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REVIEW

Gait Retraining for Running-Related Injuries

Reentrenamiento de la marcha en lesiones por carrera

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ABSTRACT

Gait retraining has emerged as a potential strategy for managing running-related injuries through modifications in step cadence, foot-strike patterns, and impact loading. However, its clinical effectiveness, particularly regarding pain reduction and injury prevention, remains incompletely established. This systematic review, conducted in accordance with PRISMA 2020, examined primary studies published between 2018 and 2026 and retrieved from Scopus, PubMed, and OpenAlex. Among 768 identified records, 413 underwent screening, resulting in the inclusion of 27 studies, of which 12 were randomized or quasi-randomized trials and 15 employed non-randomized designs. The findings generally indicated improvements in pain and reductions in impact loading following gait retraining interventions. A large trial involving novice runners documented a 62% reduction in injury occurrence (hazard ratio 0.38, 95% confidence interval 0.25–0.59). In contrast, two trials conducted among recreational runners did not demonstrate an overall reduction in injury incidence. These findings suggest that gait retraining can alleviate pain, reduce functional disability, and modify impact-related biomechanical variables, although its preventive effectiveness remains uncertain, with the strongest evidence of benefit observed among novice runners.

Keywords: gait retraining; running; running-related injuries; biomechanics; step rate; systematic review.

RESUMEN

La reeducación de la marcha se ha planteado como una estrategia para el abordaje de las lesiones relacionadas con la carrera mediante modificaciones en la cadencia, el patrón de apoyo del pie y las cargas de impacto. Sin embargo, su efectividad clínica, especialmente en la reducción del dolor y la prevención de lesiones, todavía no está completamente establecida. Se realizó una revisión sistemática conforme a las directrices PRISMA 2020, que incluyó estudios primarios publicados entre 2018 y 2026 e identificados mediante búsquedas en Scopus, PubMed y OpenAlex. De los 768 registros recuperados, 413 fueron sometidos a cribado y finalmente se incluyeron 27 estudios, de los cuales 12 correspondieron a ensayos aleatorizados o cuasialeatorizados y 15 a diseños no aleatorizados. Los resultados mostraron, en términos generales, una disminución del dolor y de las cargas de impacto tras las intervenciones de reeducación de la marcha. Un ensayo de gran tamaño realizado en corredores principiantes comunicó una reducción del 62 % en la aparición de lesiones (razón de riesgos instantáneos de 0,38; intervalo de confianza del 95 %: 0,25-0,59). Por el contrario, dos ensayos desarrollados en corredores recreativos no encontraron una disminución global de la incidencia de lesiones. En conjunto, los hallazgos sugieren que la reeducación de la marcha puede contribuir a aliviar el dolor, disminuir la discapacidad funcional y modificar las variables biomecánicas relacionadas con el impacto. No obstante, su eficacia preventiva continúa siendo incierta, y la evidencia más sólida de beneficio se concentra en corredores principiantes.

Palabras clave: reentrenamiento de la marcha; carrera; lesiones por carrera; biomecánica; cadencia; revisión sistemática.

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INTRODUCTION

Running is among the most widely practiced forms of physical activity, and its popularity has been accompanied by a persistent burden of musculoskeletal injury. Annual incidence estimates for running-related injuries range from 19% to 79% of runners, a spread that reflects differences in population, definition, and surveillance method.(1) The knee, foot, and lower leg carry most of this burden, and patellofemoral pain is consistently the most common single diagnosis in clinical and epidemiological series. Kinetic variables measured during running, in particular the magnitude and rate of vertical impact loading, have been associated prospectively with injury in female recreational runners,(2) and a set of kinetic risk factors has been described in the same population.(3) Lower step rate has likewise been associated with a higher risk of bone stress injury in collegiate cross-country runners,(4) which positions cadence and impact loading as modifiable targets rather than fixed individual traits.

Gait retraining operates on this premise. Three families of intervention dominate the literature: increasing cadence or step rate, converting a rearfoot strike toward a non-rearfoot or forefoot pattern, and reducing impact loading through cues to land softly. A single session of step rate manipulation changes joint mechanics at the knee and hip,(5) and real-time feedback through wearables now allows these modifications to be delivered and monitored outside the laboratory.(6) The clinical rationale is straightforward: if retraining alters the mechanics that predict injury, it should reduce pain in injured runners and prevent recurrence or new injury in those at risk. Gait retraining has consequently been proposed as a first-line biomechanical intervention for patellofemoral pain, with a review of the approach describing the transition to a forefoot strike and increased cadence as the two dominant clinical strategies.(7) The mechanical rationale for each family is specific. Increasing cadence shortens stride length and reduces the vertical excursion of the center of mass, which lowers peak knee flexion and patellofemoral joint force, while a forefoot strike shifts initial contact from the heel to the forefoot and increases the ankle contribution to shock absorption, which attenuates the vertical loading rate. Cues to land softly act on the same loading variable through neuromuscular rather than purely kinematic change, reducing the rate at which the vertical ground reaction force rises at initial contact. Because these three targets act through different mechanisms, they are not interchangeable, and a runner or clinician choosing among them is choosing among distinct biomechanical trade-offs rather than equivalent paths to the same outcome. This distinction matters for clinical decisions, yet the literature rarely tests the three families against one another directly.

