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Systematic Review

The Effects of Minimal Shoes on Ankle Kinematics During Running: A Systematic Review

Fateme Khorramroo[1], Seyed Hamed Mousavi[2*]

1. *Department of Sports Injuries and Biomechanics, Faculty of Sports Sciences and Health, University of Tehran, Tehran, Iran. Email: negar_moj2004@yahoo.com , ORCID: 0000-0001-8018-7650.*
2. *Department of Sports Injuries and Biomechanics, Faculty of Sports Sciences and Health, University of Tehran, Tehran, Iran. Email: musavihamed@ut.ac.ir, ORCID:0000-0003-2906-2101.*

ABSTRACT

Minimal shoes may alter ankle kinematics while running. This study aimed to systematically review studies investigating ankle kinematics in runners while wearing minimalist shoes versus traditional shoes and barefoot. Four databases including PubMed (128 studies), Web of science (224), Scopus (242 studies) and Embase (148 studies) were searched from inception to Aug 9, 2022. Two reviewers screened studies to identify studies reporting the effects of minimal shoes on ankle kinematics during running. Eleven studies with a total of 203 (wearing minimal shoes) participants and 18 controls (8 participants wearing minimal shoes without gait training and 10 wearing standard shoes) were included. The study design of the included studies were RCTs (2 studies), prospective study (1), cross-sectional study (5), and crossover (3). The Downs and Black appraisal scale was applied to assess the quality of included studies. The results showed that minimal shoe was capable of changing the kinematics of ankle while running. Uncushioned minimal shoes decreased ankle dorsiflexion at initial contact and ankle adduction, and increased plantarflexion moment, strike index, total ROM and joint excursion in stance phase compared to traditional shoes. Standardizing shoes and speeds are needed for reliable comparisons among studies. Because most studies examining the efficacy of minimal shoes, had a low level of evidence, further studies providing valid and high-quality evidence which include RCTs are required to support clinical practice in the use of minimal shoes. Uncushioned minimal shoes are better replicating barefoot running. Therefore, it is recommended for runners since they can change their foot strike pattern to mid-foot or forefoot and consequently reduce peak impact force, resulting in preventing future injuries especially in the knee.

Keywords: Minimalist shoes, Ankle, Kinematics, Biomechanics, Runner

Corresponding Author: Seyed Hamed Mousavi, Department of Sports Injuries and Biomechanics, Faculty of Sports Sciences and Health, University of Tehran, Tehran, Iran. Email: musavihamed@ut.ac.ir. Tel: +989171542600

INTRODUCTION

Running has been the most popular sport worldwide [1]. People choose running to maintain and improve cardiovascular-pulmonary health, body composition, overall fitness, and exercise capacity [2], as it is low-cost and easily implemented [3]. Much research focused on constitutes of running performance including anatomy, physiology and biomechanics [4,5].

Biomechanical factors have a major role in performance of recreational and competitive running [6] as well as running related injuries (RRIs) [7]. Most body's movements occur in the sagittal plane during running. This is reflected by the relatively high force amplitudes in the vertical and the horizontal direction [8,9]. Rearfoot strike which increases average vertical loading rate has been related to running related injuries [10]. Lower limb tendinopathies (LLT) are a great part of RRIs [7]. A recent review demonstrated that untrained runners are at higher risk of overuse injuries compared to experienced recreational runners [11]. Some biomechanical risk factors are associated with overuse injuries including increased hip internal rotation and adduction angle [12], knee adduction angle, and rearfoot eversion and knee internal rotation [7,13]. These factors are possibly related to deficits in hip strength and endurance, which may grow with training.

Running shoe manufacturers have noticed biomechanical aspects specifically [14]. Different shoes and strike patterns produce different biomechanical characteristics that can affect injury risk. Running shoes are mainly designed as light weight, minimal or traditional cushioned types [15]. The efficiency of modern running shoes has been called into question, having a negative effect on foot function [16]. Moreover, unsafe ground and low or high temperatures restrict running barefoot. Minimalist footwear, derived from barefoot running theory, has been applied to clinical, laboratory and sports fields [6,17–20]. These running practices have encouraged researchers to investigate the effects of running barefoot versus in shoes on injury mechanisms, biomechanics and performance [21]. Minimal shoes are specified by low heel-toe drop, decreased midsole stack height, great flexibility, and lighter weight [22] and do appear to decrease patellofemoral joint loading compared to a neutral cushioned shoe [23], calf and Achilles tendon loading may increase while wearing minimal shoes [24]. The 12-week gait retraining with minimalist shoes transformed rearfoot strikers into forefoot strikers at a rate of 78% [25]. There are two types of minimal shoes; cushioned shoes including Nike Free 3.0 and uncushioned including Vibram FiveFinger, Leguano, Bikila Vibram. Uncushioned minimal shoes are better simulating barefoot running compared to cushioned minimal shoes [26]. Squadrone and Gallozzi [27] found similar ankle angles at foot strike during barefoot running and running with uncushioned minimalist shoes which were significantly different from standard shoe running. Bonacci et al. [28] reported significant differences between cushioned minimalist shoes with ultraflexible soles and barefoot condition in ankle dorsiflexion during initial ground contact.

Although several studies have investigated the effect of minimalist shoes on ankle kinematics in runners, there is a lack of a systematic review of this assessment. Therefore, this study aimed to systematically review studies investigating ankle kinematics in runners while wearing minimalist shoes.

MATERIAL AND METHODS

This systematic review was conducted in accordance with the PERSIST guidelines for systematic review [29].

Search strategy

Relevant studies were identified through 4 electronic databases: PubMed (128 studies), Web of Sciences (224), Scopus (242 studies) and Embase (148 studies). The search was run on Aug 10 2022 to extract

studies from inception to Aug 9, 2022. Key terms used in the search strategy were based on broad terms and related synonyms targeting 4 categories:
#1 biomechanic* OR kinematic* OR acceleration OR velocity OR inversion OR eversion OR dorsiflexion OR angle OR "plantar flexion" OR pronation OR supination OR flexion OR extension OR "range of motion"
#2 shoe OR shoes OR footwear
#3 minimal OR minimalist OR minimalistic
#4 run OR runners OR runner OR running OR jog OR jogging
#1 AND #2 AND #3 AND #4
Reference lists from previous related systematic reviews on effect of minimalist shoes on kinematics of ankle were hand searched to ensure identification of all relevant studies.

