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Can running kinetics be modified using a barefoot training program?

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Abstract
Introduction: There is limited information about barefoot transition programs and this study will help to increase knowledge about this growing trend. The purpose of this study was, therefore, to determine the effect of a twelve-week barefoot training program on kinematic variables in long-distance runners.
Materials and methods: A total of 32 well-trained, habitually shod, long-distance runners, randomized in a control group and an experimental group who undertook a barefoot training program. At pre-test and post-test, all participants, wearing their usual sneakers, performed running tests at self-selected recovery and competitive running speeds on a treadmill. Both conditions were recorded with a 240 Hz video rate system and analyzed using a 2-D video editing program using photogrammetric techniques. Contact time, flight time, step duration and cadence were measured using an analysis of variance (ANOVA) with repeated measures was performed.
Results: In posttest, only the duration of landing phase at high speed showed significant difference, the experimental group achieved a shorter time than the control group after the barefoot training program (0.032 ± 0.007 s vs. 0.038 ± 0.006 s). In relation to within-group differences, the control group showed an increase of duration of stance phase at low speed ($\Delta = 0.014$ s, $p = 0.024$) and a reduction of flight time at high speed ($\Delta = -0.014$ s, $p = 0.034$). Moreover, the experimental group achieved a reduction of duration of landing phase at high speed ($\Delta = -0.008$ s, $p = 0.004$).
Conclusions: A twelve-week program of barefoot running changes the duration of the landing phase at high speed, being shorter in long-distance runners. In contrast, the runners who did not undertake the training showed an increase of duration of stance phase at low speed.

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¿Puede modificarse la cinética de la carrera mediante un programa de entrenamiento descalcista?

Resumen

Introducción: Existe información limitada acerca de los programas de transición a carrera descalza, y este estudio ayudará a incrementar el conocimiento acerca de esta tendencia creciente. Por tanto, el objetivo de este estudio fue determinar el efecto de un programa de entrenamiento descalcista de 12 semanas sobre las variables cinéticas en los corredores de larga distancia.

Materiales y métodos: Un total de 32 corredores de larga distancia, bien entrenados, y habitualmente calzados, fueron distribuidos aleatoriamente en un grupo experimental para llevar a cabo un programa de entrenamiento descalcista. Durante las pruebas previas y posteriores, todos los participantes realizaron las pruebas a velocidades de carrera de recuperación y competitiva auto-seleccionadas, utilizando sus zapatillas deportivas en una cinta ergométrica. Ambas situaciones se registraron con un sistema de calificación por vídeo de 240 Hz, y se analizaron mediante un programa de edición de vídeo 2D con técnicas fotogramétricas. Se midieron el tiempo de contacto, la duración del paso y la cadencia mediante análisis de la varianza (ANOVA) con mediciones repetidas.

Resultados: En la prueba posterior, solo la duración de la fase de aterrizaje a alta velocidad reflejó una diferencia significativa, logrando el grupo experimental un tiempo inferior que el grupo control tras el programa de entrenamiento descalcista ($0{,}032 \pm 0{,}007$ s frente a $0{,}038 \pm 0{,}006$ s). Con relación a las diferencias entre grupos, el grupo control reflejó un incremento en la duración de la fase de apoyo a baja velocidad ($\Delta = 0{,}014$ s; $p = 0{,}024$) y una reducción del tiempo de vuelo a alta velocidad ($\Delta = -0{,}014$ s; $p = 0{,}034$). Además, el grupo experimental logró una reducción de la duración de la fase de aterrizaje a alta velocidad ($\Delta = -0{,}008$ s; $p = 0{,}004$).

Conclusiones: Un programa de carrera descalcista de 12 semanas modifica la duración de la fase de aterrizaje a alta velocidad, que es más corta en los corredores de larga distancia. Por contra, los corredores que no realizaron el entrenamiento reflejaron un incremento de la duración de la fase de apoyo a baja velocidad.

