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Effects of a 10-week running-retraining programme on the foot strike pattern of adolescents: A longitudinal intervention study

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ABSTRACT

Background: The purpose of this study was to analyse the effects of ten weeks of different running-retraining programmes on rearfoot strike (RFS) prevalence in adolescents.
Research question: it is possible to change foot strike pattern in adolescents?
Methods: A total of 180 children (45.3% girls), aged 13–16 years, participated in this intervention study. The children were randomly assigned to one of three experimental groups (EGs) that each carried out a different retraining programme, based on running technique ($n = 39$), a 15% increased step frequency (SF) ($n = 37$) and barefoot training ($n = 30$), performed for three days each week. A control group (CG) ($n = 43$) did not perform any retraining. A 2D video-based analysis (240 Hz) was used to determine the RFS.
Results: At baseline, no significant differences in RFS prevalence were found between the EGs and the CG in either the left ($\chi^2 = 2.048$; $p = 0.559$) or the right foot ($\chi^2 = 0.898$; $p = 0.825$). In the post-test, no significant differences were found for the left foot ($\chi^2 = 7.102$; $p = 0.069$), but there were significant differences for the right foot ($\chi^2 = 9.239$; $p = 0.025$) were observed. In the re-test, no significant differences were found for either the left foot ($\chi^2 = 2.665$; $p = 0.273$) or the right foot ($\chi^2 = 2.182$; $p = 0.325$). In addition, no group displayed significant changes in RFS prevalence from the pre-test to the re-test. There was a trend towards a reduction in the RFS prevalence in both the increased SF group and the barefoot group.
Meaning: The main finding of this study was that certain running-retraining programmes performed three times per week for ten weeks are not enough to modify the adolescent foot strike pattern (FSP).

1. Introduction

Locomotive skills such as running are basic for most physical activities undertaken by children, and they promote fitness [1]. Many children participate in sporting activities such as endurance races, resulting in an increase in lower limb injuries [2]. This could be related to the dynamics of the contact of the foot with the ground (the foot strike pattern, or FSP). The orientation of a runner's foot on the initial impact with the ground is often used as a criterion to classify running technique [3]. Three categories of ground contact are often described: rearfoot strike (RFS) – landing on half of the heel or the rear third of the sole only; midfoot strike (MFS) – landing on the heel and the ball of the foot simultaneously; and forefoot strike (FFS) – landing on the ball of the foot.

Although running with FFS seems to be a characteristic of human evolution [4], young people, and adult amateur endurance runners exhibit a high prevalence (above 90%) of RFS [5,6]. RFS has been associated with higher vertical loading,higher collision forces and greater ankle stiffness [7,8], and some previous works have suggested that it is associated with a greater risk of injury [4]. In particular, RFS in children when they run produces impact forces that give rise to a transient stress wave travelling through the body [9]. Consequently, there is

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evidence that links the mechanics of running with the risk of injury, and this provides the justification for altering these parameters in the context of injury prevention [10].

Taking into account the immaturity of children's musculoskeletal systems, RFS could contribute to the development of injuries. It is therefore suggested that early retraining in running, when the young person is developing a running style, might be effective to reduce the prevalence of RFS.

The two primary gait-retraining interventions that are aimed at reducing impact forces are transition to FFS and increasing cadence [11]. In this regard, adopting a step frequency (SF) that is higher than one's preferred SF may in practice reduce the risk of developing a tibial stress fracture by decreasing the lower extremity loading variables [12]. Specifically, the peak vertical ground reaction force decreases by 2.6% when the SF is increased from 100 to 110% of the preferred SF [13]. In particular, in young people a lower running step rate is associated with a greater likelihood of shin injury ($\leq$166 steps per minute vs. $\geq$178 steps per minute) [14].

On the other hand, there is a hypothesis that a barefoot running style, which minimises impact peaks and provides increased proprioception and foot strength, helps to avoid injury [15]. For this reason, it has been suggested that barefoot running encourages an FFS pattern in children [16]. In contrast, running shoes can be a key factor leading to injury [17], because they encourage more RFS [18].

