experiences. Participants were randomly assigned to either the treatment (FAST; age: 14.9 ± 1.9 yr, stature: 1.64 ± 0.09 m, body weight: 50.1 ± 10.5 kg) or a control (C; age: 15.5 ± 1.4 yr, stature: 1.65 ± 0.07 m, body weight: 53.4 ± 12.1 kg) group with eight subjects in each group (Figure 1). FAST consisted of foot medial arch and extrinsic ankle muscles reinforcement exercises, whereas C maintained their usual

training routine (Figure 1).

Experimental protocol
Plantar pressure parameters were measured during 60 m full sprint in C and FAST groups, one week before (Pre) and immediately after (Post) the five week foot/ankle reinforcement program (within the 2 days following the end of the FAST program).

Training
In addition to their regular athletics training, experimental subjects were assigned a regimen of strength training; i.e. combined NEMS and resistance training for 5 weeks which consisted of foot medial arch and extrinsic ankle muscles reinforcement exercises (Figure 1).

NEMS: NEMS was performed at the beginning of certain athletics training sessions with each subject adopting a standing isometric position with both feet on the ground and the hands on the wall in front of him. This position, 0° to 20° ankle dorsiflexion, avoids the "back fall" and the cramps during the electrically induced contraction.

One portable stimulator (Compex 2, Medicompex SA, Ecublens, Switzerland) was used to deliver NEMS (15 min; 75 EMS contractions completed during each training session; rise time = 0.25 s and descending time = 0.75 s). For the soleus, two self-adhesive electrodes were placed under the medial and lateral muscle bellies of the gastrocnemius while two electrodes were placed behind the head of the first metatarsal of both legs for the medial arch muscles.

In order to maximize muscle tension without accompanying detrimental effects on fatigue onset, biphasic symmetric regular-wave pulsed currents (85 Hz) lasting 400 μs were delivered (Maffiuletti 2010, Papaiordanidou et al., 2010). Each 4-s steady tetanic stimulation was followed by pause lasting 8-s, during which subjects were submaximally stimulated at 4 Hz on the soleus muscle and the medial arch muscles. Subjects were consistently asked to increase the current amplitude within each training session and between sessions to attain the highest tolerable level without discomfort. For each subject and for each of the NEMS session, the average current amplitude was recorded. Table 1 displays the progression of NMES intensity during the 5 weeks of FAST protocol. Each athlete of the FAST group performed an average of 8.8 ± 1.0 NMES sessions throughout the 5 weeks as illustrated in Figure 1.

Table 1. Progression of NMES intensity (mean ± SD) (individual) and elastic resistance (pre-defined and standardized for the whole group) in FAST sessions.

	NMES intensity progression (mA)	Elastic tubing-aided exercices progression (kg)
Week 1	41 (4)	5.7
Week 2	55 (6)	6.8
Week 3	68 (7)	6.8
Week 4	74 (5)	7.9
Week 5	79 (3)	7.9

Abbreviations: NMES, Neuromuscular electromyostimulation; FAST, Foot/Ankle strength training.