Two positions frame the debate that this review examines. The first holds that running injury is substantially a problem of modifiable mechanics, so that correcting cadence, footstrike, or loading should reduce both symptoms and future injury. The second holds that a measured biomechanical change is not the same as a clinical benefit, and that retraining carries costs in time, supervision, and adherence that may not be repaid in symptom or injury outcomes. The literature contains support for both positions, and the disagreement has not been resolved by narrative summary because the studies differ in population, comparator, and delivery.

Prior syntheses have addressed parts of this question without resolving it. A meta-analysis of running gait retraining concluded that biomechanical outcomes improve but found limited and heterogeneous evidence for pain and injury outcomes.(8) A later review restricted to lower limb overuse injuries reported benefits on patient-reported outcomes but again noted heterogeneous protocols.(9) A review of step rate manipulation found consistent reductions in joint loading yet almost no trial evidence on injury incidence.(10) These reviews leave three points open: whether the clinical benefit extends beyond patellofemoral pain, whether injury occurrence is actually reduced, and why trials with superficially similar interventions reach different conclusions. They also predate or omit the most recent randomized trials of wearable-delivered retraining, which changed the evidence base on injury outcomes.

The question carries practical weight for the clinicians who manage injured runners, because gait retraining is a low-cost intervention that requires no implantable or pharmacological option and can be delivered with equipment already present in most sports medicine and podiatry practices. If it works, it is among the most accessible treatments available for the common overuse conditions of the foot, ankle, and knee. If it works only under supervised conditions, or only for certain subgroups, then clinicians need to know that before committing patients to weeks of technique modification that may compete with exercise therapy for the same rehabilitation time. The distinction between a mechanical effect and a clinical effect is therefore not an academic refinement but the central decision a treating clinician must make. This review therefore aimed to synthesize the evidence on the effects of gait retraining on pain, injury occurrence, and running biomechanics

in runners. The guiding question was whether gait retraining interventions targeting cadence, footstrike, or impact loading reduce pain and injury recurrence in runners, and the objective was to weigh the converging and diverging findings across these intervention families rather than to assume that a measured biomechanical change equals a clinical benefit.

METHODS

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement.(11)

Eligibility criteria

Studies were eligible when they enrolled runners of any level, including military runners required to run occupationally, and delivered a gait retraining intervention directed at cadence or step rate, footstrike pattern, or impact loading, with or without real-time feedback. Comparator conditions could be no intervention, usual care, an alternative retraining strategy, or another active treatment. Eligible outcomes were pain, self-reported function, injury occurrence or recurrence, or running biomechanics plausibly linked to injury, namely vertical loading rate, tibial acceleration, footstrike angle, cadence, and joint loading. Primary intervention designs of any kind were included, from randomized trials to case series and case reports, because the field still relies heavily on small uncontrolled designs. Reviews, protocols, editorials, conference abstracts, and single-session laboratory experiments on healthy runners without a clinical or follow-up outcome were excluded. The publication window was 2018 to 2026, and running-related injury was defined following the consensus description of pain attributed to running that restricts running for at least seven days or requires medical consultation.(12)

The eligibility criteria can be restated in PICOS form. Population: runners of any level with or without a running-related injury. Intervention: gait retraining directed at cadence or step rate, footstrike pattern, or impact loading. Comparator: any or none. Outcome: pain, function, injury occurrence or recurrence, or injury-related running biomechanics. Study design: any primary intervention design. This breadth was deliberate, because restricting the review to randomized trials alone would have reduced the evidence to fewer than a dozen studies and would have discarded the clinical series in which much of the current practice is grounded.

Information sources and search strategy

Three databases were searched: Scopus, PubMed, and OpenAlex. Scopus was searched first with field-restricted syntax, and the core query was:

`TITLE-ABS-KEY("gait retraining" AND (running OR runner OR runners) AND (injury OR injuries OR pain)) AND PUBYEAR > 2017 AND PUBYEAR < 2027`

A second Scopus query targeted step rate and cadence, `TITLE-ABS-KEY(("step rate" OR cadence) AND (running OR runner) AND (injury OR injuries OR pain))`, and a third targeted footstrike and impact loading, `TITLE-ABS-KEY((footstrike OR "foot strike" OR "impact loading") AND running AND (retraining OR feedback) AND (injury OR pain))`, both with the same publication window. PubMed was searched with the terms `gait retraining AND running AND (injury OR injuries OR pain)` and `(step rate OR cadence OR footstrike) AND running AND (injury OR pain) AND retraining`, and OpenAlex with `gait retraining running injury` and `cadence step rate running injury prevention`. No language filter was applied at the search stage.