Furthermore, knowing the correct technique for running is very important for the prevention of injuries [19]. In the field of sports training, it is common to train by using various technical running drills, such as skipping and foot tapping, at an early age. A trainer in running technique should try to teach athletes the appropriate manner in which to support their body-weight on their feet (and more specifically on their forefoot) [20]. However, training in running technique has not yet been reported to have any effect on FSP.

It is noteworthy that altering any motor pattern, like the way in which one runs, that has become habituated over many years and has been reinforced over millions of cycles, can be difficult [18]. Very few studies have investigated the impact of running-retraining programmes such as barefoot training, changes in SF, running technique or visual feedback on RFS prevalence [21–23]. Moreover, those studies that exist were carried out in a laboratory setting. A newly-learned gait pattern may not fully translate into running outside the laboratory environment [24]. To our knowledge, no previous works about running retraining have been conducted in a school population. Therefore, the purpose of this study was to analyse the effects of ten weeks of different running-retraining programmes on RFS prevalence in adolescents. The hypothesis was that different strategies of gait retraining might be effective in reducing the prevalence of RFS in adolescents.

2. Methods

2.1. Participants

An a priori sample size test was performed using the G*Power software (version 3.1). The following parameters were selected: moderate effect size w = 0.3, α level of 0.05, power level of 0.95, four groups, and three measurements. The sample size was determined to be at least one hundred participants. This longitudinal intervention study involved 180 children (45,3% girls) aged 13–16 years (14.20 ± 0.79 years). The sample was selected by convenience from four schools in southern Spain. Inclusion criteria included being free from physical and/or intellectual disabilities. The parents voluntarily signed an informed consent form for their children to participate in this study. The study was completed under the norms of the Declaration of Helsinki (2013 version), and was approved by the Ethics Committee at the University of Jaén. The children were randomly assigned to one of three experimental groups (EGs) or a control group (CG). The randomisation was conducted independently by a research assistant who was not involved in the data collection, using random numbers generated in Microsoft Excel 2010. A recruitment flowchart for the participants is shown in Fig. 1.

2.2. Materials and testing

Sagittal plane videos (240 Hz) were recorded using a high-speed camcorder (Casio Exilim EXF1, Shibuyaku, Tokyo 151–8543, Japan). The videos were taken from a lateral viewpoint, with the camera placed perpendicularly five metres from the participant so that he/she could be filmed in the sagittal plane. The filming location was set in a 5-metre corridor. The video data were analysed using a 2D video editor (VideoSpeed vs1.38, ErgoSport, Granada, Spain). A 2D video-based determination of the FSP has been used in a previous study [16] and, despite not being as exact as a biomechanical determination, it is practical for the assessment of a large cohort [25]. The dependent variables selected for the kinematics analysis were: RFS, MFS and FFS.

Fig. 2 shows the different FSPs. Following the procedure used in a previous study [16], the FSP was rated as RFS or non-RFS, since this dichotomous variable shows very high accuracy in determining RFS (inter-rater agreement: 0.981) and lower accuracy in deciding between FFS and MFS (0.893) [26]. Running speed was measured using two double-light barriers (WITTY; Microgate Srl, Bolzano, Italy; accuracy of 0.001 s). Finally, SF was recorded using the OptoGait system (Optogait; Microgate, Bolzano, Italy). In this study, the five parallel bars of the device system were placed in a 5-metre corridor.

2.3. Procedure

The participants were asked to run steadily wearing their usual trainers at a self-determined comfortable speed (jogging). Some instructions were given to the participants: "Run comfortably, don't run too fast". The research team conducted a demonstration, and the children performed some familiarization trials. The participants ran back and forth 40 m to the recording area, which was a corridor five metres long by two metres wide. The running test was performed on a flat, hard, non-slip surface. All measurements were made before the application of the retraining programmes, immediately after their completion and two weeks later (re-test).