Introduction

Some authors suggest that habitual barefoot running could prevent impact-related injuries.[1–3] Some studies pointed that humans had been made to run barefoot, and this running style can minimize impact peaks and provides increased proprioception and foot strength, also is hypothesized that can help avoid injury.[4] In order to reduce the risk of injury, the runner's body produces changes in lower limb kinematics. Some authors have measured the risk of injury in runners' feet before and after a training period transitioning from traditional to minimalist running shoes, participants in the training group showed significant increases in bone marrow edema in at least one bone after the training running period.[5,6] Furthermore, barefoot running is also associated with a shorter stride a higher stride cadence both low and high running speed,[7,8] reducing stride length decreased the probability of stress fracture by 3–6%.[5]

Previous studies of barefoot running specify even more the kinematic changes such as: shorter step length and larger step frequency, shorter landing phase, shorter contact time, shorter flight time and shorter step time.[7–11] Barefoot running is also related with a higher stride cadence both low and high running speed.[7,8] In addition, barefoot running reduces flight time and causes a lower peak force and higher pre-activation of the sural triceps than shod running.[12]

A recent study pointed that an intervention of six weeks of barefoot training simulation using Vibram Five-fingers shoes, is associated with a significant decrease in the loading rates and impact forces.[13] Other study question about the process in which biomechanical adaptations happen and if these can be learned by everyone.[14] It remains to be seen how training based on barefoot running can modify the kinematics of traditionally shod running. There are many aspects concerning the manner in which the athletes adapt kinematics variables to run after specific barefoot training but there is already no evidence for long term effects of barefoot running regarding biomechanics or health outcomes.[15] This insight could be enhanced by studying the difference in kinematics after a sufficiently long controlled barefoot training program (BTP).

Considering the above information, we hypothesized that neuromuscular adaptations to BTP might be responsible for the change in kinematic variables in shod condition post-intervention. Therefore, the purpose of this study is to determine if after the 12-week barefoot intervention the pointed variables will be modified even when running shoes are put on.

Materials and methods

This experimental study was conducted in adherence to the standards of the Declaration of Helsinki (2013 version) and followed the European Community's guidelines for Good Clinical Practice (111/3976/88 of July 1990), as well as the Spanish legal framework for clinical research on humans (Royal Decree 561/1993 on clinical trials). The informed consent and the study were approved by the Bioethics Committee of the University of Jaen (Spain).

Participants

Thirty-nine trained shod runners from southeast of Spain participated voluntarily in this study and were randomly allocated by simple random sampling in the experimental group (EG), and control group (CG). The main characteristics of the participants were age = 35.64 ± 11.67-years-old (mean ± standard deviation); body mass index = 22.93 ± 2.43 kg/m^2; km per week = 60.18 ± 20.41; sessions per week = 5.47 ± 1.29; and competitions per year = 13.08 ± 10.50. Only two athletes in the EG left the program because of illness. In the CG six people did not finish, because of illness during the intervention (n = 1) or did not perform the post-test (n = 3) or the data were corrupt or illegible (n = 2). All the data from lost athletes were excluded (Fig. 1).

The inclusion criteria were: (i) participants were all habitually shod runners (cushioned shoes); (ii) no significant injuries in the last three months and no damage or pain that could interfere with the proper monitoring of the training protocol without shoes; (iii) verifiable minimum sport level (have been able to participate in regional or national athletics championships in the last four years). Each participant signed an informed consent to participate in this research.

Measures

Participants were asked not to perform heavy physical exertion 72 h before taking pre-test and post-test data.[16] Participants were asked to run consistently at their comfortable recovery speed and their running 1500 meters long competition speed chosen by themselves[17] to simulate as faithfully as possible their habitual recovery and competitive running pace and then proceeded to run on a mechanical treadmill (Salter E-Line PT-320, Salter Internacional, Barcelona, Spain). When participants self-selected speeds for running, appeared to require fewer attempts before completing the acceptable trials needed for data col-

