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Systematic Review

Sensorimotor Insoles in Pediatric Flexible Flatfoot: A Systematic Review with Contextual Comparison to Conventional Orthoses and Exercise-Based Rehabilitation

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Highlights

What are the main findings?

- Customized supportive orthoses and intrinsic foot muscle exercises can reduce pain and improve function in symptomatic children over the short to medium term.
- Direct randomized evidence suggests sensorimotor insoles may have functional and neuromuscular effects; however, the available evidence remains too limited to establish their comparative effectiveness or superiority over conventional supportive orthoses.

What are the implications of the main findings?

- Conservative treatment for pediatric flexible flatfoot should be individualized and prioritize symptom relief and functional performance over pursuing permanent structural or cosmetic arch correction.
- Clinicians should consider conventional orthoses and intrinsic muscle exercises, which currently have a broader evidence base, while sensorimotor insoles require adequately powered replication studies to confirm their specific benefits.

Abstract

Background/Objectives: Pediatric flexible flatfoot is a common developmental variation, and treatment is generally considered when pain or functional limitations are present. This systematic review evaluated clinical and biomechanical evidence for sensorimotor insoles in children with flexible flatfoot and contextualized these findings alongside evidence for conventional foot orthoses and exercise-based rehabilitation; head-to-head comparative evidence was not assumed when unavailable. **Methods**: Following PRISMA 2020 guidelines, comprehensive searches were performed across PubMed/MEDLINE, the Cochrane Library, and PubMed Central up to August 2026. Eligible primary studies comprised randomized controlled trials, randomized comparative or sequence trials, prospective comparative or pre-post studies, and longitudinal cohort studies evaluating pain, function, gait, balance, posture, or neuromuscular outcomes. Risk of bias was assessed using RoB 2 and ROBINS-I, and the certainty of the evidence was summarized

Academic Editor: Johannes Michael Mayr

Received: 5 September 2026
Revised: 15 October 2026
Accepted: 20 October 2026
Published: 22 October 2026

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qualitatively using GRADE. **Results**: Ten main clinical studies met inclusion criteria, including 5 RCTs and 5 non-randomized studies, with follow-up periods ranging from 6 weeks to 2 years. Both customized supportive orthoses and intrinsic muscle exercises consistently reduced pain and improved function in symptomatic children in the short- to medium-term. Direct randomized evidence for sensorimotor insoles suggests potential functional and neuromuscular effects; however, the limited evidence base does not support firm conclusions about comparative effectiveness or superiority over supportive orthoses. Evidence for permanent structural arch correction was not established. **Conclusions**: In symptomatic pediatric flexible flatfoot, conservative treatment should prioritize pain and function. Conventional supportive orthoses and targeted exercise have a broader evidence base, whereas current evidence is insufficient to establish the superiority of sensorimotor insoles.

Keywords: flexible flatfoot; pediatric orthotics; sensorimotor insoles; intrinsic foot exercises; pes planovalgus; foot orthoses; conservative rehabilitation

1. Introduction

Flexible flatfoot is characterized by a reduced medial longitudinal arch during weight bearing, often accompanied by hindfoot valgus and forefoot abduction, with reconstitution of the arch when the foot is unloaded or when the child rises onto the toes. In many young children, flexible flatfoot represents a physiological developmental variant rather than a pathological deformity. Consequently, treatment is generally reserved for children with pain, fatigue, functional limitation, progressive deformity, or relevant associated conditions rather than for asymptomatic foot shape alone [1–3].

Conservative management includes orthotic and exercise-based strategies. Traditional biomechanical foot orthoses are designed to provide passive support to the osteoligamentous structures of the foot, redistribute plantar pressure, and improve hindfoot or arch alignment. Sensorimotor or proprioceptive insoles are conceptually distinct: they use specifically positioned pressure elements intended to modify afferent input and neuromuscular control, potentially influencing muscle activation and postural responses [4–6]. In the pediatric randomized trial by Liebau et al., supportive and sensorimotor insoles were compared with a visually similar placebo, with outcomes including muscle activity, valgus index, pain, and the Foot and Ankle Disability Index (FADI) [6]. Although these mechanisms are attractive, the clinical literature remains heterogeneous, and distinguishing mechanical support from true sensorimotor stimulation is important for interpreting treatment effects [2,7].

Exercise-based rehabilitation represents a complementary active approach. Programs targeting the intrinsic foot muscles, including short-foot exercises, are intended to improve dynamic support of the medial longitudinal arch and neuromuscular control. In contrast, broader corrective programs may also include extrinsic muscle strengthening, balance training, stretching, and proximal stabilization. Recent systematic review evidence suggests potential benefits of functional re-education, but protocols, treatment duration, outcome measures, and patient characteristics vary considerably across studies [8].

Evidence concerning pediatric foot orthoses as a broad category is inconsistent. The 2022 Cochrane review concluded that certainty was generally low or very low across major comparisons, while subsequent systematic reviews and meta-analyses emphasized heterogeneity in diagnostic definitions, orthosis designs, age groups, symptom status, follow-up duration, and outcome selection [2,7,9]. Importantly, evidence from conventional arch-support orthoses cannot be automatically extrapolated to sensorimotor devices, and

changes in radiographic or postural parameters should not be interpreted as proof of permanent structural remodeling of the developing foot [2,7,9]. Current guidance, therefore, favors symptom-directed and function-oriented management [3].