2.4. Intervention

The intervention programme was conducted by physical education teachers and previously trained graduate students. The participants in each EG performed a different retraining programme (Table 1), three times per week for a duration of 30 min, for ten weeks, in their school facilities. The EG1 (n = 39, 59.0% boys) performed retraining based on technical running drills such as foot tapping, hopping, skipping, running lunge, and jumping, which could be considered as a forefoot running instruction programme, similar to the Pose® Method [22]. The EG2 (n = 37, 59.5% boys) performed retraining based on an increase of 15% in their usual step frequency, by means of a metronome. The EG3 (n = 30, 40.0% boys) performed barefoot retraining, which, following Latorre et al. [23], consisted of the progressive inclusion of barefoot running on a flat, hard, non-slip surface (Table 2). Finally, the CG (n = 43, 58.1% boys) did not perform any retraining. A digital metronome for providing auditory feedback to the EG2 was used, and was set at 15% above the adolescent's natural SF determined at baseline.

2.5. Statistical analysis

The data were analysed using SPSS, v.22.0 for Windows (SPSS Inc, Chicago, USA) and the significance level was set at $p < 0.05$. Descriptive statistics are presented using the mean and standard deviation, and as percentages. A chi-squared (χ^2) test was used to compare RFS prevalence in the time x group interaction. To analyse the differences in RFS prevalence for the group x time interaction (within-group), Cochran's

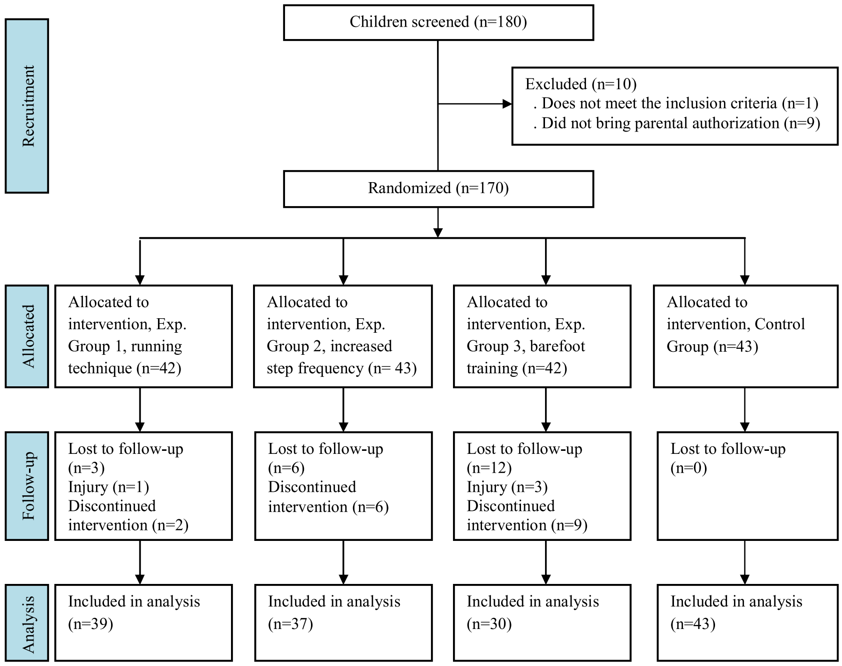


Fig. 1. Flow Diagram.

Fig. 2. Examples of foot strike patterns. From left to right, rearfoot strike, midfoot strike and forefoot strike.

Table 1
Running-retraining programmes (three times per week) with comfortable running.

Week	Training time	Total time (minutes)
	5′	15
	8′	24
	10’	30
	2 × 6′ recovering 4′ walking	36
	2 × 6′ recovering 4′ walking	36
	12’	36
	2 × 7′ recovering 4′ walking	42
	14′	42
	2 × 8′ recovering 4′ walking	48
	16′	48

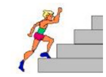
and McNemar’s tests were used. Paired t-tests were conducted to evaluate the increase in cadence and running speed. In addition, in a sample of 50 participants and with the participation of three experienced observers, intra-observer and inter-observer reliability were calculated using Cohen’s kappa and the proportion of agreement on FSP.