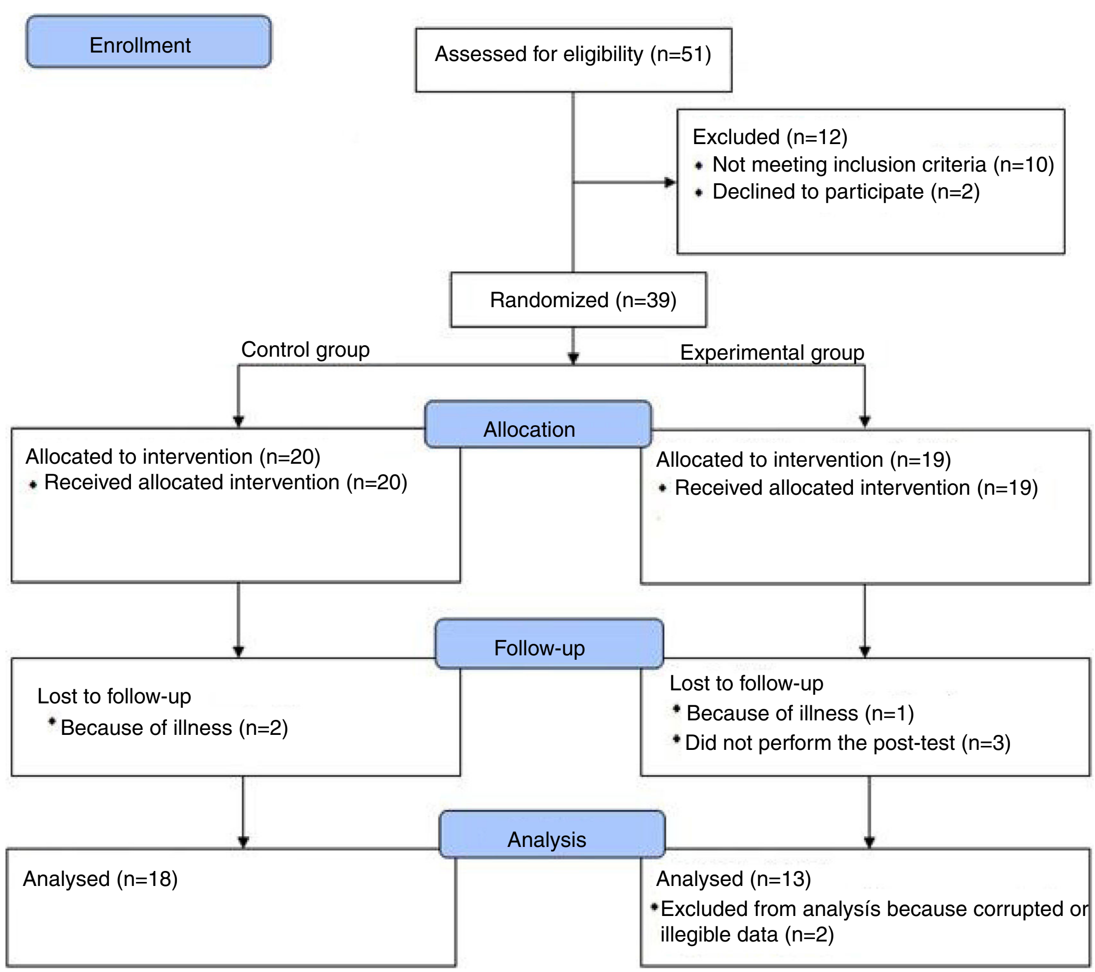

Figure 1 Flowchart progress through the study participants.

lection as compared to when the subjects were running at the standardized speed selected by the investigators.[17] Both running speeds were performed with their usual training shoes. Recordings of athletes were performed from sagittal and back view with a rate of 240 Hz camcorders (Casio Exilim EX-F1, Shibuya-ku, Tokyo 151-8543, Japan). Cameras were placed two meters away from the treadmill at ground level. Marks were placed on the floor to indicate the exact point of the cameras. Video data were observed using a 2D video editing program (VideoSpeed vs.1.38, ErgoSport, Granada, Spain). Before recordings, the athletes warmed up and habituate to the treadmill and speed in each condition for about 8 min. A period of 8 min was chosen because previous studies on human locomotion have shown that accommodation to a new condition occurs within this period.[18,19] Participants were instructed to run continuously during each trial without stops. Participants were freely allowed to adjust the speed up and down until they found a speed that matched their perceived over ground speed, which has been shown to improve the repeatability in kinematic variables.[17] Speed was increased from recovery speed to competition speed. Eight steps of each athlete at high speed and low speed conditions were measured.

Based on previous studies variables tested were: total contact time (time the foot is in contact with the ground) divided into three different moments (landing phase, stance phase and take-off phase); flight time (time where there is no contact with the ground); step duration (total time of the movement of the lower limbs including flight phase and contact phase) and cadence (number of step per minute).[7,10,20]

Procedures

Following Lieberman[4] the BTP consisted of the progressive inclusion in the usual weekly training of the EG of an increasing amount of barefoot running on a grass surface (Table 1). During the final weeks, more intense exercises such as progressive races were added. The principal researcher reviewed the implementation of the BTP and controlling the risk of significant aches and pains. Before starting the protocol, a meeting with the athletes in the EG was held to advise on training and any questions were explained and answered. The CG performed only the normal daily training. Athletes were informed of the possible increased risk of injury because of the possible changes in the pattern of the race and the strike. It was advised to decrease the intensity of training or even to abandon it when there was pain or injury. During the BTP, participants were not allowed to change their running shoes.

Statistical analysis

The data were analyzed with the statistical program SPSS.v.19.0 for Windows, (SPSS Inc., Chicago, USA) and the significance level was set at $P < 0.05$. The data are shown in descriptive statistics for mean and standard deviation (SD). Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's, respectively) were conducted on all data before analysis. Analysis of variance (ANOVA) with repeated measures was performed between pre-test and post-test in EG and CG, taking as dependent variable, the experimental condition and the kinematic parameters as independent variables. A Student's t-test was performed to ascertain running speed differences.