The primary objective of this systematic review was to systematically evaluate the clinical and biomechanical effects of sensorimotor or proprioceptive insoles in children and adolescents with flexible flatfoot. The secondary objective was to contextualize these findings alongside evidence for conventional/customized foot orthoses and exercise-based rehabilitation, focusing on pain; validated patient-reported function, activity, and participation; quality of life, where reported; foot posture; gait; balance; muscle activation or morphology; and treatment safety. Because the three intervention categories differ in mechanism and implementation, no comparative-effectiveness inference was made in the absence of direct head-to-head evidence [3,6].

While this review mainly concentrates on sensorimotor insoles, the pediatric literature on the topic is scarce. Therefore, we also examined evidence on traditional foot orthoses and exercise-based rehabilitation to provide a suitable clinical context for interpreting sensorimotor interventions. This method helps determine whether the effects of sensorimotor approaches differ meaningfully from those observed with standard conservative managements.

2. Materials and Methods

2.1. Protocol and Review Question

The review was structured according to the PRISMA 2020 statement [10]. A formal review protocol was developed before data extraction and study assessment; however, it was not prospectively registered with PROSPERO or any other international registry. The methodology, eligibility criteria, search strategy, risk-of-bias assessment, and planned narrative synthesis were defined in advance and applied throughout the review. The absence of prospective protocol registration is acknowledged as a methodological limitation and is considered when interpreting the transparency and reproducibility of the review process.

The primary review question was: in children or adolescents with flexible flatfoot, do sensorimotor or proprioceptive insoles improve pain, function, foot posture, plantar loading, muscle activation, gait, balance, participation, or adverse-event outcomes compared with placebo, no treatment, or conventional orthoses? A secondary question examined how the evidence for sensorimotor insoles compares with the broader literature on conventional foot orthoses and exercise-based rehabilitation.

2.2. Eligibility Criteria (PICOS Framework)

Eligibility criteria were evaluated using the PICOS framework (Table 1).

Table 1. PICOS eligibility criteria.

Domain	Inclusion Criteria	Exclusion Criteria
Population	Children and adolescents aged <18 years with a clinically diagnosed flexible flatfoot/pes planovalgus.	Rigid flatfoot; tarsal coalition; neuromuscular or syndromic flatfoot, unless separately reported; adult-only samples.
Intervention	Sensorimotor, sensomotoric, proprioceptive, or afferent-stimulating insoles; conventional/customized foot orthoses used as active comparators or contextual evidence; exercise-based rehabilitation targeting intrinsic and/or extrinsic foot musculature.	Corrective footwear alone, taping, isolated surgical treatment, or interventions not directed at the flexible flatfoot or its functional consequences.

Comparator	Placebo/sham, no treatment, usual footwear, conventional supportive orthosis, another sensorimotor design, or an alternative exercise sequence/program.	No comparator for efficacy synthesis, except when a prospective single-arm study provided clinically relevant symptom, function, safety, or mechanistic data.
Outcomes	Pain; patient-reported function; activity/participation; foot posture; plantar pressure/contact area; EMG; gait; balance; adherence; adverse events.	Studies reporting only manufacturing properties or non-clinical bench testing.
Study design	Randomized or quasi-randomized trials and prospective comparative studies; prospective/retrospective longitudinal safety cohorts.	Reviews, editorials, case reports, retrospective opinion-based reports, and conference abstracts, when a full report from the same study existed.

2.3. Information Sources and Search Strategy

Searches were conducted through August 2026 in PubMed/MEDLINE, the Cochrane Library, PubMed Central/Europe PMC, the German Medical Science meeting archive, clinical guideline repositories, and the reference lists of eligible articles and relevant systematic reviews. No publication-date restriction was applied.

PubMed/MEDLINE was selected as the principal biomedical database; the Cochrane Library was used to identify controlled trials and systematic review records; PubMed Central/Europe PMC was searched to facilitate retrieval of open full-text biomedical records; and supplementary repositories and citation tracking were used to identify additional relevant material. The relatively small number of eligible studies reflects the narrow pediatric intervention question and should not be interpreted as evidence of complete coverage of all potentially relevant literature.

The electronic search was supplemented by backward and forward citation tracking of eligible primary studies and relevant systematic reviews. Databases such as Embase, Scopus, and PEDro were not systematically searched; this is acknowledged as a limitation because relevant biomechanical or rehabilitation literature may have been missed. The supplementary citation search was therefore used to improve retrieval, but it cannot fully substitute for searching additional bibliographic databases. The PubMed/MEDLINE strategy combined controlled vocabulary and free-text terms for flexible flatfoot, pediatric populations, insoles/foot orthoses, sensorimotor or proprioceptive stimulation, and foot-muscle exercise. Filters were limited to humans, English, and pediatric age, where applicable. The core strategy is reported in Table 2.

Table 2. Core reproducible search strategy.