Eligibility Criteria

All searches were carried out independently using predetermined inclusion criteria and extraction forms. Details on the titles read, abstracts read, full text articles. The inclusion criteria were: Runners, Level-3 evidence or higher, minimalistic shoes, ankle kinematics, and studies written in English. The exclusion criteria were: Non-English studies, Non-runners, studies not assessing the effect of minimalist shoes, studies not assessing the ankle kinematics.

Study selection

Two reviewers independently screened the title, abstract and full-text of studies (FK and SHM), in line with the inclusion criteria. In any case of disagreements, a consensus was reached by discussion of 2 reviewers.

Quality assessment

Two authors (FK and SHM) independently assessed the methodological quality of the included studies using the modified Downs and Black checklist [30] The average score of eligible studies was 13.7 points on the Downs and Black.

Data collection

One author (FK) extracted all relevant data from the included articles. To reduce any bias or errors in the extraction of data, all data were verified by SHM. In this review, Ankle kinematics data were extracted. Information from Participants, Sample size, study design, sex, age, height, mass, weekly running time, intervention, task, tools were extracted from the included studies. The RevMan version 5.4 was used to show the results of included studies using forest plots.

RESULTS

The main literature search yielded a total of 742 from which 341 items remained after duplicate removal. 330 studies were excluded due to not meeting the inclusion criteria and 9 were included after screening of titles and abstracts for further eligibility check [10,25,26,28,31–35]. Two studies added by hand search [6,27]; totally 11 studies were included. Figure 1 shows the flow diagram, summarizing the selection process and the number of studies excluded at each stage with reasons.

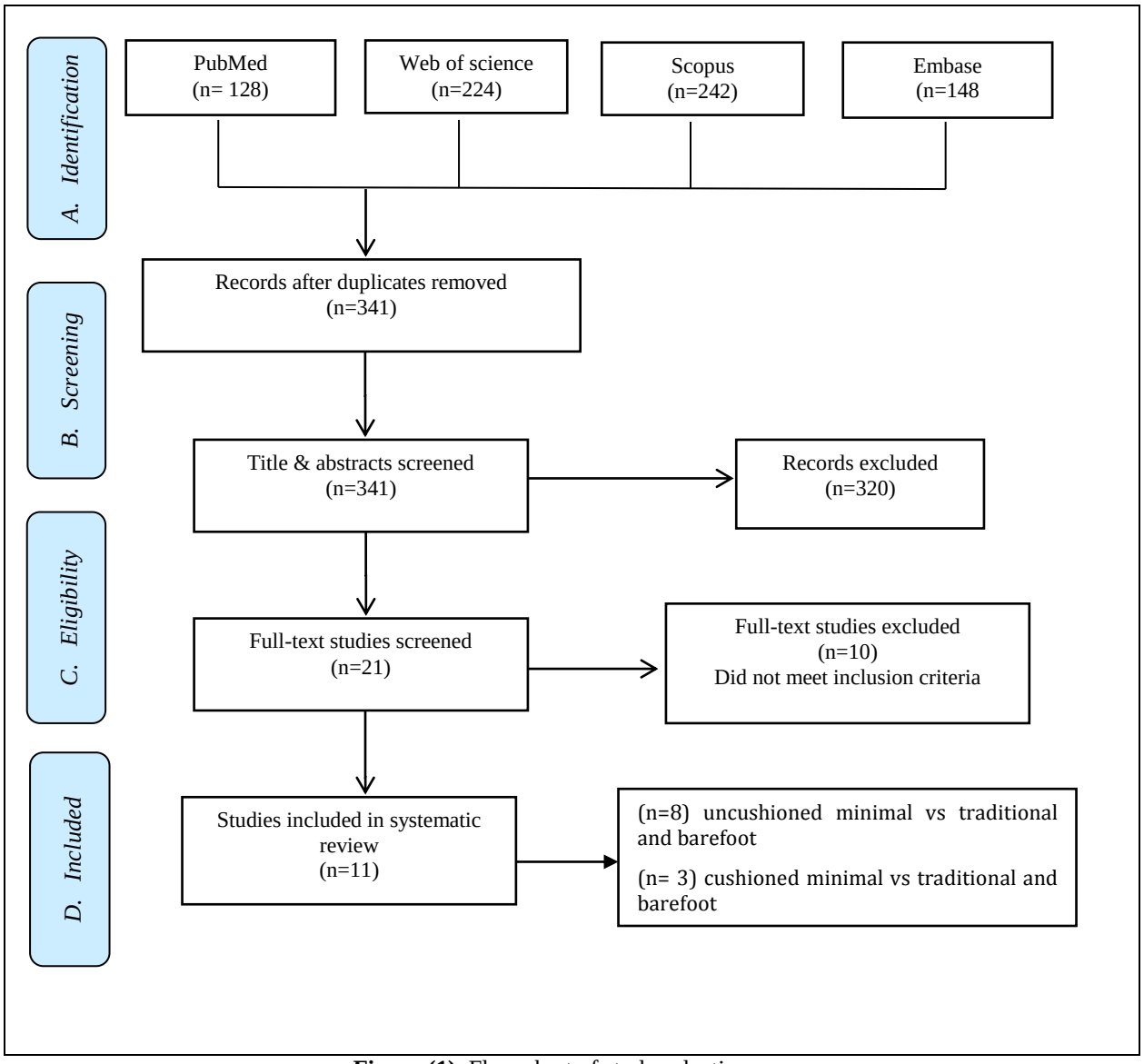

Figure (1). Flow chart of study selection process

Study characteristics

Table 1 summarizes the characteristics of the included studies. There were 8 cross-sectional studies [10,26–28,31,33–35] and 2 RCTs [6,25] and one observational prospective study [32] assessing the effect of minimalist shoes on ankle kinematics.