Results

There are no significant differences between groups in relation to comfortable speed (EG = 11.21 ± 1.28 km/h vs. CG = 10.97 ± 1.20 km/h, $p = 0.611$) and competition speed (EG = 15.56 ± 2.08 km/h vs. CG = 15.45 ± 1.67 km/h, $p = 0.873$).

The results of BTP are presented in Table 2. At pretest, no significant between-group differences were found in any variable. At post-test, only the duration of landing phase at high speed showed significant difference, the EG achieved shorter time than CG after the BTP (0.032 ± 0.007 s vs. 0.038 ± 0.006 s). In relation to within-group differences, CG showed an increase of stance phase at low speed

Table 1 Weekly training protocol used during the study.

Weeks	Experimental group weekly workout
1–2	Normal daily training. +10′ barefoot running in 50% of the weekly sessions during cool down.
3–4	Normal daily training. +10′ barefoot running in 75% of the weekly sessions during cool down.
5–6	Normal daily training. +15′ in 75% of the weekly sessions during cool down.
7–8	Normal daily training. +20′ in 50% of weekly sessions during cool down. +4 progressive 80-m races at 90–95% effort sprint.
9–10	Normal daily training. +20′ in 75% of weekly sessions during cool down. +4 progressive 80-m races at 90–95% effort sprint.
11–12	Normal daily training. +40′ barefoot race once a week at recovery pace. +20′ in other two weekly sessions during cool down.

Table 2 Temporal variables results.

	Pre-testMean (SD)	Post-testMean (SD)	Difference post−pre	*p*-Value	95% confidence interval
Landing phase time at low speed (s)					
CG	0.046 (0.010)	0.040 (0.010)	−0.006	0.069	−0.013/0.001
EG	0.044 (0.014)	0.039 (0.011)	−0.005	0.065	−0.011/0.000
Stance phase time at low speed (s)					
CG	0.094 (0.022)	0.108 (0.010)	0.014	0.024	0.002/0.026
EG	0.098 (0.017)	0.104 (0.014)	0.007	0.212	−0.004/0.017
Take off phase time at low speed (s)					
CG	0.129 (0.014)	0.131 (0.016)	0.002	0.772	−0.010/0.013
EG	0.130 (0.015)	0.129 (0.018)	−0.001	0.833	−0.011/0.009
Flight time at low speed (s)					
CG	0.085 (0.025)	0.072 (0.032)	−0.013	0.111	−0.029/0.003
EG	0.084 (0.027)	0.080 (0.028)	−0.004	0.548	−0.018/0.010
Step duration at low speed (s)					
CG	0.709 (0.046)	0.716 (0.039)	0.007	0.385	−0.010/0.025
EG	0.706 (0.034)	0.699 (0.037)	−0.007	0.373	−0.022/0.009
Landing phase time at high speed (s)					
CG	0.038 (0.007)	0.038 (0.006)	0.000	0.916	−0.006/0.005
EG	0.040 (0.009)	0.032 (0.007)*	−0.008	0.004	−0.012/−0.002
Stance phase time at high speed (s)					
CG	0.080 (0.013)	0.084 (0.019)	0.004	0.389	−0.006/0.015
EG	0.080 (0.013)	0.080 (0.016)	0.000	0.923	−0.010/0.009
Take off phase time at high (s)					
CG	0.108 (0.010)	0.111(0.011)	0.003	0.547	−0.007/0.012
EG	0.109 (0.013)	0.014 (0.017)	0.005	0.231	−0.003/0.013
Flight time high at speed (s)					
CG	0.103 (0.026)	0.089 (0.029)	−0.014	0.034	−0.028/−0.001
EG	0.106 (0.022)	0.098 (0.028)	−0.008	0.194	−0.019/0.004
Step duration at high speed (s)					
CG	0.681 (0.042)	0.663 (0.048)	−0.018	0.140	−0.042/0.006
EG	0.670 (0.033)	0.662 (0.045)	−0.008	0.478	−0.029/0.014
Contact time at low speed (s)					
CG	0.271 (0.035)	0.262(0.025)	−0.009	0.332	−0.027/0.009
EG	0.270(0.025)	0.264 (0.029)	−0.006	0.477	−0.022/0.010
Contact time at high speed (s)					
CG	0.215 (0.023)	0.218 (0.029)	0.003	0.625	−0.011/0.017
EG	0.214 (0.020)	0.220 (0.034)	0.006	0.348	−0.007/0.018
Cadence step/min at low speed					
CG	85.047 (5.942)	84.051(4.949)	−0.996	0.338	−3.084/1.092
EG	85.178 (4.215)	86.043 (4.576)	0.865	0.345	−0.977/2.706
Cadence step/min at high speed					
CG	88.369 (5.707)	90.863 (6.530)	2.494	0.124	−0.723/5.711
EG	89.709 (4.419)	90.902 (6.008)	1.193	0.397	−1.644/4.031