Source	**Search String/Approach**
PubMed/MEDLINE	(“flatfoot” OR “flat foot” OR “pes planus” OR “pes planovalgus” OR “flexible flatfoot”) AND (child* OR pediatric* OR adolescent*) AND ((sensorimotor OR sensomotor* OR propriocept*) AND (insole* OR “foot orthos*” OR orthotic*) OR (“short foot” OR “intrinsic foot muscle*” OR “foot exercise*”))
Supplementary searching	Backward and forward citation checking of eligible primary studies, pediatric orthosis reviews, the Cochrane review, functional re-education reviews, and contemporary clinical guidance.

All retrieved records were collected, and duplicates were removed before screening. Screening followed the predefined PICOS eligibility criteria in two sequential stages: title/abstract screening followed by full-text eligibility assessment. Full texts were retrieved for records considered potentially relevant, and reasons for exclusion were recorded at

the full-text stage and summarized in the PRISMA 2020 flow diagram. Reports originating from the same recruitment cohort were linked and treated as a single study. For included studies, extracted data comprised study design, sample characteristics, diagnostic criteria, intervention details, comparator, follow-up, outcome measures, adherence, adverse events, and conflicts of interest. Conventional orthoses and exercise-based rehabilitation were included as contextual conservative-treatment evidence because direct pediatric sensorimotor-insole evidence was limited; they were not treated as equivalent interventions or as a basis for indirect claims of comparative effectiveness.

Records were deduplicated before screening. Titles and abstracts were assessed against the predefined PICOS eligibility criteria, followed by full-text review of potentially eligible reports. Reports arising from the same recruitment cohort were linked and treated as a single study. No automated screening or data-extraction tools were used. Eligibility assessment and data extraction were performed using predefined criteria. Disagreements between reviewers at any stage of study selection, data extraction, or methodological assessment were resolved through discussion and consensus. No third-party adjudication was required; this procedure was applied consistently across the information-synthesis process.

2.4. Risk of Bias and GRADE Assessment

Randomized trials were appraised using the revised Cochrane Risk of Bias tool (RoB 2) [11], randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. RoB 2 was applied to the five randomized studies: Liebau et al. [6], Hsieh et al. [12], Jafarnezhadgero et al. [13], Ahn et al. [14], and Ketabchi et al. [15]. Risk-of-bias judgments were categorized as low risk, some concerns, or high risk.

Non-randomized studies were appraised using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool [16], which evaluates seven domains: bias due to confounding, selection of participants, classification of interventions, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. ROBINS-I was applied to the five non-randomized studies [17–21].

The certainty of evidence across outcome domains was evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework. In accordance with GRADE guidelines for systematic reviews without meta-analysis (SWiM) [22], certainty of evidence was evaluated domain-by-domain based on standard qualitative criteria: Risk of Bias (derived from RoB 2 and ROBINS-I tool outputs), Inconsistency (evaluating clinical and methodological variability across studies), Indirectness (assessing applicability of study populations and surrogate laboratory endpoints), Imprecision (evaluating sample sizes and event counts), and Publication Bias. Certainty was graded as high, moderate, low, or very low.

3. Results

3.1. Study Selection

The search identified 25 records. Five duplicates were removed, leaving 20 records for title and abstract screening. Eight records were excluded at this stage. Twelve full-text reports were assessed for eligibility; two were excluded (one for including an adult-only sample and one for lacking clinical or functional outcome measures). Ten primary clinical studies were retained for qualitative synthesis. No meta-analysis was performed because of substantial clinical and methodological heterogeneity across interventions and outcomes (Figure 1).