Resistance training: Each session of the resistance
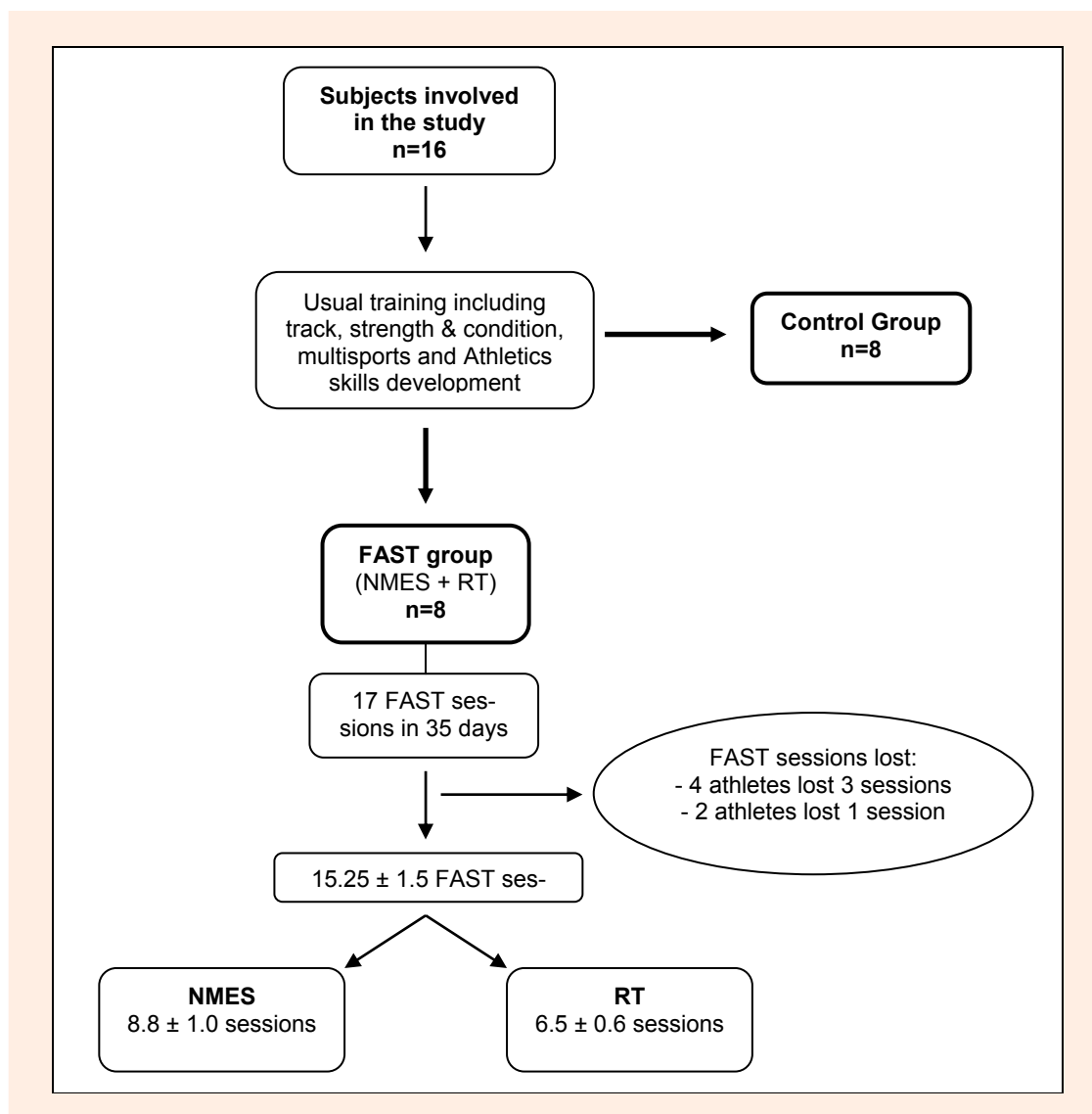
Figure 1. Illustration of the training procedure for both FAST and control groups.
During the experimental procedure, both groups performed their usual training (9 sessions a week). In addition, the FAST group underwent a 5-week electromyostimulation (NMES) and resistance training (RT).

training protocol (RT) lasted 25 min and started with a standardized warm-up lasting 10 min including ergometer bicycle and rope skipping. This was implemented in the normal strength and conditioning sessions.

The six different exercises and the volume that were implemented are displayed in Table 2. Each athlete of the FAST group performed an average of 6.5 ± 0.6 RT sessions throughout the 5 weeks as illustrated in Figure 1. One or two of these six exercises were randomly implemented in the daily training program. One RT session was considered completed as soon as the six exercises have been performed within one week or less. Inversion and

eversion exercises consisted of concentric and eccentric contractions using elastic tubing (Thera- Band Tubing Resistive Exerciser, The Hygenic Corporation, Akron, OH). Resistance progression is illustrated in Table 1. In accordance with the information provided by the manufacturer, 5.7 kg, 6.8 kg and 7.9 kg are equivalent to 150%, 200% and 250% of the black colored elastic tubing elongation, respectively). Lost training sessions due to athletes' absence are reported in Figure 1.