* Significant differences ($p \leq 0.05$) between EG and CG. EG: experimental group. CG: control group. SD: standard deviation.

($\Delta = 0.014$ s, $p = 0.024$) and a reduction of flight time at high speed ($\Delta = -0.014$ s, $p = 0.034$). Moreover, EG achieved a reduction of landing phase at high speed ($\Delta = -0.008$ s, $p = 0.004$). No other significant differences were showed after BTP.

Discussion

The purpose of this study was to determine the effects of a 12-week BTP on kinematic variables in long-distance runners. The main finding of this study showed that 12-week

BTP does not alter significantly kinematic variables in long-distance runners. Only EG achieved a reduction of landing phase at high speed; no other significant differences were showed after BTP. Other studies found no changes in strength and proprioception after 8 weeks of a progressive BTP on a grass surface[21] or changes in biomechanics after an 8-week, progressively introduced barefoot running program.[22] Likewise, other studies showed that no biomechanical changes were found in the intervention group after 8 weeks of a progressive BTP.[14] However, there was indicated that a 12-week intervention of controlled simulated barefoot running training was sufficient to elicit significant changes in lower limb kinematics not only during barefoot running, but also during running in regular cushioned running shoes.[23] These controversial results indicate that future studies should be performed to clarify doubts about the effect of BTP on kinematic variables.

The authors suggest that the lack of significant effects in the current study may be due to several points: (i) shoes annul this effect; (ii) the insufficient duration of BTP; (iii) the insufficient load of the training program; (iv) the effect of training surface. When athletes run unshod, the hardness of the surface where they are running causes an alteration on foot strike pattern. In previous studies only the 20% of the participants ran with a midfoot or forefoot pattern on the soft surface whereas 65% of the participants ran with a midfoot or forefoot patterns on hard surface.[24] Surface used in this study was grass, which may be a significant factor in causing no alteration in runner's kinematics pattern.

An unexplored area of the theory of barefoot running is the process by which biomechanical adaptations occur and if these are universally learned.[14] Thus, the associated kinematic barefoot running can be a trainable ability, and requires adaptive training with changes in the neuromuscular activation of calf muscles to facilitate plantar flexion before ground impact. In this sense, when sufficient unshod steps in relation to shod steps, are made, this produces higher triceps sural muscles previous activation, which can lead to a reduction in the peak of impact and the subsequent reduction in mechanical stress during running.[12,13]

In contrast to recent studies in which numerous problems related to greater incidence of bone marrow edema due to barefoot training protocols and uncontrolled loads, a positive finding of this study may be the non-detection of physical problems or injuries occurring in athletes associated with designed barefoot training program.[6] On balance a sufficient workload to cause changes in lower limb kinematics and a training protocol design which does not cause harm is needed. Referring to the correct progression from shod to barefoot condition, a prior step for adaptation to barefoot running could be minimalist footwear.

Finally, some limitations need to be considered such as 2D techniques in the video analysis. Moreover, it is very difficult to know how much barefoot training and at what intensity each subject has performed. It would be necessary to standardize training with caution to control the progress and problems of each athlete, as each runner progresses differently. Additionally, force measures does not has been included that would also be interesting to evaluate given their relationship to injury risk. However, the strengths of our study are that it provides new information about protocols for transitioning from shod to barefoot running and provides new insight into the already open debate about barefoot running with a protocol only based on running unshod without other interventions like plyometrics or neuromuscular workout. To the best of our knowledge, there is limited information about barefoot transition programs and this study will help to increase knowledge about this growing trend.

Conclusion

Despite no athlete suffered any harm during the study intervention, 12-week BTP based on the addition of barefoot running time at the end of daily training was not sufficient to cause chronic changes in lower limb kinematics shod, only in landing phase at high speed (that was lower). The authors suggest that running shoes may reduce the chronic effects of barefoot running. On the other hand, increasing the volume of workload or running on harder surfaces may be required to produce more chronic changes.

Conflict of interest

Authors declare that they don't have any conflict of interests.

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