3. Results

For the intra-observer reliability for FSP, the kappa was 0.926 and the proportion of agreement was 98%. For the inter-observer reliability, the kappa was 0.801 ± 0.09, and the proportion of agreement was 90%. At the baseline, the average running speed was 3.09 ± 0.48 m/s, in the post-test it was 3.12 ± 0.33 m/s, and in the retest it was 2.99 ± 0.29 m/s ($p > 0.05$). In the EG2, the increase of cadence was from a preferred SF of 173.75 ± 9.05 steps per minute to an SF increased by 15%–199.81 ± 10.41 steps per minute ($p < 0.001$).

At the baseline, no significant differences between the EGs and the CG were found for RFS prevalence in either the left foot ($\chi^2 = 2.048$; $p = 0.559$) or the right foot ($\chi^2 = 0.898$; $p = 0.825$). In the post-test, no significant differences were found for the left foot ($\chi^2 = 7.102$; $p = 0.069$), but significant differences were found for the right foot ($\chi^2 = 9.239$; $p = 0.025$). In the re-test, no significant differences were found for either the left foot ($\chi^2 = 2.665$; $p = 0.273$) or the right foot ($\chi^2 =$

Table 2
Technical Running Drills.

Exercise	Description	Graphic description	Exercise	Description	Graphic description	Repetitions with each leg
1	Skipping with high knees		6	Running with high knees		15
2	Butt kicks (heel to butt)		7	Vertical and horizontal power skips (bounding). Alternate leg bounds		15
3	Straight leg running		8	Running lunge, alternate leg bounds		15
4	Circular running with high knees		9	Running step-ups, alternate leg bounds, on a flight of stairs		15
5	Circular power skips (bounding). Alternate leg bounds		10	Running step-ups, alternate leg bounds		15

Exercises performed over a 30 m route with two repetitions of each exercise.

2.182; $p = 0.325$).

Regarding the group x time interaction (within-group), the analysis of repeated measures from the pre-test to the re-test using Cochran's test reveals that in neither foot were there significant changes in the prevalence of RFS. For the EG1, for the left foot Cochran's Q was 0.400, $p = 0.819$, and for the right foot Cochran's Q was 0.400, $p = 0.819$. For the EG2, for the left foot Cochran's Q was 1.600, $p = 0.449$, but differences were found for the right foot (Cochran's Q = 6.333; $p = 0.042$). For the EG3 for the left foot, Cochran's Q was 0.857, $p = 0.651$, and for the right foot Cochran's Q was 3.250, $p = 0.197$. In the CG, from pre-test to post-test, for both the left foot and the right foot, McNemar's test noted $p = 1.000$. Finally, Fig. 3 shows that no groups displayed significant changes ($p > 0.05$) in RFS prevalence from the pre-test to the re-test. We observed a trend towards a reduction of the RFS percentage in both the SF increase group and the barefoot group.

4. Discussion

The purpose of this study was to analyse the effects of ten weeks of different running-retraining programmes on RFS prevalence in an adolescent population. The main finding of this study was that no group displayed changes in RFS prevalence from pre-test to re-test. A tendency towards a reduction of the prevalence of RFS was observed in two of the EGs (i.e., the SF increase group and the barefoot group).

Looking at RFS prevalence, previous studies have shown high values of RFS, at 85.9% in a population of children [27]. In the current study, the RFS prevalence was at about this value in all groups and for almost all measures. However, very few studies have investigated the impact of FSP on injury rates in children. A previous study has shown that the running biomechanics of pre-adolescent children are influenced by the use of footwear, especially by cushioned running shoes, which elicit significantly increased maximum and impact ground reaction forces, step length, step width, and rate of RFS, which may pose an injury risk [28]. Additionally, a cross-sectional study [27] noted that barefoot running reduced the prevalence of RFS in children aged 6–16 years: in the barefoot condition there was a significant reduction ($p < 0.001$) of RFS prevalence both in boys (shod condition 83.95% vs. 62.65% unshod condition) and in girls (shod condition 87.85% vs. 62.70% unshod condition). An intervention study with adult runners [23] noted that twelve weeks of barefoot running, applied progressively, causes significant changes in FSP, with a tendency towards midfoot or forefoot strikes.