Plantar pressure data and sprint testing
Instrumentation: Insole plantar pressure distribution was

Table 2. Resistance exercises protocol used in foot/ankle strength training group (FAST).

Exercise	Resistance	Sets	Repetitions	Volume
Inversion	Elastic band	3	10	30
Eversion	Elastic band	3	10	30
Double leg toe raises	Body-weight	3	10	30
Single leg toe lowers	Body-weight	3	10	30
Horizontal calf jumps	Body-weight	2	10	20
Vertical calf jumps	Body-weight	2	10	20

recorded using the X-Pedar Mobile System (Novel GmbH, Munich, Germany). Each pressure insole consisted of a 2-mm-thick array of 99 capacitive pressure sensors. Before commencement of data collection, the insoles were calibrated according to the manufacturer's guidelines. This involved loading the insoles to a range of known pressure values, which resulted in an individual calibration curve for all sensors within the shoe (TruBlu Calibration, Novel GmbH, Munich, Germany). The insoles were placed in the right participant's spikes shoe between the foot/sock and sock liner. All the participants wore the same type spikes shoes, provided by the institution at the beginning of the season. The data logger for data storage was in a harness on the chest of the participant. Plantar pressures were sampled at 100 Hz via Bluetooth technology. Excellent reliability has been reported for this device (Hurkmans et al., 2006).

After a warm-up, the subjects performed three maximal 60 m sprints on a synthetic indoor athletics track, starting in a standing position. All the tests took place at the same indoor track. Sprint time for the last 30 m was measured with a dual-beam timing gate system (Speed Light, Swift Performance Equipment, Lismore, Australia) with simultaneous plantar pressure data collection. Sprints were also videotaped in order to define the corresponding right foot steps during the last 30 m and to assess the stride frequency. Stride frequency was calculated by dividing the stride count (i.e. number of steps of the last 30m over the fastest sprint) by the sprint time (i.e. sprint performance in the last 30m over the fastest sprint).
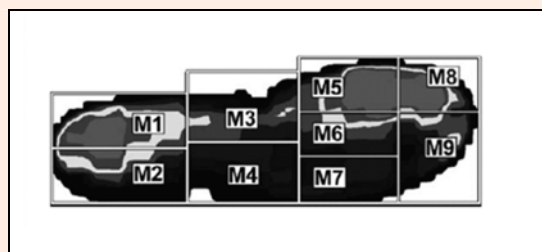

Figure 2. Regions of interest at the foot were masked to the size of the Pedar insole (Groupmask Evaluation, Novel GmbH, Munich, Germany). The regions consisted of the following: M1 medial heel, M2 lateral heel, M3 medial midfoot, M4 lateral midfoot, M5 medial forefoot, M6 central forefoot, M7 lateral forefoot, M8 hallux and M9 lesser toes.

Data analysis: The fastest sprint was chosen for the analysis of the sprint times and foot loading patterns. All the right foot contacts during the last 30 m of the fastest sprint were averaged for further analysis. A regional analysis of each foot was performed utilizing nine separate ''masks'' or areas of the foot; *i.e.* medial and lateral heel, medial and lateral mid-foot, medial, central and lateral forefoot, hallux and lesser toes (Groupmask Evaluation, Novel GmbH, Munich, Germany) (Figure 2). The following parameters were determined for the whole foot and the nine selected regions; maximum (MF) and mean force (mF), peak (PP) and mean pressure (mP) (e.g. the maximum mean pressure output from the novel software), ground contact times (CT) and mean area (mA). In

addition, the relative load in each foot region (RL%) was calculated as the force time integral (area under the force curve) in each individual region divided by the force time integral for the total plantar foot surface (Eils et al., 2004). Analyses were performed with the appropriate software (Novel Win, Novel GmbH, Munich, Germany).

Concurrently, the arch index, defined as the area under the midfoot area divided by sum of the areas under the forefoot, midfoot, and heel regions (Nagel et al., 2008) was calculated in order to assess potential foot shape variations. The arch index calculated from dynamic foot prints has been reported as an accurate measure in non-obese subjects when measured both statically and dynamically (Taisa Filippin et al., 2008).