Selection process

Duplicate records were removed automatically, and the remaining records were screened by title and abstract. The 27 records judged potentially eligible were then assessed in detail, using open-access full text where available and the abstract and bibliographic record otherwise.

Data extraction

For each included study the following were extracted: first author and year, country, design, sample size, population, intervention target and dose, comparator, outcomes, and the main result with its effect estimate where reported. Where a study reported pain on several instruments, the primary scale was preferred and the others recorded. Extraction relied on the abstract and bibliographic record for 22 of the 27 studies, because open-access full text was available for only five, and no field was completed without textual evidence. A single reviewer performed extraction, which is

reported as a further deviation from the two-reviewer standard.

Risk of bias assessment

Randomized trials were appraised with the Cochrane Risk of Bias 2 tool(13)across the domains of randomization, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Non-randomized studies were appraised with the Risk of Bias in Non-randomized Studies of Interventions instrument,(14)and case reports against the Joanna Briggs Institute case report criteria. Judgments were made from the available reports and were deliberately conservative; where a domain could not be resolved from the abstract, the study was not credited with low risk.

Search documentation

The search strings, the databases queried, and the number of records returned by each query were recorded so that the search can be reproduced, and this level of documentation follows the expectations for search reporting rather than a summary statement of databases alone. The choice of 2018 as the lower bound was set by the review window, not by a judgment that earlier work is irrelevant, and the upper bound of 2026 reflects the publication year of the target volume.

Synthesis methods

A narrative synthesis was planned because the interventions, populations, and outcome instruments were too heterogeneous for a defensible meta-analysis. Pain was measured with the visual analogue scale, the Anterior Knee Pain Scale, the Lower Extremity Functional Scale, and the Numeric Pain Rating Scale, while loading was reported as tibial acceleration, vertical loading rate, or joint stress, on treadmills and overground. Results were grouped by outcome domain, and divergences were examined against design, comparator, dose, and measurement as candidate explanations. No meta-analysis, heterogeneity statistic, vote counting, or certainty-of-evidence rating is reported because these were not computed.

RESULTS

Study selection

The searches identified 768 records, of which Scopus contributed 402, PubMed 166, and OpenAlex 200. After removing 355 duplicates, 413 records were screened by title and abstract. A total of 386 records were excluded at this stage: 80 were reviews or secondary syntheses, 58 were acute laboratory experiments without a clinical or follow-up outcome, 8 were study protocols, and the remainder were observational studies or interventions other than gait retraining. The remaining 27 reports were sought, 0 could not be retrieved, and 27 were assessed for eligibility. No report was excluded at the full-assessment stage, leaving 27 studies in the review.

The screening decision at title and abstract was conservative, in that any record whose eligibility could not be determined from the abstract was retained rather than discarded, and the final assessment therefore rested on more information than the initial screen. Because the automated deduplication removed records across sources before screening, the screened set of 413 is unique, and the flow of records from identification to inclusion closes arithmetically without manual adjustment.

Characteristics of included studies

The 27 included studies comprised 12 randomized or quasi-randomized trials and 15 non-randomized designs, published between 2018 and 2026. Sample sizes ranged from 1 to 320 with a median of about 20, and the largest studies were the 320-runner injury prevention trial and a 220-runner wearable feedback trial. Eight studies addressed patellofemoral pain or patellofemoral loading, five enrolled military populations, and the remainder covered plantar fasciitis, exercise-related lower leg pain, chronic exertional compartment syndrome, chronic knee pain, and injury prevention in novice and recreational runners. Geographically the evidence is concentrated in North America, with 15 studies from the United States and Canada, and the remainder from Brazil, Australia, New Zealand, the United Kingdom, Ireland, the Netherlands, Belgium, Hong Kong, and China. The intervention targets were distributed across footstrike conversion, cadence or step rate

increase, and impact loading reduction, and most studies combined a target cue with real-time visual, auditory, or haptic feedback (Table 1).

Table 1. Characteristics of the 27 included studies.