Table 1. Study charectristics

	Authors	Design	shoes	variables	Tools	Duration	Participants	sex	No of participants	age (year)	height (m)	mass (kg)	weekly running volume (km/wk)
1	Squadrone R, Gallozzi C. 2009 [27]		1.Vibram, Fivefingers Classic (VF) model 2.Neutral protective	Ankle angle (15 ms before touchdown), ROM (support phase)	SVHS sony vedeocamera 60HZ, Zebris FDM-T instrumented treadmill (Zebris Medical GmbH, Isny, Germany)	2 session	Healthy runners	M	8	32±5	1.75±0.05	71±6	
2	R. W. Willy and I. S. Davis 2013 [31]		1.Nike Pegasus (Nike, Beaverton): standard cushioned 2. Nike Free 3.0 :minimalist	foot inclination (footstrike), dorsiflex angle	strumented treadmill (AMTI, Watertown, MA), Visual 3D (CMotion, Bethesda, MD).	Single session	RFS runners who had never run in a minimalist shoe	M	14	24.8± 3.2	NA		31.9 (10.5)

3	J. Bonacci et al.	2013 [28]	Experimental	1.Minimalist shoe (NIKE Free 3.0); reduced heel-forefoot offset (4 mm) 2.Racing flat: low heel-forefoot offset (6 mm) 3.Lightweight racing flat: (NIKE LunaRacer2, regular	Dorsiflexion	22-camera VICON motion analysis system (Oxford Metrics Ltd, Oxford, UK)	10 days familiarization	highly trained runners	14 M 8F	22	29.2 (6.0)	1.76 (0.07)	65.6 (8.8)	105.3 (33.5)
4	C. McCarthy et al.	2013 [6]	Repeated measure RCT	1.Vibram FiveFingers Classic model shoes 2.Standard, neutral cushioned (Adidas Duramo)	Ankle flexion angle (foot-strike), peak ankle dorsiflexion (stance), ankle ROM (absorptive phase), ankle flexion angle (toe-off), knee flexion angle (foot-strike)	Coda Dual CX1 system (Charnwood Dynamics, Rothley, UK).	12 week	recreational athletes	F	9 (10 control)	29 ± 3	1.66 (0.06)	60.9 (10.5)	28.9 (11.5)
5	J. D. Willson et al.	2014 [32]	Observational prospective	1.Conventional cushioned heel :(model 629; New Balance, Boston, MA) 2.Minimalistic: (Bikila;Vibram USA, Concord, MA).	ankle flexion, strike pattern	120 Hz 8-camera motion analysis system (Motion Analysis Corp, Santa Rosa, CA)	2 week	RFS runners habitually running in conventional shoes	F	19	21.2 (1.6)	1.66 (0.06)	60.5 (5.7)	24.5 (15.3)

6	K. Hollander et al.	2015 [26]	Randomized crossover	1.Asics GT-2160:standard, Nike free 3.0:cushioned minimal, 2.Leguano:uncussioned minimalist).	Ankle angle(foot strike),rate of rearfoot strike	8-camera IR motion analysis system 200 Hz (VICON, Oxford, UK). Treadmill (Ergo-Fit TRAC 4000, ERGO-FIT GmbH & Co. KG, Pirmasens, GERMANY)	2 sessions	Distance runners	22 M 13F	35	27.9 ± 6.2	179.2 ± 8.4	73.4 ± 12.1	24.9 ± 10.9
7	W. Fredericks et al.	2015 [33]		1.Personal 2.standardized :Nike © Air Pegasus + 27; Nike, Inc., Beaverton, OR) 2.Minimal (Vibram, FiveFinger © KSO; Concord, MA) maximum sole thickness of < 5mm 3.barefoot	ankle angle at foot strike, plantarflexion,	two digital video cameras (Basler A601f® ; Basler AG,Ahrensburg, Germany)		Recreational runners	13 M 13F	26	26.5 (6.1)	1.71 (0.10)	66.6 (11.3)	25.8 (20.7)
8	J. T. Fuller et al.	2016 [34]	Crossover	1.Conventional : Asics Gel Cumulus-14 (Asics Corporation, Kobe, Japan), 16% minimalist index. 2. Minimal: Asics Piranha SP4 racing flat (Asics Corporation). 72% minimalist index	Sagittal-plane kinematics	12-camera system (model MX-F20; Vicon Motion Systems Ltd, Oxford, United Kingdom) 300 Hz.		Trained runners	M	26	30±7.9	1.79±0.06	75.3± 8.2	27±15

9	J. J. Hannigan et al.	2019 [10]	Repeated measure	1. The traditional running shoe: New Balance Fresh Foam Boracay 980 v2. Adding 2. Maximal shoe) or removing 3. Minimal shoe) cushioning from traditional shoe.	Eversion	8-camera Vicon motion capture system (Oxford Metrics Ltd) 250 Hz		Recreational runners	6M 14F	20	32.3 ± 6.1	1.69 ± .08	65.5 ± 10.1	24.5 ± 10.6
10	Y. Yang et al.	2020 [25]	parallel RCT	1.Minimal shoe, type INOV-8 Bare-XF 210 V2	foot strike angle, plantarflexion angle and hip joint angular extension velocity	10-camera motion capture system (100 Hz, T40, Vicon Motion Inc., Oxford, United Kingdom),	12 weeks	recreational runners	M	17 (9 GR+ 8 MIN)	30±6.4	175±5.2	71.9± 9.4	27.4±8.7
11	K. Hébert-Losier et al	2022 [35]	Crossover	1.Super:Nike Vaporfly 4% (VP4), 2.Minimal: Saucony Endorphin Racer 2 lightweight racing flat (FLAT), 3.Own shoes	ankle ROM, plantarflexion velocities, Foot-ground angles	8-camera Oqus 700+ 3D motion 300 Hz	4 sessions in 14 days	Recreational runners	M	16	33±12	1.79 ± 0.06	77.0 ± 8.7	

Minimalist shoes

Three studies used Nike free [26,28,31] and 3 studies used Vibram [6,27,32] as minimalist shoes. One study utilized Leguano uncushsioned minimalist shoes along with Nike [26]. One study used Asics Piranha SP4 racing flat [34] while another study used a costume-designed shoes with cushions removed [10]. The other study used Saucony Endorphin Racer 2 FLAT [35]. One study used INOV-8 Bare-XF 210 V2 [25].