Statistical analysis

Mean (SD) values were calculated for all variables of interest. An independent samples *t*-test was used to examine the differences in plantar loading parameters for the whole foot. A three-way repeated measures ANOVA was performed with training mode (treatment *vs.* control group), condition (pre- *vs.* post-tests) and foot regions (masks one to nine) as the repeated factors and the foot loading parameters designated as dependent variables. This analysis revealed the global effect of training mode, the global effect of condition, the global effect of foot region and the interaction between training mode, Pre- and Post- conditions and foot regions. When significant main effects were observed, Tukey post hoc analyses were used to identify differences among means. The statistical analyses were performed using SigmaStat software (Jandel Corporation, San Rafael, CA). Statistical significance was accepted at $p < 0.05$.

Results

Sprint times remained unchanged between Pre- and Post-: 3.90 ± 0.32 vs. 3.98 ± 0.46 s in FAST and 3.83 ± 0.42 vs. 3.81 ± 0.44 s in C. No significant interaction was observed in sprint times and contact times. Moreover, no significant correlation was found between the pre- and post-training differences in sprint times and contact times for both groups.

No significant changes were observed both for contact times (122.6 ± 10.1 vs. 146.8 ± 41.4 ms and 122.4 ± 21.5 vs. 124.8 ± 21.7 ms, in FAST and C respectively), and stride frequency (3.96 ± 0.30 vs. 3.89 ± 0.31 strides.s^{-1} and 4.04 ± 0.33 vs. 4.12 ± 0.28 strides.s^{-1}, in FAST and C respectively).

Pre- and post- plantar pressure parameters for each foot region for C and FAST are presented in Table 3. Regarding the whole foot, there was no statistically significant difference in foot plantar parameters significant interactions ($p < 0.05$) between C and FAST were found in MF, PP, mP, mF, mA and RL% (Table 4).

The changes in force and pressure from heel to forefoot were different between FAST and C: In FAST, mP (Figure 3) and mF (Figure 4) increased in heel, i.e. M2 (67.1 ± 44.1 vs. 82.9 ± 28.6 kPa [$p = 0.06$]; 25.5 ± 17.8 vs. 34.1 ± 14.3 N [$p = 0.05$]) and did not change in forefoot, i.e. M6 (151.0 ± 23.2 vs. 146.1 ± 30.0 kPa;

Table 3. Foot loading parameters for each foot region before (Pre) and after (Post) the foot/ankle strength training in Control and experimental (FAST) groups. Values are means (±SD).