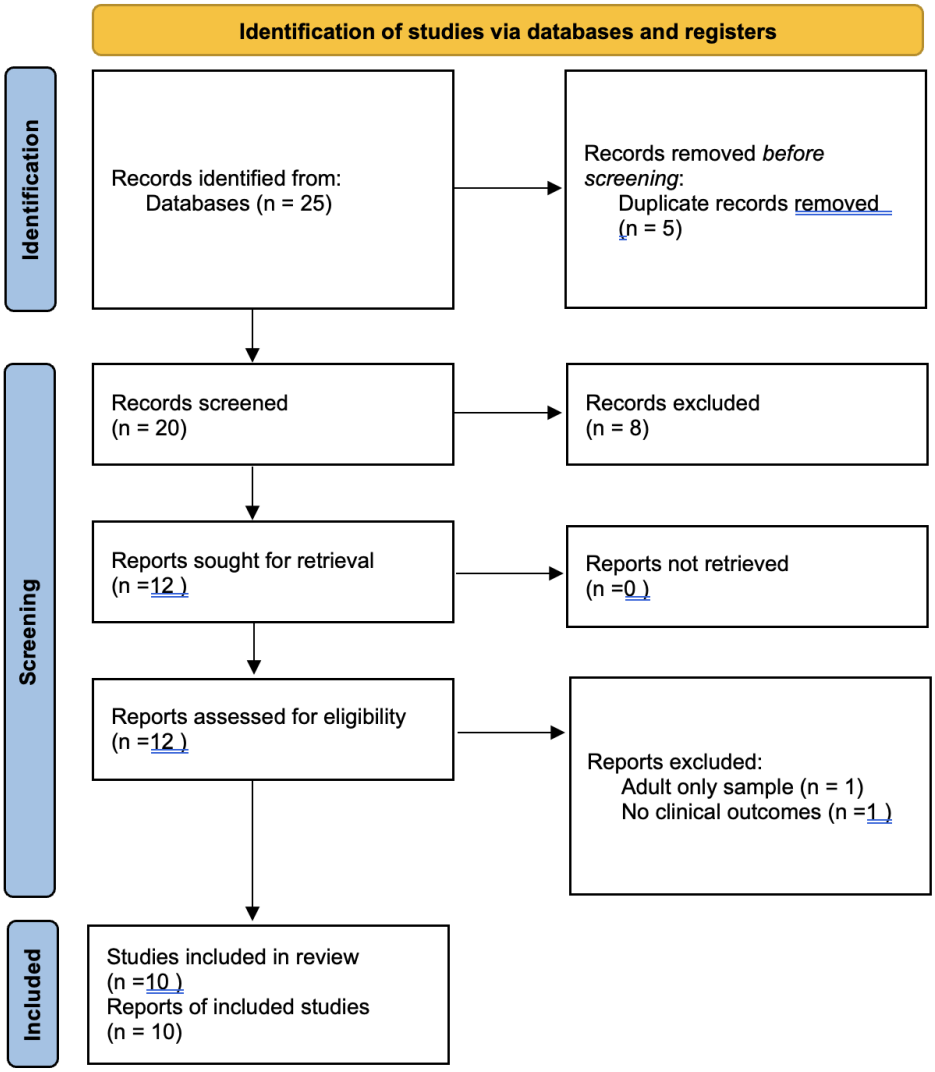

Figure 1. PRISMA 2020 flow diagram for new systematic reviews.

3.2. Characteristics of Included Studies

The ten included primary studies covered sensorimotor and conventional orthoses, as well as exercise-based rehabilitation [6,12–15,17–21]. Follow-up ranged from 6 weeks to two years.

Outcome domains included pain and patient-reported function, static and dynamic balance, gait kinematics and kinetics, hindfoot and arch alignment, muscle morphology and activation, and foot posture (Table 3).

Table 3. Characteristics and principal findings of the ten primary clinical studies included in the qualitative synthesis.

Study	Design/Sample	Intervention/Comparator	Follow-Up/Outcomes	Main Findings and Limitations
Liebau et al.[6].	Double-blind RCT; *n*= 52; age 6–16 y	Sensorimotor insole vs. supportive insole vs. placebo; crossover after 6 months	12 months; FADI, pain, valgus index, plantar contact, EMG	Within-period FADI improvement with sensorimotor insoles; both therapeutic designs altered tibialis anterior activity vs. placebo. No consistent superiority of sensorimotor over supportive insoles. Small sample size, crossover carryover concerns.

Hsieh et al., [12].	RCT; *n* = 52; symptomatic pediatric flexible flatfoot	Customized arch-support insoles vs. no-insole control	12 weeks; pain/comfort, physical function, mobility	Significant improvement in symptom and functional domains with customized arch support. High risk of bias due to lack of participant blinding and unblinded subjective reporting.
Jafarnezhadgero et al. [13].	RCT; *n* = 30 boys; age 8–12 y	Medial arch-support orthoses vs. 2 mm sham insoles	4 months; 3D gait kinematics and ground reaction forces	Improved selected lower-limb kinetic and kinematic variables during walking. Boys-only sample limits generalizability.
Ahn et al. [14].	Randomized comparative study; *n* = 40 children	Talus-control foot orthosis vs. rigid foot orthosis	Clinical and radiographic follow-up	Greater improvement in selected radiographic and clinical measures with talus-control orthosis. Limited data on patient-reported outcomes.
Lee et al. [17].	Prospective pre-post study; *n* = 20 completed; age >6 y	Custom-molded rigid foot orthoses	1 and 3 months; pain, posturography	Decreased pain frequency and improved balance measures. Lack of a control group limits causal inference.
Lee et al. [20].	Retrospective longitudinal study; *n* = 66; age <13 y	Modified corrective insoles	~24 months; RCSPA and radiographic parameters	RCSPA improved after fitting, especially in younger children. Natural growth and lack of a control group are major confounders.
Cho et al. [21].	Prospective cohort study; *n* = 24; age 10–18 y	Custom rigid foot orthoses	12 months; ultrasound CSA ratio of invertors/evertors, pain (FFI)	Orthoses increased the peroneus longus CSA ratio and reduced compensatory invertor hypertrophy, accompanied by pain reduction. Small non-randomized sample.
Li et al. [18].	Retrospective longitudinal cohort; *n* = 32; age ≥ 6 y	Customized polyurethane insoles ≥8 h/day	2 years; pain VAS, valgus angle, arch index	Pain and posture measures improved at 2 years. An uncontrolled design cannot separate the orthotic effect from natural growth.
Markowicz et al. [19].	Prospective preliminary study; *n* = 45 analyzed; age 7–12 y	6-week intrinsic foot muscle activation program	6 weeks; medial longitudinal arch, balance	Improved foot posture and postural balance (eyes closed). Lack of control group, short follow-up.
Ketabchi et al. [15].	Randomized sequence trial; *n* = 22 analyzed; age 10–12 y	Intrinsic-first vs. extrinsic-first exercise sequence	12 weeks; muscle thickness/CSA (ultrasound), navicular drop	Intrinsic-first sequence yielded superior intrinsic muscle morphometry and changes in navicular drop. Male-only sample, sequence/carryover effects.