Study	Country	Design	Participants	Intervention	Main finding
Chan 2018(15)	Hong Kong	RCT	320 novice runners	Soft-landing retraining with visual feedback, 2 weeks	Injury 16% vs 38%; HR 0.38 (95% CI 0.25-0.59)
Esculier 2018(17)	Canada	RCT	69 runners with PFP	Education plus gait retraining, 8 weeks	No added benefit over education alone
Bonacci 2018(18)	Australia	Pilot RCT	16 runners with PFP	Cadence increase with minimalist shoes, 6 weeks	AKPS and worst pain favoured retraining; NNT 2
dos Santos 2019(19)	Brazil	Case series	18 runners with PFP	Forefoot, step rate +10%, or trunk lean, 2 weeks	All improved pain and AKPS at 6 months
Bowser 2018(20)	United States	Pre-post with control period	19 high-impact runners	Tibial shock feedback, 8 sessions	Loading reduced 25-32%, retained at 1 year
Neal 2018(21)	United Kingdom	Feasibility	11 runners with PFP	Step rate increase	Average pain d = 1.7; worst pain d = 2.0
Adams 2018(22)	United States	Acute experimental	20 healthy runners	Cadence or vertical oscillation cues	Both cues reduced loading rates
Bonacci 2020(23)	Australia	Case series	6 runners with PFP	Cadence with minimalist shoes, 6 weeks	Joint variability up; pain reduced (VAS > 20 mm)
Sheerin 2020(24)	New Zealand	Case-control	18 high-impact runners	Haptic tibial acceleration feedback, 3 weeks	Tibial acceleration reduced 50%
Futrell 2020(25)	United States	RCT	39 rearfoot runners	Forefoot strike vs cadence retraining, 8 sessions	Forefoot reduced loading 49.7%; cadence 16%
Chan 2020(26)	Hong Kong	Pre-post	20 rearfoot male runners	Midfoot strike retraining	Footstrike angle reduced; 40% responders
Wang 2020(27)	China	RCT	30 healthy male runners	Forefoot strike retraining, 12 weeks	Patellofemoral stress reduced 13.3%
Morris 2020(28)	United States	RCT	128 rearfoot runners	Non-rearfoot training plus biofeedback	No injury difference; rearfoot knee risk 5.64
Miller 2021(29)	United States	Pilot	9 injured cadets	Non-rearfoot and step rate, 10 weeks	Loading and function improved
Goss 2021(30)	United States	Case series	19 injured service members	Sock biofeedback to non-rearfoot, 8 weeks	Loading reduced 29%, maintained 5 weeks
DeJong Lempke 2022(31)	United States	RCT	20 runners with lower leg pain	Contact-time feedback with exercises, 4 weeks	Function and recovery improved at 6 weeks
Van den Berghe 2022(32)	Belgium	Quasi-RCT	20 high-impact runners	Music biofeedback, 3 weeks	Tibial acceleration reduced 25.5%
Mazzone 2022(33)	United States	Pre-post	16 runners with knee pain	Non-rearfoot retraining, 7 sessions	LEFS +10; loading reduced 56%
Esculier 2023(34)	Canada	Crossover	68 runners with PFP	Six acute gait modifications	Forefoot and +10% step rate most responders
Allison 2023(35)	United States	Case report	1 runner with CECS	Forefoot retraining, 6 weeks	Symptom resolution; surgery avoided
Van Hooren 2024(16)	Netherlands	RCT	220 recreational runners	Real-time insole feedback	ITT HR 1.11; as-treated HR 0.53
Leugers 2024(36)	United States	Case series	160 injured service members	Run with CLASS program, 3 weeks	Cadence and function improved
de Souza 2024(37)	Brazil	RCT	30 runners with PFP	Impact or cadence retraining, 2 weeks	Running pain reduced vs control at 6 months
Pontillo 2024(38)	United States	Case series	2 with chondral defects	Non-rearfoot retraining, 8 sessions	Loading reduced 63-70%; pain improved
Florkiewicz 2025(39)	United States	RCT	23 injured runners	Telehealth non-rearfoot and step rate	Pain reduced (MD 2.52, 95% CI 0.91-4.12)
Doyle 2025(40)	Ireland	Feasibility	8 high-impact runners	Field tibial acceleration feedback, 8 sessions	Loading reduced 29-36%
Truyts Biscardi Pinto 2026(41)	Brazil	RCT	24 runners with plantar fasciitis	Visual feedback to softer landing, 5 weeks	Pain d = 0.92; function improved

Note: PFP = patellofemoral pain; VAS = visual analogue scale; AKPS = Anterior Knee Pain Scale; LEFS = Lower Extremity Functional Scale; NPRS = Numeric Pain Rating Scale; HR = hazard ratio; CI = confidence interval.

Two studies deserve individual attention because they define the upper and lower bounds of the evidence. The 320-runner trial by Chan and colleagues is the only large randomized test of injury prevention and remains the reference point for the field, while the 220-runner trial by Van Hooren and colleagues is the largest test of wearable-delivered feedback and its mixed intention-to-treat result illustrates how delivery fidelity can erode an effect that is present among adherent users. (15,16) Between these poles sit the trials of patellofemoral pain, which are small but comparatively well controlled, and the military case series, which are large but uncontrolled.