Group	Measure	Medial heel	Lateral heel	Medial midfoot	Lateral midfoot	Medial forefoot	Central forefoot	Lateral forefoot	Hallux	Lesser toes
Maximum force (N)										
Control	Pre	157 (134)	129 (107)	155 (118)	251 (106)	235 (80)	239 (82)	242 (85)	240 (79)	302 (96)
	Post	114 (77)	112 (96)	146 (69)	263 (92)	282 (103)	296 (98)	241 (91)	255 (101)	297 (83)
FAST	Pre	98 (86)	115 (92)	122 (48)	263 (42)	252 (101)	219 (40)	221 (58)	259 (56)	273 (54)
	Post	135 (77)	147 (71)	135 (44)	272 (69)	233 (96)	214 (48)	216 (71)	247 (61)	276 (48) *†
Peak pressure (kPa)										
Control	Pre	98 (53)	112 (61)	117 (46)	215 (91)	290 (119)	276 (111)	274 (87)	368 (100)	325 (100)
	Post	86 (45)	93 (55)	157 (53)	225 (83)	314 (92)	295 (74)	258 (73)	377 (150)	294 (74)
FAST	Pre	90 (60)	96 (56)	119 (31)	202 (50)	290 (112)	224 (46)	228 (56)	379 (99)	254 (51)
	Post	107 (49)	120 (42)	127 (36)	205 (79)	278 (98)	220 (52)	217 (75)	336 (101)	240 (55) ‡
Mean pressure (kPa)										
Control	Pre	68 (37)	79 (44)	64 (24)	108 (42)	191 (63)	167 (47)	173 (52)	220 (62)	164 (40)
	Post	57 (29)	65 (40)	66 (18)	110 (32)	219 (68)	203 (60)	170 (56)	237 (87)	157 (33)
FAST	Pre	60 (36)	67 (44)	55 (10)	100 (16)	200 (69)	151 (23)	154 (37)	238 (53)	142 (28)
	Post	70 (30)	83 (29)	58 (13)	102 (20)	186 (64)	146 (30)	148 (42)	225 (60)	145 (29) ‡†
Mean force (N)										
Control	Pre	38 (33)	31 (22)	50 (37)	113 (51)	144 (50)	146 (53)	142 (56)	139 (49)	195 (65)
	Post	29 (16)	26 (20)	53 (34)	113 (48)	162 (64)	177 (63)	147 (65)	150 (70)	195 (60)
FAST	Pre	25 (20)	26 (18)	42 (17)	112 (16)	157 (68)	142 (29)	133 (27)	152 (44)	182 (46) ‡
	Post	33 (20)	34 (14)	46 (17)	113 (22)	143 (63)	136 (34)	127 (37)	145 (48)	177 (39)
Mean area (cm²)										
Control	Pre	6 (4)	5 (3)	9 (5)	15 (4)	11 (2)	12 (2)	12 (3)	9 (1)	16 (2)
	Post	6 (3)	5 (3)	10 (5)	14 (4)	11 (2)	13 (2)	12 (3)	9 (1)	17 (2)
FAST	Pre	5 (2)	5 (1)	10 (3)	16 (2)	12 (2)	13 (1)	13 (1)	10 (1)	17 (2)
	Post	6 (2)	6 (2)	10 (2)	15 (1)	11 (1)	13 (1)	12 (2)	10 (1)	17 (2) ‡
Relative load (%)										
Control	Pre	4 (2)	3 (3)	5 (3)	11 (4)	15 (3)	14 (2)	14 (2)	14 (3)	20 (5)
	Post	3 (2)	3 (2)	5 (3)	11 (4)	16 (4)	17 (2)	13 (4)	14 (4)	19 (4)
FAST	Pre	3 (3)	3 (2)	4 (1)	12 (3)	16 (4)	15 (2)	14 (3)	16 (2)	19 (3)
	Post	4 (3)	4 (2)	5 (2)	12 (3)	15 (4)	14 (2)	13 (3)	15 (3)	18 (2) †

*, † and ‡ p < 0.05 for region 5, 6 and 2 respectively. Abbreviations: FAST, Foot/Ankle strength training; Pre, one week before FAST protocol; Post, immediately after FAST protocol

Table 4. Foot loading parameters for the whole foot.

Group	Pre	Post	Change (%)
Maximum force (N)			
Control	1544 (587)	1634 (488)	5.8
FAST	1417 (238)	1401 (266)	-1.1
Peak pressure (kPa)			
Control	379 (98)	398 (134)	5.0
FAST	396 (93)	362 (92)	-8.6
Mean pressure (kPa)			
Control	137 (30)	150 (32)	9.7
FAST	134 (24)	131 (25)	-2.5
Mean force (N)			
Control	1000 (318)	1054 (304)	5.4
FAST	972 (167)	955 (177)	-1.8
Mean area (cm²)			
Control	97 (23)	98 (18)	1.2
FAST	99 (11)	99 (6)	0.0

FAST, Foot/Ankle strength training; Pre, one week before FAST protocol; Post, immediately after FAST protocol

142.1 ± 29.4 vs. 136.0 ± 33.8 N). Mean area increased in FAST under the lateral heel between Pre- and Post-tests (4.5 ± 1.3 vs. 5.7 ± 1.6 cm² [p < 0.05]) and remained unchanged in C (5.5 ± 2.8 vs. 5.0 ± 3.0 cm²). No additional changes were observed in other foot areas for plantar parameters after FAST.

Finally, arch index remained unchanged between Pre- and Post-: 0.40 ± 0.03 vs. 0.39 ± 0.02 in FAST and 0.39 ± 0.03 vs. 0.39 ± 0.03 in C.