3.3. Effects of Interventions

3.3.1. Sensorimotor and Conventional Foot Orthoses

The orthosis literature showed the most consistent signal for symptom relief and for selected functional or biomechanical outcomes, rather than for permanent structural correction. In symptomatic children, customized arch-support orthoses were associated with improvements in pain/comfort and selected functional measures [12,17]. Other studies reported changes in gait mechanics, hindfoot alignment, or muscle morphology after

orthotic treatment [9,13,14,17]. However, the clinical relevance of these changes is difficult to compare across studies because they used different orthosis designs, diagnostic thresholds, outcome instruments, and follow-up periods.

Direct evidence for genuinely sensorimotor insoles was much narrower. Liebau et al. randomized 52 children to supportive, sensorimotor, or placebo insoles and then conducted a crossover between the two therapeutic designs after 6 months [6]. Sensorimotor treatment was associated with a within-period improvement in FADI, while both therapeutic designs affected tibialis anterior activity compared with placebo; however, sensorimotor insoles were not consistently superior to supportive insoles across pain, posture, or muscle-activity outcomes [6]. Interpretation is limited by the sample size relative to the original power calculation, baseline group imbalances, the crossover design, incomplete reporting of adherence, and the multiplicity of outcomes.

Structural and postural outcomes should be interpreted cautiously. Ahn et al. reported greater improvement in selected radiographic and calcaneal stance parameters with talus-control orthoses than with rigid orthoses [14]. In contrast, longitudinal studies reported improvements in resting calcaneal stance position, valgus angle, arch index, or radiographic parameters after orthotic use [17,18]. Nevertheless, several of these studies lacked an untreated comparator, and the developing pediatric foot changes naturally with growth. Accordingly, longitudinal improvement cannot be attributed confidently to the orthosis itself, and current evidence does not establish permanent structural remodeling of the medial longitudinal arch [2,7].

3.3.2. Exercise-Based Rehabilitation

Exercise-based studies supported the role of active neuromuscular rehabilitation. Markowicz et al. reported improved foot position and postural balance after a six-week program emphasizing intrinsic foot muscle activation [19]. Ketabchi et al. randomized boys with flexible flatfoot to an intrinsic-first or extrinsic-first corrective-exercise sequence and observed more favorable changes in muscle morphometry and navicular drop when intrinsic muscle training was performed first [15]. These findings are consistent with the concept that the intrinsic foot muscles actively contribute to medial longitudinal arch support and may be a clinically relevant target for rehabilitation [8,15,19].

The exercise evidence remains limited by small sample sizes, short follow-up periods, heterogeneous protocols, and variation in symptom status and outcome selection. Nevertheless, active rehabilitation has the practical advantage of addressing neuromuscular control and muscle function rather than relying exclusively on passive arch support. This may be especially relevant when the treatment goal is improved balance, gait efficiency, activity tolerance, or dynamic foot control rather than radiographic correction [8,15,19].

3.3.3. Balance, Postural Control, Gait, and Motor Function

Balance and gait outcomes were heterogeneous but generally favored active treatment in selected domains. Custom-molded orthoses were associated with improvement in some pain and posturographic measures [17], whereas medial arch-support orthoses modified selected lower-limb kinematic and kinetic variables during walking [13]. Intrinsic foot muscle rehabilitation was associated with improved postural control, particularly when visual input was reduced [19]. Taken together, these findings suggest that interventions may influence both local foot mechanics and the sensorimotor strategies used for whole-body stability, but the magnitude, patient importance, and durability of these changes remain uncertain [8,13,17,19].

3.3.4. Narrative Interpretation and GRADE Summary

Across the included literature, the strongest clinically relevant signal concerns symptomatic improvement rather than correction of foot shape. Pain and comfort improved in several studies of customized or rigid orthoses, particularly in children who were symptomatic at baseline [12,17,18]. This pattern is clinically important because contemporary pediatric guidance does not recommend treating asymptomatic flexible flatfoot solely to normalize appearance [1–3]. The available evidence, therefore, supports separating the question of symptom relief from the question of structural correction.

Patient-reported function showed a possible benefit, but certainty is limited. Liebau et al. reported an improvement in FADI during the sensorimotor treatment period [6], while Hsieh et al. found improvements in several functional domains after customized arch-support insoles [12]. These findings suggest that orthoses may improve perceived function in selected children, yet differences in intervention design, symptom status, outcome instruments, and trial quality prevent a precise estimate of effect. Importantly, the available direct randomized evidence does not establish that sensorimotor insoles are superior to conventional supportive orthoses [6].

For balance, gait, and neuromuscular outcomes, the evidence is mechanistically interesting but clinically heterogeneous. Orthoses have been associated with changes in balance or gait variables [13]. In contrast, intrinsic foot muscle rehabilitation has been associated with improved postural control and favorable changes in muscle morphology and navicular drop [15,19]. Sensorimotor insoles may modify lower-leg muscle activity [8], but a specific sensorimotor mechanism has not yet been consistently demonstrated. Overall certainty for these mechanistic outcomes remains low or very low because most findings come from small studies, single-center cohorts, short follow-up periods, or multiple secondary outcomes [2,8].

A qualitative summary of evidence across these key outcome domains, along with GRADE certainty assessments and key references, is provided in Table 4 below.