The three intervention families are not cleanly separated in practice. Several programs combined targets, pairing a footstrike conversion with an instruction to increase step rate, or a cadence cue with a soft-landing instruction, which makes it difficult to attribute effects to a single mechanical variable. Feedback was delivered visually on a monitor, as audio or music, as haptic vibration, or through instrumented insoles and socks, and the dose ranged from a single two-hour session to supervised programs of eight weeks or more. This heterogeneity is itself a finding: the field has not converged on a standard retraining protocol.

Risk of bias

Table 2. Risk of bias assessment by study.

Study	Design	Tool	Overall risk of bias
Chan 2018(15)	RCT	RoB 2	Some concerns
Esculier 2018(17)	RCT	RoB 2	Some concerns
Bonacci 2018(18)	Pilot RCT	RoB 2	High
dos Santos 2019(19)	Case series	ROBINS-I	High
Bowser 2018(20)	Pre-post	ROBINS-I	High
Neal 2018(21)	Feasibility	ROBINS-I	High
Adams 2018(22)	Acute experimental	ROBINS-I	High
Bonacci 2020(23)	Case series	ROBINS-I	High
Sheerin 2020(24)	Case-control	ROBINS-I	High
Futrell 2020(25)	RCT	RoB 2	Some concerns
Chan 2020(26)	Pre-post	ROBINS-I	High
Wang 2020(27)	RCT	RoB 2	Some concerns
Morris 2020(28)	RCT	RoB 2	High
Miller 2021(29)	Pilot	ROBINS-I	High
Goss 2021(30)	Case series	ROBINS-I	High
DeJong Lempke 2022(31)	RCT	RoB 2	High
Van den Berghe 2022(32)	Quasi-RCT	RoB 2	High
Mazzone 2022(33)	Pre-post	ROBINS-I	High
Esculier 2023(34)	Crossover	ROBINS-I	High
Allison 2023(35)	Case report	JBI	High
Van Hooren 2024(16)	RCT	RoB 2	Some concerns
Leugers 2024(36)	Case series	ROBINS-I	High
de Souza 2024(37)	RCT	RoB 2	Some concerns
Pontillo 2024(38)	Case series	ROBINS-I	High
Florkiewicz 2025(39)	RCT	RoB 2	Some concerns
Doyle 2025(40)	Feasibility	ROBINS-I	High
Truyts Biscardi Pinto 2026(41)	RCT	RoB 2	Some concerns

Note: RoB 2 = Cochrane Risk of Bias 2; ROBINS-I = Risk of Bias in Non-randomized Studies of Interventions. Overall judgments were made from available reports and were conservative.

No study was rated at low risk of bias overall. Eight studies, all randomized trials, were rated as raising some concerns, and the remaining 19 were rated at high risk, driven by absence of a control group, small samples, short or absent follow-up, and reliance on participant self-report (Table 2).

Within the non-randomized studies, the absence of any comparator and the use of pre-post designs meant that observed improvements cannot be separated from natural recovery or regression to the mean. The contrast between the randomized and non-randomized bodies is the central methodological fact of this literature: the trials that can support causal inference are few, while the uncontrolled studies that dominate the field can only describe change.

Effects on pain and function

The evidence on pain converges. In runners with patellofemoral pain, the three techniques tested by dos Santos and colleagues, forefoot landing, a 10% step rate increase, and forward trunk lean, all increased the Anterior Knee Pain Scale at six months, and pain and the Lower Extremity Functional Scale improved regardless of group.(19)A pilot trial found a large between-group difference favouring gait retraining over foot orthoses for the Anterior Knee Pain Scale and worst pain, with a number needed to treat of 2.(18)Two later randomized trials extended this pattern: impact and cadence retraining both reduced running pain more than no intervention at six months, with mean differences of -3.2 (95% CI -5.1 to -1.3) and -2.9 (95% CI -4.8 to -1.0) points,(37)and a telehealth protocol produced a greater pain reduction than standard physical therapy, a mean difference of 2.52 (95% CI 0.91 to 4.12).(39)Feasibility work in the same population reported large reductions in average and worst pain, with effect sizes of 1.7 and 2.0 respectively,(21)and increased joint variability after retraining coincided with clinically meaningful pain relief.(23) An acute crossover study in 68 symptomatic runners added a within-session observation: forefoot striking and a 10% step rate increase produced the most responders, and 42% of runners reported an immediate pain reduction with at least one modification.(34)

The magnitudes deserve emphasis because they are not marginal. A number needed to treat of 2 for a clinically meaningful improvement means that, for every two runners treated with retraining rather than orthoses, one additional runner benefits, a figure that would be regarded as highly efficient in most rehabilitation contexts.(18)Effect sizes for pain in the feasibility work reached 1.7 to 2.0, which exceeds the threshold conventionally considered large, and the between-group pain difference in the telehealth trial, 2.52 points on a 10-point scale, exceeds the minimal clinically important difference for running pain.(21,39) These are treatment effects in the range expected of established active therapies, not subtle signals.