Ten studies compared running wearing minimal shoes versus traditional shoe types [6,10,26–28,31–35]. Four studies compared running in minimal shoes against barefoot running [26–28,33]. Three studies assessed minimal shoes versus uncushioned minimal shoes [26], minimal shoes along with gait training [25], and maximal shoes [10].

Quality assessment

Eleven studies were assessed by the Downs and black scale [30]; Five studies scored 13 [10,25,33–35], four studies scored 14 [27,28,31,32] and 2 studies scored 15 [6,26]. Any disparities in scoring were rechecked by both authors. Table 2 shows the results of the quality assessment. The average score of eligible studies was 13.7. All study outcomes were reported from more than 85% of the subjects initially allocated to a treatment or control group.

Table 2. Studies quality assessment based on Downs and Black checklist

	Item	1	2	3	5	6	7	10	11	12	16	18	20	21	22	25	
		Aim clear	Outcome described	Subjects clear	Distribution of confounding	Findings clear	Estimate of random	P-value report	Subjects representative of	Proportion of subjects	Performed analysis were	Proper statistic	Valid reliable outcome	Subjects in group from same	Subjects recruited same	Adjustment of confounding	Total
1	Joe T Fuller et al., 2016 [34]	1	1	1	2	1	1	1	0	0	1	1	1	1	0	1	13
2	Bonacci et al., 2013 [28]	1	1	1	2	1	1	1	0	0	1	1	1	1	1	1	14
3	Frederick et al., 2015 [33]	1	1	1	2	1	1	1	0	0	1	1	1	1	0	1	13
4	Yang Yang et al. 2020 [25]	1	1	1	2	1	1	1	0	0	1	1	1	1	0	1	13
5	JJ Hannigan et al., 2019 [10]	1	1	1	2	1	1	1	0	0	1	1	1	1	0	1	13
6	J. D. Willson et al., 2014 [32]	1	1	1	2	1	1	1	0	0	1	1	1	1	1	1	14
7	C. Mc Carthy et al., 2013 [6]	1	1	1	2	1	1	1	1	0	1	1	1	1	1	1	15

8	K. H.Loiser et al., 2022 [35]	1	1	1	2	1	1	0	1	0	1	1	1	1	0	1	13
9	R. Willy and I. s. Davis 2013 [31]	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	14
10	K. Hollander et al., 2015 [26]	1	1	1	2	1	1	1	1	0	1	1	1	1	1	1	15
11	R. Squadrone and C. Gallozzi 2009 [27]	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	14

Minimalist versus traditional

The results of studies investigating uncushioned and cushioned minimal shoes versus traditional shoes on ankle kinematics are shown in Figure 2 and 3. Minimal shoes decreased dorsiflexion in landi ng and increased total ROM and joint excursion ($p < 0.05$) [27].

After 12-week running in minimalistic shoes, plantarflexion increased while wearing minimalistic shoes at foot-strike and toe-off versus pre-test ($p < 0.001$, $p < 0.01$) and control ($p < 0.01$, $p < 0.05$) [6]. A greater ankle ROM in the absorptive phase of stance was observed wearing minimal shoes compared with pre-test ($p < 0.01$) and controls ($p < 0.001$) [6].