Table 4. Qualitative summary of the direction and certainty of the evidence.

Outcome Domain	Overall Signal	Most Relevant Interventions	Interpretation	Key Ref.	GRADE Certainty	Rationale for GRADE Rating
Pain/comfort	Favorable in symptomatic children	Customized/supportive orthoses	Short- to medium-term pain reduction established in symptomatic children; unproven in asymptomatic children.	[12,17,18,21]	Low	Downgraded due to risk of bias (unblinded controls) and imprecision (small sample sizes).
Patient-reported function	Possible improvement	Sensorimotor and customized orthoses	FADI improvement observed; direct trial data show no proven superiority of sensorimotor over supportive orthoses.	[6,12]	Very Low	Downgraded due to severe imprecision, crossover carryover, and risk of reporting bias.
Balance/postural control	Favorable in selected parameters	Custom orthoses; intrinsic muscle exercises	Active exercise and custom insoles enhance dynamic equilibrium and sensorimotor control.	[17,19]	Low	Downgraded due to lack of control groups in observational designs and small cohorts.
Gait mechanics	Biomechanical modification	Arch-support orthoses	Favorable alterations in joint kinetics and ground reaction forces during gait.	[13]	Low	Downgraded due to indirectness (laboratory endpoints) and a restricted single-sex sample.

Arch/hindfoot posture	Postural gains reported	Orthoses; exercise sequences	Improvements documented, but growth and natural maturation remain major unadjusted confounders.	[14,20,21]	Very Low	Downgraded due to serious confounding in nonrandomized designs and high risk of bias.
Muscle morphology/activation	Neuromuscular adaptations	Sensorimotor insoles; intrinsic-first exercise	Muscle hypertrophy and altered EMG activation support neuromuscular conditioning mechanisms.	[6,15,19,21]	Low	Downgraded due to small sample sizes, short intervention periods, and methodological variability.

Evidence for arch or hindfoot posture is the least secure basis for long-term clinical claims. Improvements in radiographic angles, resting calcaneal stance position, valgus measures, or arch indices have been reported [14,20], but natural maturation is an important alternative explanation, especially in uncontrolled longitudinal studies. Systematic reviews have therefore cautioned against interpreting short- or medium-term changes in alignment as proof that orthoses permanently alter the developmental trajectory of the medial longitudinal arch [2,9].

3.4. Risk of Bias Assessments

3.4.1. Randomized Controlled Trials (RoB 2)

Five included studies were randomized and were therefore evaluated with RoB 2 [6,11,14,15]. The judgments below are conservative summaries based on the published reports and the principal outcomes. Hsieh et al. were judged to be at high overall risk because participant blinding was not feasible for the no-insole comparison, several outcomes were participant- or parent-reported, and a previous systematic appraisal identified selective reporting concerns [2,12]. The other randomized studies were judged to have some concerns, mainly due to incomplete reporting of allocation procedures, crossover or sequence effects, attrition, lack of blinded assessment for some outcomes, or absence of a clearly prespecified statistical analysis plan [6,13–15]. The RoB 2 domain assessments for randomized controlled trials are detailed in Table 5.

Table 5. RoB 2 assessment for randomized controlled trials.

Study	D1	D2	D3	D4	D5	Overall	Rationale
Liebau et al. [6].	Some concerns	Some concerns	Some concerns	Low	Some concerns	Some concerns	External allocation reported, but baseline imbalance, complete-case analysis, crossover carryover, and adherence reporting raise concerns.
Hsieh et al. [12].	Low	Some concerns	Low	High	High	High	Participant blinding was impossible for the no-insole control; outcome measurement and selective reporting carry a high risk.
Jafarnezhadgero et al. [13].	Some concerns	Low	Low	Low	Some concerns	Some concerns	Sham control supported internal validity, but details of random sequence generation and outcome prespecification were incomplete.
Ahn et al. [14].	Some concerns	Some concerns	Some concerns	Some concerns	Some concerns	Some concerns	Randomization was reported, but allocation concealment,

						examiner blinding, and handling of missing data were insufficiently detailed.
Ketabchi et al. [15].	Low	Some concerns	Some concerns	Some concerns	Low	Some concerns	Computer randomization and trial registration are present, but unblinded exercise delivery, a small male sample, and sequence effects warrant caution.

RoB 2 assessment for randomized controlled trials. RoB 2 domains: D1, Randomization process; D2, Deviations from intended interventions; D3, Missing outcome data; D4, Measurement of the outcome; D5, Selection of the reported result.

3.4.2. Non-Randomized Studies (ROBINS-I)

Non-randomized studies were appraised using ROBINS-I [16]. Non-randomized studies exhibited a serious-to-critical risk of bias, predominantly due to unadjusted confounding, the absence of untreated control cohorts, and potential reporting bias [17–21]. The domain-specific ROBINS-I judgments for non-randomized studies are presented in Table 6.

Table 6. ROBINS-I assessment for non-randomized studies of interventions.