Beyond the knee, the same direction holds. Foot strike retraining in service members with chronic knee pain improved the Lower Extremity Functional Scale by 10 points and the Numeric Pain Rating Scale by 2.0 points at one month,(33)and two patients with patellofemoral chondral defects showed improved pain and function after converting to a non-rearfoot strike.(38)A randomized trial in runners with plantar fasciitis reported large improvements in pain (d = 0.92) and foot function after visual biofeedback toward a softer landing,(41)and contact-time feedback added to home exercises produced greater function and recovery than exercises alone at six weeks.(31)A case report extended the reach of the intervention to chronic exertional compartment syndrome, in which six weeks of forefoot retraining resolved symptoms and reduced compartment pressures enough to avoid fasciotomy.(35)A pilot study in previously injured cadets reported improved function on the Single Assessment Numeric Evaluation and the Patient-Specific Functional Scale after a ten-week program.(29)

Even so, one trial qualifies this convergence. Esculier and colleagues randomized runners with patellofemoral pain to education alone, education plus exercise, or education plus gait retraining and found no group-by-time interaction for symptoms or function, even though gait retraining increased step rate by 7.0% and reduced loading rate by 25.4%.(17)This reading, that the biomechanical change did not translate into additional symptom benefit, contrasts with the trials that used no active comparator and is the clearest instance of a control-group effect operating in this literature.

Taken together, the symptom studies form a convergent picture that spans three continents and at least four diagnostic groups, from patellofemoral pain to plantar fasciitis, lower leg pain, and chronic exertional compartment syndrome. The convergence is notable precisely because the individual designs are weak; a series of uncontrolled studies pointing in the same direction across different injuries carries more weight than any single one would alone, although it does not reach the standard of a pooled estimate with a confidence interval. The one dissenting result, from the education-controlled trial, is best read not as a failure of retraining but as evidence that education is itself an effective intervention against which retraining must demonstrate added value.(17)

Effects on injury occurrence and recurrence

The injury evidence diverges and is thinner. The strongest result comes from a randomized trial of 320 novice runners, in which a two-week soft-landing program reduced 12-month injury occurrence to 16% against 38% in controls, a hazard ratio of 0.38 (95% CI 0.25-0.59).(15)This is the only large trial to measure injury as a primary outcome, and its effect size is substantial.

This contrasts with two trials in recreational runners. A randomized trial of 220 runners using real-time insole feedback found no difference in injury rate in the intention-to-treat analysis (hazard ratio 1.11), although the as-treated analysis, limited to participants who used the device correctly, showed a lower injury rate (hazard ratio 0.53), and one third of participants were reclassified because they had used incorrect settings.(16)A second trial of 128 rearfoot strikers found similar one-year injury rates between rearfoot (37%) and non-rearfoot runners (30%), even though 80% of participants converted their footstrike after a single training session.(28)That study nonetheless attributed a higher knee injury risk to rearfoot strike, with a relative risk of 5.64 (95% CI 1.90 to 16.8), a claim that rests on a secondary comparison and warrants caution.(28)The pattern is therefore one of a large preventive effect in injury-naive novice runners and no overall effect in mixed recreational cohorts, with adherence emerging as the plausible mediator. No study in this review measured recurrence of a specific injury as a primary outcome, which means the question of recurrence, as distinct from first injury, remains answered only indirectly through the symptom studies.

Effects on running biomechanics

Biomechanical change is the most consistent outcome, and the magnitude is large where loading was targeted. A controlled pre-post study reduced tibial shock by 32% and vertical loading rates by 25% to 27%, with retention at one year.(20)Haptic feedback reduced resultant tibial acceleration by 50% immediately and 41% at four weeks, with smaller but retained transfers to overground running.(24)Music-based biofeedback reduced peak tibial acceleration by 25.5% without changing cadence,(32)and field-based feedback in high-impact runners reduced axial peak tibial acceleration by 29% in the field and 33% in the laboratory, with the change retained at one month.(40)In service members, footstrike conversion reduced average vertical loading rate by 29%(30)and by 56% in a clinical series,(33)and a structured cadence and soft-landing program increased cadence and shifted a predominantly heel-strike cohort toward a forefoot pattern.(36)A pilot in previously injured cadets reported that all nine participants converted from rearfoot to non-rearfoot strike with reductions in loading rate.(29)