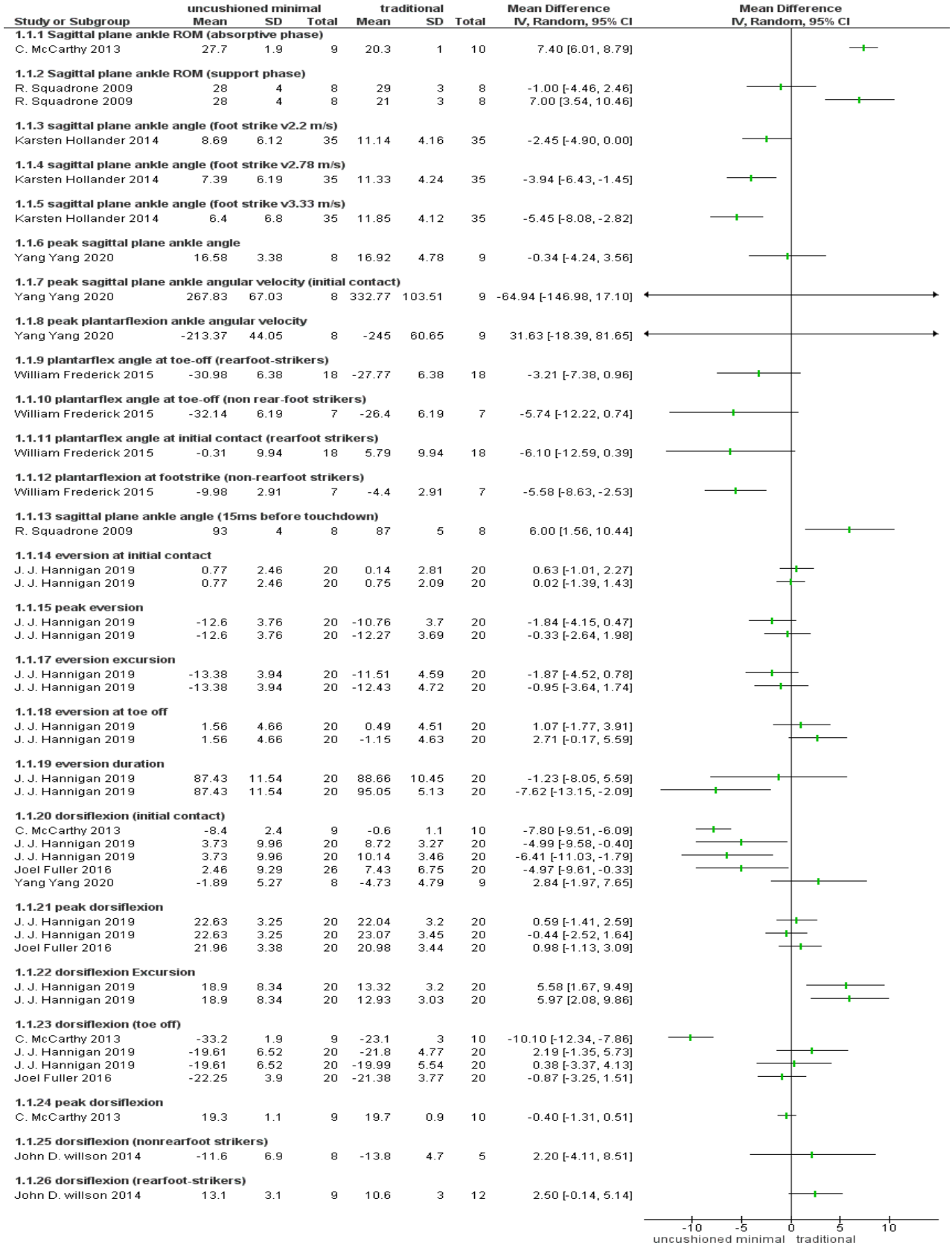

Figure (2). Forest plot of the results of uncushioned minimal shoes versus traditional shoes on ankle kinematics

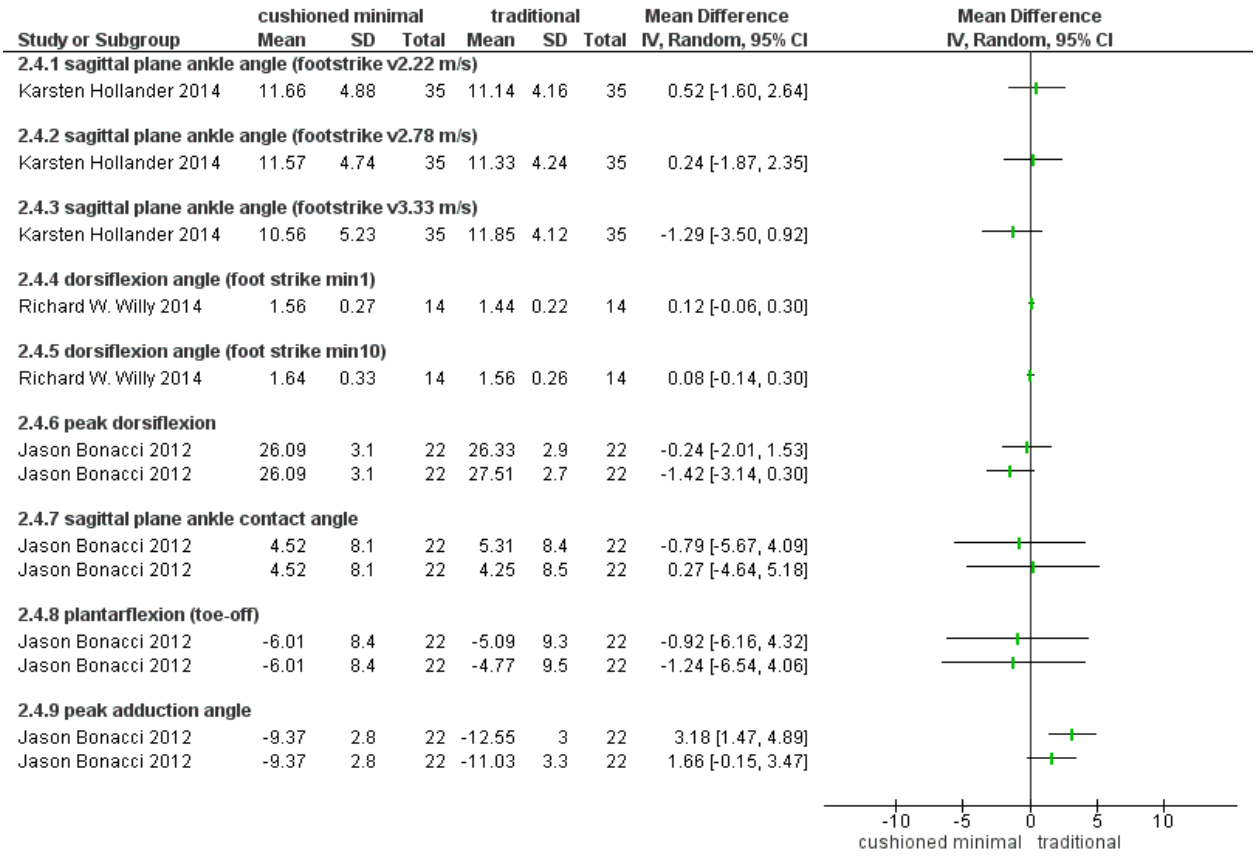

Figure (3). Forest plot of the results of cushioned minimal shoes versus traditional on ankle kinematics

In a study [10] peak eversion was increased in the minimal shoe (12.60 ± 3.76°) compared to the traditional shoe (10.76 ± 3.70°). Dorsiflexion decreased at initial contact (3.73 ± 9.96°) compared to the traditional shoe (10.14 ± 3.46°) and dorsiflexion excursion was greater in the minimal shoe (18.90 ± 8.34°) compared to the traditional shoe (12.93±3.03°).

In a study [26] ankle angle at foot strike during 3 different speeds, footwear conditions and running velocity significantly ($p < 0.001$) changed, except for comparison of cushioned minimalist and standard shoe conditions ($p = 0.674$). Wearing uncushioned minimalist running shoes decreased dorsiflexion (3.78°) during foot landing compared to cushioned minimalist running.

In another study [31] Runners struck the ground with a more dorsiflexed foot ($p = 0.025$), and less inclination ($p = 0.048$) and dorsiflexion ($p = 0.035$) at foot-strike wearing minimalist shoes.

In the study [33] plantarflexion increased with speed ($p < 0.001$). There was an interaction effect of speed and shod condition for toe-off plantarflexion ($p < 0.0001$). In rearfoot strikers, toe-off plantarflexion was greater when barefoot versus minimalist ($p = 0.000$) and greater in personal footwear versus minimalist footwear ($p = 0.05$) and minimalist versus standard footwear ($p = 0.05$). In non-rearfoot strikers, plantarflexion was greater in barefoot than minimal shoes ($p = 0.05$), and both were greater than traditional shoes (various $p < 0.05$).