Study	D1 Confounding	D2 Selection	D3 Classification	D4 Deviations	D5 Missing Data	D6 Measurement	D7 Reporting	Overall Risk
Lee et al. [17].	Serious	Moderate	Low	Low	Low	Moderate	Moderate	Serious
Lee et al. [20].	Critical	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious
Cho et al. [21].	Serious	Moderate	Low	Low	Low	Moderate	Low	Serious
Li et al. [18].	Critical	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious
Markowicz et al. [19].	Serious	Moderate	Low	Low	Moderate	Moderate	Low	Serious

4. Discussion

This systematic review indicates that conservative treatment may improve selected symptoms and functional outcomes in children with flexible flatfoot, particularly when treatment is directed toward symptomatic or functionally limited patients. The most reproducible clinical signal across the included evidence concerns pain, comfort, and selected measures of function rather than permanent correction of foot morphology [2,12,17,18,21]. This distinction is clinically important because pediatric flexible flatfoot has a strong developmental component and is frequently asymptomatic. An intervention that reduces pain or improves activity tolerance may therefore be useful even if it does not permanently reshape the medial longitudinal arch. In contrast, radiographic change alone should not be assumed to represent a meaningful clinical benefit [1–3].

The distinction between conventional and sensorimotor orthoses deserves particular emphasis. Conventional devices primarily modify contact mechanics, pressure distribution, and passive support, whereas sensorimotor insoles are intended to influence afferent input and neuromuscular control through strategically positioned pressure elements [4,5]. In theory, the latter could alter muscle recruitment and postural strategies without relying exclusively on structural support. The trial by Liebau et al. provides the most direct pediatric test of this hypothesis because it compared sensorimotor, supportive, and visually similar placebo insoles [6]. Although the sensorimotor treatment period was associated with an improvement in FADI, and both active insole designs influenced tibialis anterior activity compared with placebo, the trial did not demonstrate consistent superiority of the sensorimotor design across pain, posture, and muscle activity outcomes [6]. Thus, the mechanistic rationale remains plausible, but current direct pediatric evidence does not

justify presenting sensorimotor insoles as categorically more effective than conventional supportive orthoses.

It is noteworthy that most conclusions regarding sensorimotor insoles currently rely on a single pediatric randomized trial with some methodological limitations. Therefore, the distinction between sensorimotor-specific mechanisms and generic orthotic effects remains insufficiently established, highlighting the need for adequately powered replication studies.

The broader orthosis literature supports a more pragmatic interpretation. Hsieh et al. reported short-term improvements in pain and comfort, as well as several functional domains, with customized arch-support insoles in symptomatic children [12]. Jafarnezhadgero et al. demonstrated changes in selected lower-limb kinematic and kinetic variables after four months of medial arch-support orthoses compared with sham insoles [13] while Ahn et al. reported greater improvement in selected clinical and radiographic measures with talus-control orthoses than with rigid orthoses [14]. Other longitudinal studies found reductions in pain or changes in calcaneal position and muscle morphology after orthotic treatment [17,18,20,21]. These data suggest that orthoses can modify symptoms and measurable biomechanical variables, but they also demonstrate why the category "foot orthosis" should not be treated as a single intervention. Material stiffness, arch contour, heel posting, talus-control elements, sensorimotor elements, footwear interaction, wear time, and adjustment schedules vary substantially and may influence outcomes. Despite heterogeneity in orthosis design and indication, these findings support the clinical use of appropriately selected, customized foot orthoses for symptomatic children when the therapeutic objective is pain relief or improved function; the current evidence should be interpreted as heterogeneous rather than as evidence of the absence of clinical benefit.

Exercise-based rehabilitation provides a complementary model because it targets the active, rather than the passive, stabilizing system of the foot. Markowicz et al. observed improvements in foot position and balance after a six-week program that activated the intrinsic foot muscles [19], and Ketabchi et al. found more favorable changes in muscle morphometry and navicular drop when a corrective program began with intrinsic rather than extrinsic foot-muscle exercises [15]. These findings support the "foot core" concept and suggest that sequencing of rehabilitation may matter. However, exercise studies remain small and methodologically heterogeneous, and changes in muscle thickness or navicular drop should not automatically be equated with durable improvements in pain, participation, or quality of life [23]. The systematic review of functional re-education similarly concluded that exercise is promising but emphasized variability in protocols and outcome measures [8].

Balance and gait findings further illustrate the difference between mechanistic and patient-important outcomes. Improvements in posturographic variables, ground reaction forces, joint kinematics, or muscle activation may provide evidence that an intervention alters lower-limb function [6,13,17,19]. Nevertheless, the clinical magnitude of such changes is often uncertain, and many studies were not powered around a single predefined patient-important endpoint. For a child and family, outcomes such as pain during walking or sport, fatigue, participation, footwear tolerance, and the ability to maintain normal physical activity are generally more directly relevant than small changes in isolated laboratory variables. Future studies should therefore retain biomechanical measures as secondary outcomes while prioritizing validated pediatric patient-reported function and activity measures as primary endpoints.

The question of structural correction requires particular caution. Several studies reported improvements in valgus angle, resting calcaneal stance position, arch index, navicular drop, or radiographic alignment after orthotic or exercise treatment

[14,15,17,18,20,21]. However, the pediatric medial longitudinal arch undergoes natural maturation, and uncontrolled before-and-after designs cannot adequately separate treatment effects from growth, regression to the mean, changes in body mass, or spontaneous development. This limitation is reflected in systematic reviews that have not established convincing evidence that orthoses permanently alter the natural development of the pediatric arch [2,7,9]. For this reason, the goal of conservative treatment should be framed primarily in terms of symptoms, function, activity, and tolerance rather than cosmetic normalization of foot posture [1–3].