Discussion

The aim of this study was to evaluate the effects of a brief foot/ankle muscles strength training program (FAST) including NMES on performance and the plantar loading distribution during sprinting in young athletes. It was found that such a program over a short period induced significant changes in in-shoe plantar pressure and forces patterns without any change in sprinting performance. Overall, FAST induced both varus (i.e. lateral shift) and posterior effects that are contradictory in term of running mechanics. Previous studies have reported that FAST lead to notable change in foot muscles' strength, foot structure, or running mechanics (Docherty et al., 1998; Feltner et al., 1994). In the present study, FAST displayed strong varus and posterior effects, as shown by the changes observed in lateral heel (for mean force, peak pressure, mean pressure and mean area) and medial forefoot (for maximum force, mean pressure and relative load).

Lateral shift
As suggested previously (Eils et al., 2004; Queen et al., 2007), one of the main characteristics of sprint biomechanics in terms of plantar loading patterns is the load
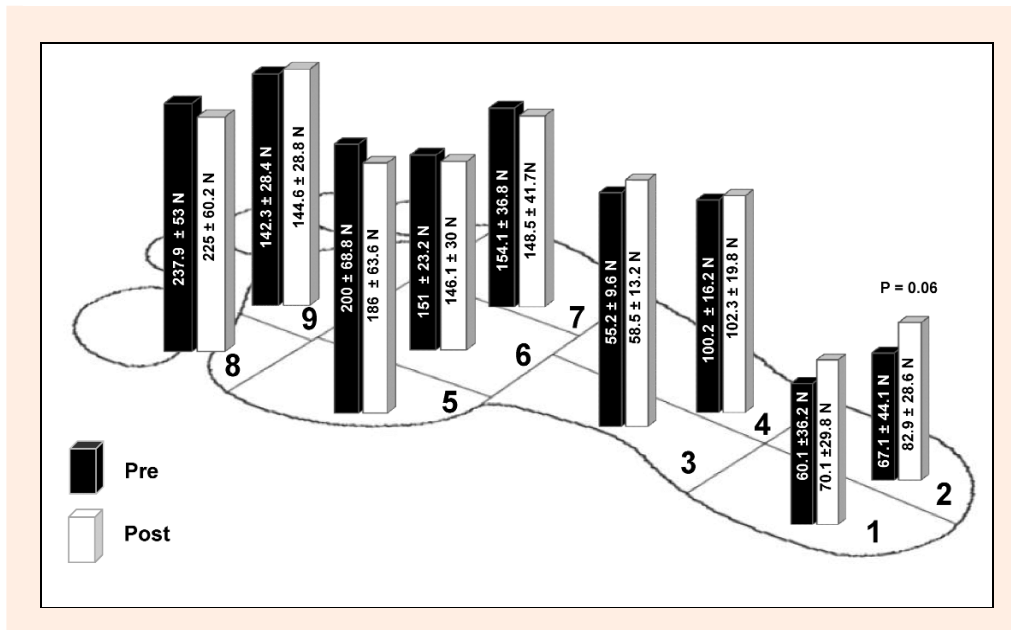
Figure 3. Mean and standard deviation mean pressure (kPa) during sprinting in each of the nine areas of interest for experimental group before and after foot/ankle strength training (FAST). Abbreviations: Pre, before foot/ankle strength training; Post, immediately after foot/ankle strength training.

under the 1st and 2nd ray, the hallux and the lateral toe. It has been previously noted that the intrinsic musculature in the plantar aspect of the foot has a role in supporting the MLA in stance (Fiolkowski et al., 2003); and even the fatigue of these muscles led to an increase in pronation (Headlee et al., 2007).

In the present study, we reported a shift of the load from the medial and central forefoot to the lateral part of the heel after FAST protocol; i.e. the reinforcement of the MLA and extrinsic ankle muscles induced the transfer of a part of the plantar loads from the medial and central forefoot to a more lateral part of the foot. The first component of this load transfer is the lateral shift which can