In a study [34] runners landed with a more plantar-flexed ankle at initial contact and in another study [32] no changes in the ankle flexion angle at initial contact were observed in minimalist shoes compared to conventional shoes.

In a study [10] wearing maximal shoes, eversion at toe-off was greater in the maximal shoe (1.15±4.63°) compared to the minimal shoe (–1.56±4.66°). Eversion duration was greater in the maximal shoe (95.05 ± 5.13%) compared to the minimal shoe (87.43 ± 11.54%). In addition, dorsiflexion excursion was greater in the minimal shoe (18.90±8.34°) versusmaximal shoe (13.32±3.20°)

In a study [35] minimal exhibited smaller foot-ground angles (i.e., less rearfoot) than VP4 (super shoes) and greater peak dorsiflexion in stance. Peak plantarflexion velocities in the late stance were greatest in minimal. Ankle ROM in stance was greatest in minimal shoes.

Two studies compared Minimalist vs. participants' own shoes; In one study [35] minimal exhibited smaller foot-ground angles (i.e., less rearfoot) than participant own shoes and greater peak dorsiflexion in stance. Peak plantarflexion velocities in the late stance were greatest in minimal shoes. Ankle ROM in stance was greatest in minimal shoes. In another study [33], toe-off plantarflexion in rearfoot strikers was greater in personal footwear versus minimalist footwear ($p = 0.05$). Toe-off plantarflexion in non-rearfoot strikers was greater in minimalist than personal shoes ($p < 0.05$)

In a study [28] running barefoot compared to regular shoes, the ankle joint was less dorsiflexed at initial contact and more plantarflexed at toe-off ($p \leq 0.001$). Peak ankle dorsiflexion and adduction during stance were reduced when barefoot and in the minimalist shoe compared to the racing flat and regular shoe ($p = < 0.005$ for dorsiflexion and $p \leq 0.008$ for adduction).

Minimalist versus barefoot

The results of studies investigating uncushioned and cushioned minimal shoes versus barefoot on ankle kinematics are shown in Figure 4 and 5. Three studies compared minimalist vs. barefoot. In a study [26] running barefoot reduced dorsiflexion compared to uncushioned and cushioned minimalist shoes. In another study [33] toe-off plantarflexion in rearfoot strikers was greater when barefoot versus minimalist ($p = 0.04$). Toe-off plantarflexion in non-rearfoot striking was greater in minimalist and barefoot than personal condition (various $p < 0.05$) and in barefoot than minimal shoe ($p = 0.05$). In the other study [28] when running barefoot the ankle joint was less dorsiflexed at initial contact and more plantarflexed at toe-off compared with all shod conditions ($p \leq 0.001$). A study [25] compared running with Minimal shoes versus minimal shoes added with gait training. Foot-strike angle of the gait-training (GR) group decreased by 10.3 ◦ after training ($p = 0.015$). The foot-strike angle of the GR group was diff erent from that of the minimal (MIN) group in the post-test ($p = 0.017$). After training, the ankle angle decreased by 4.6 ◦ (GR) and 2.5 ◦ (MIN) at touchdown.

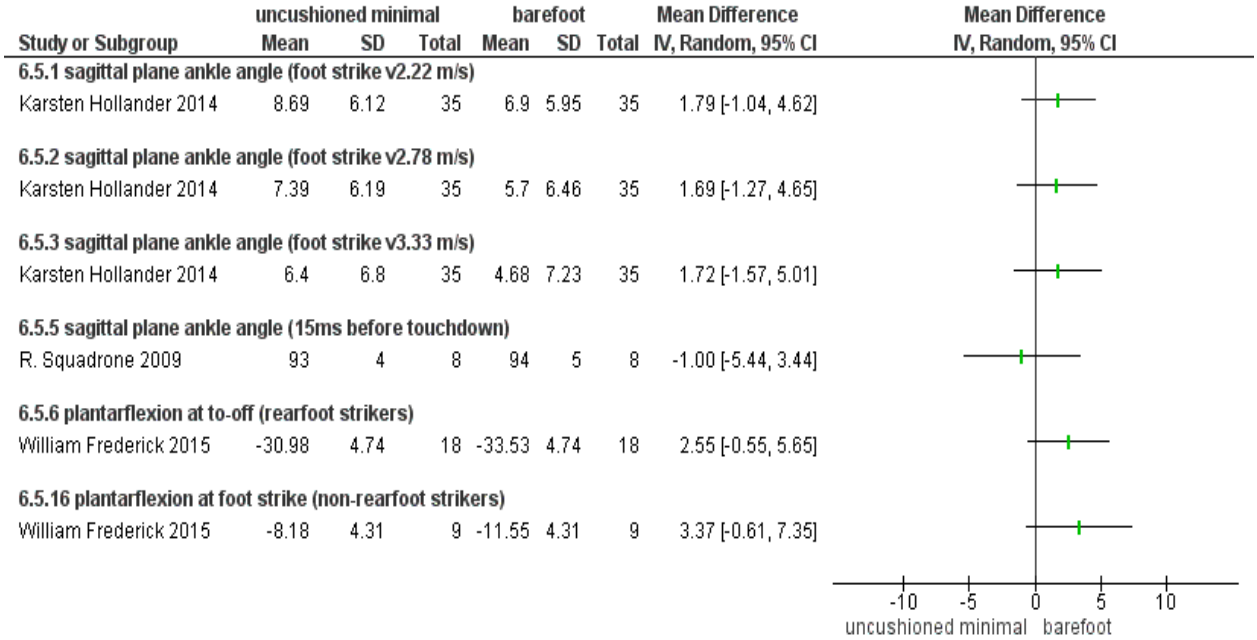

Figure (4). Forest plot of the results of uncushioned minimal shoes versus barefoot on ankle kinematics