On the other hand, an SF manipulation of 10% or greater may be enough to change FSP from a RFS to a MFS–FFS pattern in recreational

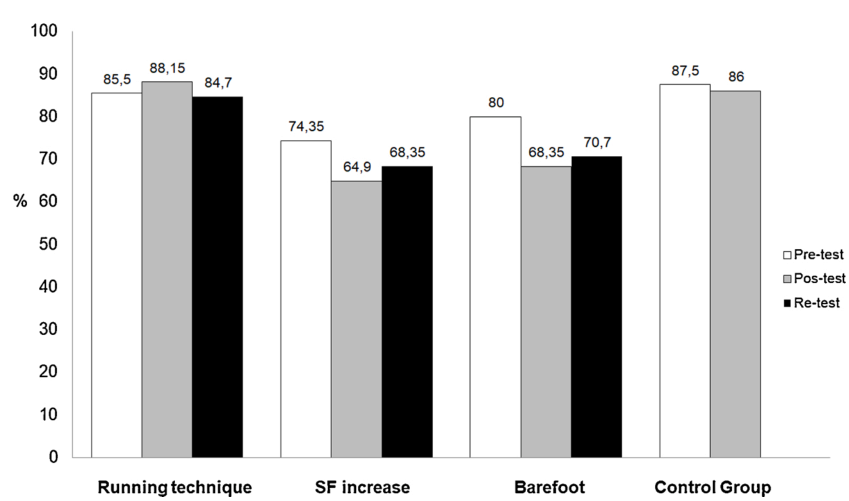


Fig. 3. Rearfoot strike prevalence in the different experimental groups and in the control group, from pre-test to re-test.

runners running in their usual running shoes [21]. Likewise, a statistically significant change has been shown in FSP from a heel strike pattern to a midfoot or forefoot strike pattern at step rates of both 10% and 15% above the preferred rate [21]. It has been shown to be both more natural and easier to transition to a combined gait modification involving FFS and increased step rate than to an isolated gait modification involving either FFS or increased step rate [29]. These previous studies are cross-sectional studies, but in an intervention study it was noted that the foot angle at initial contact did not change in the experimental group who increased their SF by 7.5% during eight sessions of gait-retraining [11].

The absence of significant effects found in the current study after the different retraining programmes is probably not because of the duration of the programmes, since previous studies that lasted for only two weeks or eight sessions of treatment [24] or for 12 weeks [23], and studied barefoot-based retraining, FFS instruction and increasing cadence, did show significant changes in the different gait parameters, especially in an adult population. According to Kampmiller et al., [30], a possible explanation for the findings of the current study is that there is high ontogenetic stability of the kinematics parameters during running in the population of those aged 7–18 years, except that in the prepubescent period and the beginning of the pubescent period, between the ages of 11 and 15, the SF reduces significantly. This reduction relates to the rapid growth of body height and weight and the deterioration of the biomechanical and coordination conditions of the organism. In addition, is possible that a more precise quantitative analysis using foot angle at initial contact would have demonstrated significant changes.

Therefore, the findings reported in the current study rejected our initial hypothesis and suggest that i) the characteristics of the different retraining programmes (frequency and duration) were inadequate, and ii) it is very difficult to modify motor learning such as FSP that has been performed over thousands of steps. Some limitations to this study must be mentioned. It used a video analysis system to measure FSP, which is less accurate than a 3-D motion capture system. In addition, footwear was not controlled nor assessed. Notwithstanding those limitations, this is the first study to perform several running-retraining programmes in adolescents through a longitudinal cohort study. Taking into account our findings, improvements to the training programmes used in this study may be needed to obtain significant effects on RFS prevalence. In conclusion, several running-retraining programmes performed three times per week for ten weeks are not enough to modify the FSP in adolescents.

Declaration of Competing Interest

The authors report no declarations of interest.

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