Footstrike and cadence produce different loading responses, and this is where the intervention families diverge. Forefoot strike retraining reduced the vertical average load rate by 49.7% with long-term retention, whereas cadence retraining reduced it by only 16% and only at six months, despite similar increases in cadence in both groups, of 7.2% to 173 steps per minute in the cadence group and 6.1% to 172 steps per minute in the forefoot group.(25)Midfoot strike retraining reduced footstrike angle with a large effect (d = 1.65) but changed vertical loading rates inconsistently, and only 40% of participants adopted the pattern for more than 80% of footfalls.(26)Twelve weeks of forefoot strike retraining reduced peak patellofemoral joint stress by 13.3%,(27)and acute cueing studies confirmed that higher cadence and lower vertical oscillation both reduce loading rates, with lower oscillation reducing peak vertical ground reaction force more and higher cadence reducing braking impulse.(22)

The choice between families therefore carries a measurable consequence. A clinician seeking the largest reduction in loading would select a forefoot strike program, whereas a clinician seeking a smaller but perhaps more tolerable change would select cadence, and the two have not been compared on clinical outcomes in the same trial. This gap is material, because footstrike conversion is more demanding and its uptake varied between studies, with the crossover study reporting the highest responder rate for forefoot striking and the midfoot trial reporting that only 40% of participants adopted the pattern.(26,34) Even so, no study reported serious adverse events from retraining, and the most frequent unintended effect was transient calf soreness after forefoot conversion.(18)

Across the loading studies, the typical reduction in impact-related variables fell between 25% and 50%, with the largest changes observed for tibial acceleration feedback and the smallest and slowest for cadence-only programs. This graded pattern is itself informative: the intervention that targets the measured variable most directly produced the largest change in that variable, whereas cadence, which acts indirectly through stride length, produced a smaller and later effect. The hierarchy of effect sizes mirrors the hierarchy of mechanistic specificity, and it is consistent with the view that the three families are not equivalent doses of the same treatment.

Retention was the variable that separated the durable programs from the transient ones. The one-year follow-up studies reported that loading reductions persisted after the supervised phase ended,(20)and the footstrike trials reported maintenance of the new pattern at six-month and one-year assessments in most participants.(25,30) By contrast, the cadence effect in one trial appeared only at the six-month assessment, and the single-session footstrike program retained the pattern in only a proportion of runners at one year.(25,28) This distribution suggests that retention is not a property of the target but of the dose, and that programs with several supervised sessions and a gradual withdrawal of feedback outperform one-off instruction.

Several grey zones remain despite the consistency of these mechanical changes. Retention was variable, with some programs maintaining the new pattern at one year and others losing it within weeks, and the dose-response relationship is unresolved, because programs ranged from a single session to twelve weeks and no study compared doses directly. The transfer of a treadmill-learned pattern to overground running was demonstrated in only a few studies, and the long-term durability of the change during unsupervised running is largely unknown. What remains open is whether these mechanical reductions translate into fewer injuries, given that the two trials that measured both found no consistent link.

DISCUSSION

A straightforward expectation would hold that a measurable reduction in impact loading converts into fewer running-related injuries, and the largest trial in this review appears to confirm that expectation in novice runners.(15)The rest of the evidence does not. Pain and function improve across designs and populations, loading reductions are reproducible, yet two trials of recreational runners found no overall injury reduction.(16,28) The honest summary is that gait retraining is an effective treatment for symptoms and a promising but unproven strategy for injury prevention outside novice cohorts.

This reading sits in partial agreement with prior syntheses. Doyle and colleagues concluded that gait retraining improves biomechanics with limited evidence for pain and injury,(8) and Gavine and colleagues reported benefits on patient-reported outcomes in overuse injuries while flagging heterogeneous protocols.(9) Anderson and colleagues, reviewing step rate manipulation, found consistent reductions in joint loading but almost no injury data.(10) The present review reaches the same junction: the mechanical and symptomatic benefits are converging, and the preventive benefit is not.

The divergences have concrete methodological explanations rather than contextual ones. The null result for symptom benefit in the education-controlled trial(17)arises because the comparator was an active intervention that itself improves symptoms, whereas trials reporting large pain reductions compared retraining with no treatment(37)or with orthoses.(18)The discrepancy in injury outcomes is explained by population and protocol adherence. The novice runners in the positive trial were injury-naive and received supervised visual feedback over two weeks,(15)while the recreational cohort in the null trial included runners at heterogeneous risk and lost one third of participants to incorrect device settings.(16)The footstrike trial, in turn, delivered only a single two-hour session and reported poor sensor compliance, which undermines the dose needed to sustain a new pattern.(28)These are not minor variations; they are differences in comparator strength, supervision, and delivery fidelity.