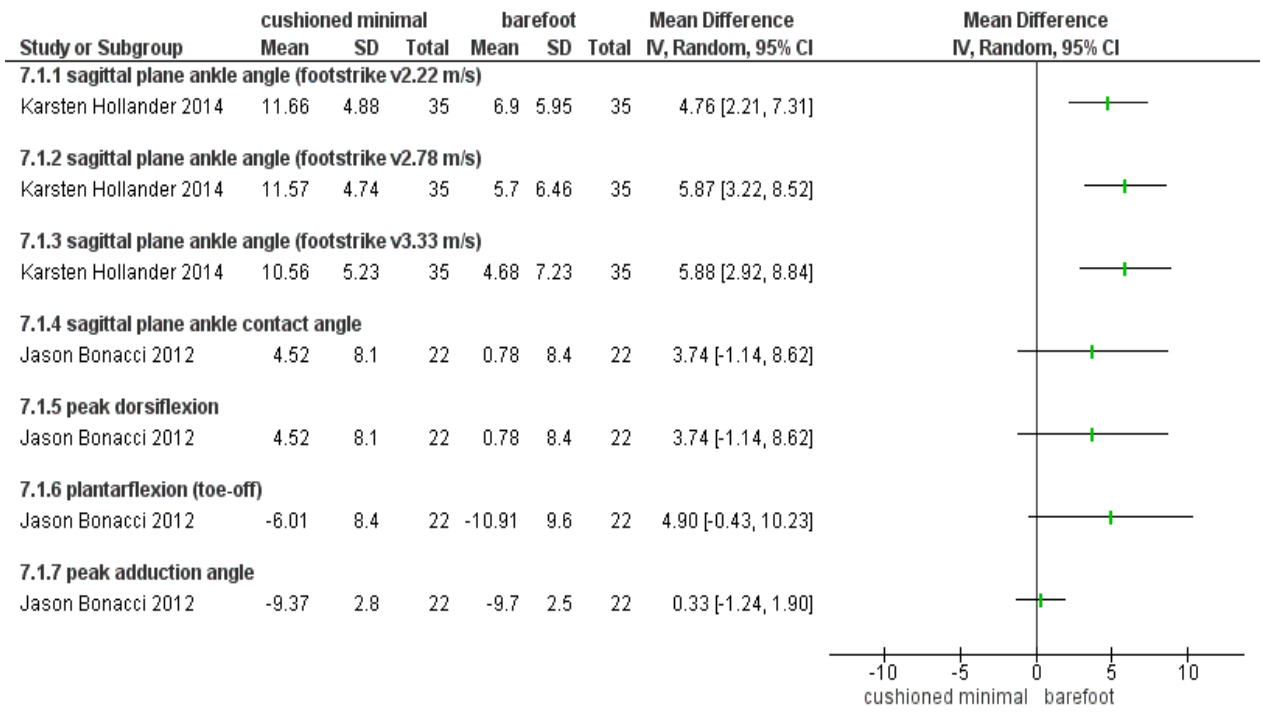

Figure (5). Forest plot of the results of cushioned minimal shoes versus barefoot on ankle kinematics

DISCUSSION

We aimed to systematically review the effects of minimalist shoes on ankle kinematics in runners. Two comparisons were done in the included studies: cushioned minimal shoes versus traditional shoes and barefoot, and uncushioned minimal shoes versus traditional shoes and barefoot.

Our systematic review suggests some alterations in ankle dorsiflexion, plantarflexion, eversion, abduction and ROM which may have positive effects on injury prevention. Most runners have a rear foot strike pattern (RFS); however, barefoot runners contact the ground with mid-foot or forefoot, making the absorption of collision forces with the ground to eliminate excessive pressure at the heel [18]. The difference in strike patterns may be due to kinetic and kinematic changes in GRFs, loading rates, joint moments and powers, joint ROM, muscle activation patterns, and running economy. These alterations while barefoot or wearing minimalist shoes make avoidance against RRIs [36–38] and/or excel running performance [39,40]. Evidence shows a forefoot strike pattern when barefoot, leading to a flatter foot placement at contact [41] and more plantarflexion. Wearing the traditional cushioned shoes, runners contact the ground with the heel [26] and the ankle is more dorsiflexed [27] which requires more work from knee extensor muscles and could lead to knee injury risk [34]. Moreover, Stride length was longer and stride frequency was lower [26,28]. As speed increases, relative step length increases faster in personal and standard shoes than in minimalist or barefoot [33]. These spatiotemporal characteristics can influence impact shock [42].

Cushioned minimal shoes versus traditional shoes and barefoot

Cushioned minimal shoes were less effective in decreasing dorsiflexion during foot landing in the study by k. Hollander et al. [26] compared to standard shoes and more different from running barefoot [26][28]. Running kinematics for uncushioned minimalist shoes were more similar to barefoot running than cushioned minimalist shoes [26]. Minimalist footwear cannot entirely replicate the mechanics of running barefoot [28]. During barefoot running, ankle dorsiflexion angles and rate of rear-foot strikes were the lowest and increased with augmented cushioning of footwear [26]. Less dorsiflexion decreases the pressure underneath the heel [27] and may be an attempt to eliminate the discomfort associated with the

large and rapid impact peak that occurs when rearfoot striking while barefoot [18]. The dynamics of [42]running barefoot are different to that of running in a minimal shoe that is cushioned and has an elevated heel [28].

A study [10] reported a significantly greater eversion at toe-off in the maximal shoes versus traditional shoe and minimal shoes. In other words, participants were still everted at toe-off in the maximal shoe, while inverted at toe-off in the minimal shoes. This study also reported a greater eversion duration and less dorsiflexion excursion in those who wore maximal shoes compared to those with minimal shoes. As a greater eversion was reported as a potential risk factor for some RRIs [7], minimal shoes may have a positive impact on reducing RRIs.

Uncushioned minimal shoes versus traditional shoes and barefoot

Uncushioned minimal shoes decreased ankle dorsiflexion at initial contact and ankle adduction and increased plantarflexion moment, strike index, total ROM and joint excursion in stance phase compared to traditional shoes. Moreover, gait training while in minimalist shoes decreased foot strike angle at initial contact. The increase of ankle plantarflexion moment when running barefoot increases eccentric work of the triceps surae muscles [43]. Ultimately, this could increase the risk of Achilles tendon injury and may be a risk of running barefoot [44].