Risk of bias materially affects the interpretation of the findings. Among the randomized studies, Hsieh et al. was judged to be at high overall risk due to concerns about outcome measurement and selective reporting [12]. The remaining randomized trials were judged to have some concerns rather than being uniformly low risk [6,13–15]. In addition, half of the included primary studies were non-randomized, exhibiting a serious risk of bias due to confounding and the absence of untreated control groups [17–21]. These design limitations increase susceptibility to confounding, maturation effects, and expectation bias. Accordingly, statistically significant within-group changes should not be interpreted as equivalent to evidence of comparative efficacy.

The findings support an individualized treatment model rather than a uniform prescription. For a symptomatic child, a monitored trial of an orthosis may be reasonable when the primary goal is pain reduction or improved activity tolerance. In contrast, an exercise program targeting intrinsic foot muscle control can be incorporated when dynamic stability, balance, or active arch control are treatment priorities [15,19]. Sensorimotor insoles may be considered when there is a specific clinical rationale for proprioceptive stimulation, but families should be informed that superiority over conventional supportive devices has not been established [6]. Treatment response should be reassessed using predefined clinical goals, and devices that cause discomfort, poor footwear tolerance, or no meaningful functional benefit should be modified or discontinued. Future research should use adequately powered, multicenter parallel-group trials. Sensorimotor insoles should be described in sufficient technical detail to permit replication, including the base material, location, and dimensions of the stimulatory elements, fitting algorithm, footwear requirements, wear-time prescription, and the adjustment schedule. A credible supportive-orthosis comparator and a sham condition would help distinguish specific sensorimotor effects from generic orthotic effects. Exercise trials should standardize frequency, intensity, progression, supervision, and adherence monitoring. A 12- to 24-month follow-up is desirable to determine whether early symptomatic or biomechanical improvements are maintained and whether any structural changes exceed those expected with normal growth [2,3,15].

Limitations

This review has several limitations. First, the review protocol was not prospectively registered in PROSPERO or another international registry, which limits protocol transparency and is acknowledged as a methodological limitation. Second, although PubMed/MEDLINE, Cochrane, and Europe PMC cover the vast majority of biomedical and clinical literature, databases such as Embase, Scopus, and PEDro were not systematically searched. However, extensive citation tracking of systematic reviews and primary trials was conducted to minimize the risk of missing relevant studies. Third, the initial objective focused on sensorimotor insoles; however, because of the scarcity of pediatric studies on this intervention, conventional orthoses and exercise programs were included as contextual comparators. While this broadens the scope, it reflects the true state of current literature, where sensorimotor-specific evidence remains exceptionally limited. Fourth, substantial heterogeneity existed in diagnostic criteria, age ranges, intervention protocols,

outcome measures, and follow-up duration, preventing quantitative synthesis. Fifth, a large proportion of the available evidence originated from small single-center studies or non-randomized designs with moderate to critical risk of bias. Finally, direct evidence specifically evaluating sensorimotor insoles was limited, and most included studies investigated conventional orthoses or exercise-based interventions. Consequently, conclusions about the superiority of sensorimotor devices should be interpreted with caution.

5. Conclusions

This review identified limited direct evidence for the use of sensorimotor insoles in children with flexible flatfoot. Individual studies suggest possible functional and neuromuscular benefits. Still, the small sample sizes, clinical and methodological heterogeneity, and risk of bias preclude firm conclusions regarding comparative effectiveness or superiority over conventional supportive orthoses. Conventional orthoses and exercise-based rehabilitation have been investigated more frequently, but the certainty and comparability of this evidence also remain limited.

Exercise programs targeting intrinsic foot musculature may improve selected measures of active arch control, muscle morphology, and postural stability, but these findings require confirmation in larger and methodologically robust studies. Current evidence does not establish permanent structural correction of the developing arch. Clinical management should therefore be individualized, symptom-directed, and function-oriented, prioritizing pain, validated patient-reported function, activity, and participation, and quality of life where available, with goals defined prospectively and reassessed over time.

Author Contributions: Conceptualization, A.G.A. and M.M.; methodology, M.M., A.S. and A.P.; validation, A.G.A. and M.M.; formal analysis, M.M. and A.G.A.; data curation, T.S.V. and G.M.; writing—original draft preparation, M.M. and A.G.A.; writing—review and editing, A.G.A. and M.M.; supervision, A.G.A., M.G. and F.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Italian Ministry of Health with "Current Research funds".

Institutional Review Board Statement: Not applicable (systematic review of published literature).

Informed Consent Statement: Not applicable.

Data Availability Statement: All extracted data supporting the findings of this review are contained within the manuscript.

Acknowledgments: During the preparation of this manuscript, Grammarly (Grammarly Inc., San Francisco, CA, USA) was used for language editing. The authors reviewed and edited the resulting text and take full responsibility for the publication's content.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

FADI	Foot and Ankle Disability Index
ROBINS-I	Risk of Bias in Non-randomized Studies of Interventions
GRADE	Grading of Recommendations Assessment, Development and Evaluation
RoB 2	Risk of Bias tool
SWiM	systematic reviews without meta-analysis

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