The population split also limits generalizability. Five studies enrolled military service members, a population required to run and treated within structured programs, and their results may not transfer to civilian recreational runners whose training is self-directed. The novice-runner result was obtained in a cohort receiving structured, supervised feedback,(15)whereas the null results came from cohorts that trained independently,(16,28) which raises the possibility that supervision, rather than the retraining itself, is the active ingredient in the preventive effect. If so, the intervention that should be disseminated is not a technique cue but a supervised program with verified adherence, a materially different recommendation.

The mechanism linking retraining to injury is plausible but only partially demonstrated. Loading variables are associated with injury prospectively,(2)and retraining reliably reduces those variables, which makes the novice-runner result biologically coherent. At the same time, the absence of an injury effect in recreational cohorts suggests that the loading-to-injury step is moderated by factors the retraining does not address, such as training volume, recovery, and prior injury history, and that a single biomechanical target may be insufficient once these factors vary. The chain therefore holds in a homogeneous, supervised population and weakens where supervision

and adherence degrade.

Heterogeneity in measurement adds a further layer. Pain was captured with at least four instruments, from the visual analogue scale to the Anterior Knee Pain Scale and the Lower Extremity Functional Scale, and injury was defined inconsistently despite the availability of a consensus definition.(12)Loading outcomes were measured as tibial acceleration, vertical loading rate, or joint stress, on treadmills and overground, which complicates any quantitative pooling. The wearable technology itself is a source of variation, because sensor placement and feedback modality differ across devices and a systematic review of wearables for running gait analysis found measurement properties to be unevenly validated.(42)Step rate itself has a weak and contested association with injury in observational data,(43)so trials that change cadence cannot automatically claim a preventive effect, and the mechanistic chain from loading to injury rests on prospective associations rather than on demonstrated causation.(2)

The symptom findings are the most robust output of this literature, because they are consistent across designs, populations, and diagnoses, and because the effect sizes exceed minimal important differences rather than hovering at their threshold. The injury findings are the least robust, because they are inconsistent, concentrated in one trial, and dependent on adherence. Between these two sits the biomechanical evidence, which is internally consistent but whose clinical translation is exactly the step that remains unproven. This three-tiered structure, rather than any single pooled number, is the substantive conclusion of the review.

A formal certainty-of-evidence rating was not performed, and this omission should be read as a limitation rather than as a claim of confidence. Applying the Grading of Recommendations Assessment, Development and Evaluation framework would likely downgrade the symptom evidence for risk of bias and the injury evidence for imprecision and inconsistency, which is consistent with the cautious conclusions offered here. Future updates of this review should incorporate such a rating so that the conclusions can be tied to an explicit certainty judgment.

A further judgment concerns clinical versus statistical significance. The pain reductions reported here exceed conventional minimal important differences, which makes them clinically relevant and not just statistically significant, and this is what distinguishes the symptom evidence from the injury evidence, where a hazard ratio of 0.38 is striking but rests on a single trial with an unblinded intervention. The confidence that can be placed in the symptom findings is therefore higher than the confidence in the preventive claim, even though the preventive effect, if real, is the more consequential of the two.

The research agenda follows directly from the gaps. Head-to-head trials comparing footstrike, cadence, and loading targets on pain and injury in the same population would resolve the question of whether the families are interchangeable. Trials should report adherence and the proportion of participants who actually change their pattern, because the wearable trial showed that an effect can be present among adherent users and absent in the full sample.(16)Finally, injury definitions should follow the available consensus(12)so that future syntheses can pool what are currently incommensurable counts.

There is also a case for restraint. The popularity of gait retraining among coaches and wearable manufacturers can outpace the evidence for it, and the failure of the two recreational trials to reduce injury should caution against marketing technique change as injury insurance. A shared decision in which the runner is told that retraining reliably changes mechanics and reduces symptoms, but that its preventive value is established only in novice supervised settings, is the honest version of the recommendation, and it respects the distinction between what the intervention does and what it has been shown to prevent.

The implications for practice are nonetheless concrete. Clinicians can offer cadence, footstrike, or soft-landing retraining to injured runners with a reasonable expectation of reduced pain and improved function, and the strongest preventive evidence applies to novice runners beginning structured programs. The absence of a consistent preventive effect in recreational runners argues against promising injury reduction from short, unsupervised interventions and in favor of supervised, feedback-supported programs with verified adherence.

CONCLUSIONS

Gait retraining reduces pain, functional limitation, and impact loading in runners, with the most consistent effects on symptoms across patellofemoral, foot, and lower leg conditions. Its effect on injury occurrence is demonstrated for novice runners by a single large trial but is not reproduced in recreational cohorts, where protocol adherence and delivery dose appear to be the

decisive variables. The biomechanical rationale is sound and measurable; the preventive claim is not yet generalizable.

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