Biomechanics of running in minimalist shoes is more similar to that of barefoot. Studies reported that barefoot running reduces ankle dorsiflexion at initial contact. This can decrease local pressure under the heel [45]. In the shod condition, this local pressure is eliminated by cushioning through an elevated heel, which enables runners to land with a dorsiflexed ankle [18]. Squadrone and Gallozzi [27] reported that minimalist shoes increased the strike index and decreased the ankle angle at initial contact.

All included studies reported altered ankle kinematics in those with minimal shoes compared to others except one study [32] which used minimal shoes modelBikila, Vibram USA, concord, and MA.

Limitations and recommendations for future studies

This study had several limitations. First, there is no evidence to investigate the long-lasting effects of minimal shoes; the longest follow-up was 12 weeks. Second, only 2 RCTs [6,25] were included due to the small sample size in some studies, further studies should include high-quality randomized control trials with rigorous methodology (ie, a large number of participants, apply concealment of allocation of subjects into their respective groups and adjust for confounding factors in the statistical analysis, optimizing the reporting of studies) and assessing 3D kinematics not to miss angular values. Furthermore, extrapolating the results to different types of minimalist shoes must be done cautiously, especially the uncushioned ones without an elevated heel. Runners should not expect to instantly simulate barefoot running while in minimal shoes.

CONCLUSION

Studies indicated changes in ankle kinematics in those who wear minimal shoes compared to those who wear other shoes. Minimal shoes decreased ankle dorsiflexion at initial contact and increased plantarflexion at toe off. Moreover, minimal shoes decreased ankle adduction and foot strike angle at touch down and increased strike index and total ROM in stance. Standardizing shoes and speeds are needed for reliable comparisons among studies. Because most studies examining the efficacy of minimal shoes, had a low level of evidence, further studies providing valid, high-quality evidence which include RCTs are required to support clinical practice in the use of minimal shoes. Uncushioned minimal shoes are better replicating barefoot running. Therefore, it is recommended for runners since they can change their foot strike pattern to mid-foot or forefoot and consequently reduce peak impact force, resulting in preventing future injuries especially in the knee.

Author Contributions: Conceptualization, FK, SHM; methodology, FK, SHM; formal analysis, FK, SHM; investigation, FK, SHM; resources, FK, SHM; data curation, FK, SHM; writing—original draft

preparation, FK, SHM; writing—review and editing, FK, SHM; supervision, SHM; project administration, FK, SHM. All authors have read and agreed to the published version of the manuscript.

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تاثیر کفش های مینیمال بر کینماتیک مچ پا هنگام دویدن: یک مطالعه سیستماتیک ریویو

فاطمه خرم رو[1]، سید حامد موسوی*[1]

۱. گروه آسیب شناسی و بیومکانیک ورزشی، دانشکده علوم ورزشی و تندرستی، دانشگاه تهران، تهران، ایران

چکیده: کفش های مینیمال ممکن است کینماتیک مچ پا را در حین دویدن تغییر دهند. هدف از این مطالعه، بررسی سیستماتیک مطالعاتی است که به بررسی اثر کفش‌های مینیمال در مقایسه با کفش های سنتی و پابرهنه بر کینماتیک مچ پا در حین دویدن پرداخته بودند. چهار پایگاه داده شامل PubMed (۱۲۸مطالعه)، Web of Science (۲۲۴ مطالعه)، Scopus (۲۴۲ مطالعه) و Embase (۱۴۸ مطالعه) از ابتدا تا ۹ اوت ۲۰۲۲ جستجو شدند. مطالعات توسط دو محقق غربالگری شدند تا مطالعاتی را که اثر کفش مینیمال را بر کینماتیک مچ پا هنگام دویدن گزارش می‌کردند شناسایی کنند. برای ارزیابی کیفیت مطالعات وارد شده از مقیاس ارزشیابی داونز و بلک استفاده شد. یازده مطالعه با مجموع ۲۰۳ شرکت‌کننده (که کفش مینیمال پوشیدند) و ۱۸کنترل (۸ آزمودنی که آموزش راه رفتن را دریافت نکردند و ۱۰ آزمودنی با کفش های استاندارد خودشان دویدند) وارد تحقیق شدند. نوع تحقیق مطالعات شامل کارآزمایی بالینی تصادفی شده (۲ مطالعه)، مطالعه آینده نگر (۱ مطالعه)، مطالعه مقطعی (۵ مطالعه) و مطالعه متقاطع (۳ مطالعه) بود. برای ارزیابی کیفیت مطالعات وارد شده از مقیاس ارزشیابی داونز و بلک استفاده شد. نتایج نشان داد که کفش مینیمال توانایی تغییر کینماتیک مچ پا در حین دویدن را دارد. کفش‌های مینیمال بدون بالشتک باعث کاهش دورسی فلکشن مچ پا در تماس اولیه و کاهش اداکشن مچ پا، و افزایش ممان پلانتار فلکشن، شاخص ضربه، دامنه حرکتی کل و گردش مفصل در فاز ایستادن نسبت به کفش‌های سنتی شد. استاندارد کردن کفش ها و سرعت های دویدن برای مقایسه قابل اعتماد در بین مطالعات مورد نیاز است. مطالعات بیشتری با ارائه شواهد معتبر و باکیفیت که شامل کارآزمایی بالینی تصادفی شده می‌شود برای حمایت از تمرین بالینی در استفاده از کفش‌های مینیمال مورد نیاز است. کفش های مینیمال بدون بالشتک راه رفتن پا برهنه را بهتر شبیه سازی می کنند بنابراین کفش های مینیمال به دوندگان توصیه می شود زیرا می توانند الگوی ضربه پا را به وسط پا یا جلوی پا تغییر دهند که در نتیجه باعث کاهش اوج ضربه هنگام دویدن و جلوگیری از آسیب های بعدی به ویژه در زانو می شودند.

واژه های کلیدی: کفش مینیمال، مچ پا، کینماتیک، بیومکانیک، دونده