be considered as a beneficial decrease of pronation. Similar results have been reported regarding counterbalancing the effects of overpronation. Feltner et al. (1994) suggested that one strategy to decrease pronation in runners is to use the inversion muscles at the ankle during the early part of the support phase. In the present study, FAST included strengthening of *posterior tibialis* and *flexor hallucis longus* that may have contributed to a more inverted foot position during the swing phase, at the contact and to the loads lateral excursion at the stance phase. The present results also confirmed the findings mentioned in two recent studies and reporting respectively a significant decrease of the navicular drop (Fourchet et al.,
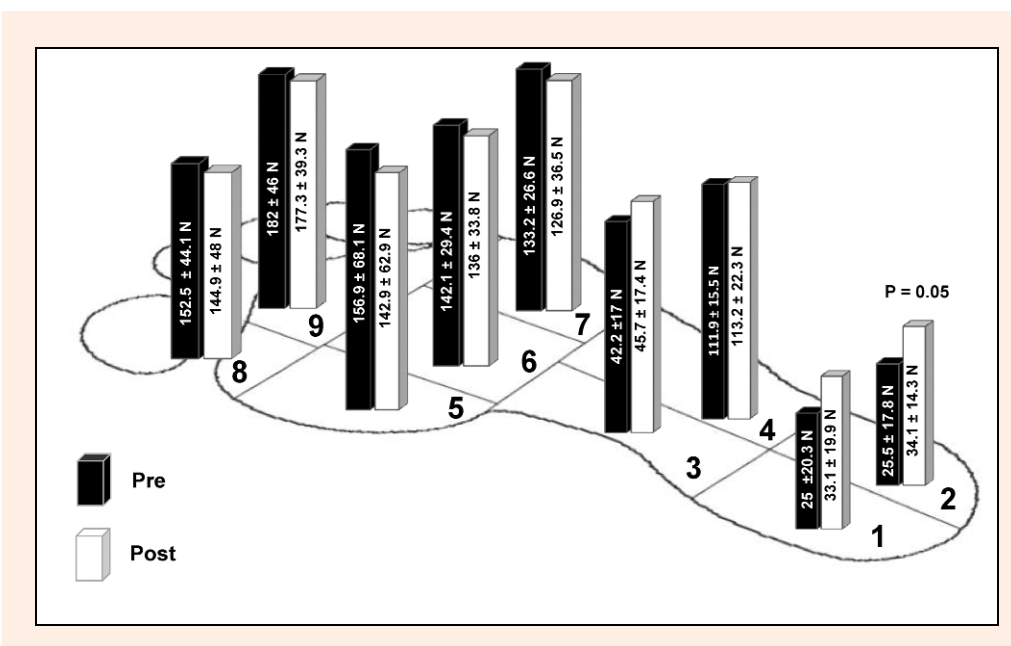

Figure 4. Mean and standard deviation mean force (N) during sprinting in each of the nine areas of interest for experimental group before and after foot/ankle strength training (FAST). Abbreviations: Pre, before foot/ankle strength training; Post, immediately after foot/ankle strength training.

2009) and a lateral displacement of anterior maximal pressure point of the stimulated foot (e.g. inversion) in standing position (Gaillet et al., 2004), following MLA muscles strengthening by NMES exclusively. Similarly, the reinforcement of the MLA of the foot by NMES has possibly contributed to dampen force and pressure under the medial and central forefoot. Interestingly, it was shown by Robbins and Hanna (1987) that MLA strengthening via intrinsic musculature activation allows the foot to act as a dynamic impact dampening structure. One may suggest therefore that after the FAST protocol the MLA was shortened due to the increased intrinsic foot muscles tone, induced by NMES. This would induce the reported lateralization and the probable ability of the foot to act as a more efficient dynamic dampening structure (Headlee et al., 2007; Robbins and Hanna, 1987).

Posterior shift

The second shift component of the FAST protocol is an unwanted posterior transfer of the load that is likely to be detrimental for the running efficiency. It is known that a posterior load transfer during the stance phase is not biomechanically appropriate, because it may lead to higher decreases in horizontal and vertical velocities during the braking phase (Novachek, 1998; Stacoff et al., 1991). In sprint running, plantar flexors are the main muscles involved in the task of halting the negative (downward) vertical velocity of the body through eccentric contraction (Mann, 1981). Furthermore, in accordance with the degree of flexion of the knee, the soleus is the main muscle involved in this dissipation phase (Novachek, 1998). It may be assumed that the NMES reinforcement of the soleus was responsible for the posterior shift: this isometric strengthening (even though performed in a 0° to 20° ankle dorsiflexed position) possibly increased muscle fiber tightness. This could significantly decrease the muscle's stretch response, affecting the subsequent activation of the stretch reflex and then compromising force production or stability during movement (Cronin et al., 2008). This hypothesis is also supported by the normally accepted role of plantar flexors as active agonists in controlling forward toppling of centre of gravity in the standing position (e.g. when the foot is constrained on the ground) (Di Giulio et al., 2009): In the present program, the soleus muscle might have over-controlled the forward shift of the shank over the ankle at the stance phase and then consequently increased rear foot loading. In addition, there were no changes in the arch index values between pre- and post-training. This finding seems to confirm that the posterior effect of FAST protocol is not in relation with a MLA structure modification.

One limitation of the present study could be the lack of homogeneity in terms of sprint performance within the group (and thus large SDs), which might have induced non-significant changes with training. Nevertheless it is worth mentioning that several studies in the literature reported similar variability in sprint performances (Babault et al., 2007; Gains et al., 2010). Despite the performances not being statistically different, from a practical point of view a change of 0.08 s is not negligible in 30m sprint running. The observed trend of increased

running and ground contact times (although not statistically significant) after FAST protocol is interesting but cannot be explained by the present data (no correlation was found between the pre- and post-training differences in sprint times and contact times neither in FAST nor in C). Similarly, ground contact times did not change significantly but we noticed a non negligible extension of this parameter in FAST group after the protocol. However, as the sprint times did not change clearly, it is difficult to conclude whether the increase of the ground contact times is detrimental or not. Finally, as the FAST group displayed an increase in sprint times which didn't achieve significance, it might be worthwhile repeating this experiment with larger groups to determine if this finding is significant.

Given the importance of the braking phase on sprint biomechanics (Ciacci et al., 2009) and the detrimental effect of heel contact on the kinetic and therefore mechanical cost, one may conclude that the current foot strength training protocol is likely to be detrimental for the running mechanics. However we suggest that the observed effect of lesser load on the metatarsal heads might be useful for reducing the stress fracture risks in runners considered 'at-risk' of this injury. As a whole, from running performance point of view, modification of the training protocol may be needed to avoid the possible decline in running performance (i.e. by excluding additional soleus reinforcement via NMES in order to avoid the observed posterior shift).

Injury prevention

Further kinematic and kinetic analyses are required for detailing the subsequent changes in running biomechanics induced by FAST and some components of this protocol may be of interest in preventing injuries. The effect of FAST on the dampening characteristics of the MLA are likely to be similar to the ones shown previously to protect the medial forefoot and mid-foot by using foot orthoses or tapes (Vicenzino et al., 2005). These findings could be of interest in terms of injuries prevention; i.e. for reducing the effects of overpronation characterized by a flattening of the MLA and a hyper mobile midfoot (Cote et al., 2005; Fourchet et al., 2009). Overpronation is an important risk factor for many injuries like plantar fasciitis, Achilles tendonitis, 1st and 2nd metatarsals stress fracture, metatarsalgia, shin splint, posterior tibialis tendonitis and femoro-patellar syndrome (Burne et al., 2004; Weist et al., 2004).

Conclusion

The aim of this study was to evaluate the effects of a brief foot/ankle strength training program on sprint performance and on related plantar loading characteristics in teenage athletes. The results showed no significant pre- to post- changes in sprint performance but revealed initially a lateral transfer and secondly a posterior unwanted transfer of the plantar loads after FAST protocol. Finally, it would be of interest to assess some adjustment to the present protocol in order to avoid the observed posterior shift and a possible decline in running performance. The

FAST protocol involving intrinsic and extrinsic foot/ankle muscles may appear to be of interest for some at-risk groups such as flexible flat foot morphology, subjects with high navicular drop, or overpronators.

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Key points

- We have evaluated the effects of a foot/ankle strength training program on sprint performance and on related plantar loading characteristics in teenage athletes, and this have not been examined previously.
- Our results showed no significant pre- to post-changes in sprint performance.
- This study revealed initially a lateral transfer and secondly a posterior transfer of the plantar loads after the foot/ankle strength training program.

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