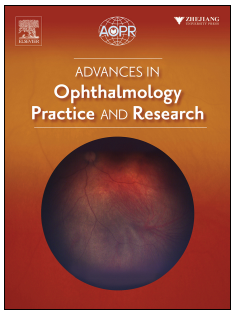
Journal Pre-proof



Instrument-Based, Non-Cycloplegic Versus Cycloplegic Refraction in Pediatric and Young Adult Populations (≤25 years): A Systematic Review and Meta-Analysis

Ana Roque, Amélia Fernandes Nunes, Henrique Nascimento, Clara Martinez-Perez

PII: S2667-3762(25)00065-4

DOI: https://doi.org/10.1016/j.aopr.2025.11.004

Reference: AOPR 100191

To appear in: *Advances in Ophthalmology Practice and Research*

Received Date: 15 September 2025

Revised Date: 11 November 2025

Accepted Date: 14 November 2025

Please cite this article as: Roque A, Nunes AF, Nascimento H, Martinez-Perez C, Instrument-Based, Non-Cycloplegic Versus Cycloplegic Refraction in Pediatric and Young Adult Populations (≤25 years): A Systematic Review and Meta-Analysis, *Advances in Ophthalmology Practice and Research*, https://doi.org/10.1016/j.aopr.2025.11.004.

Instrument-Based, Non-Cycloplegic Versus Cycloplegic Refraction in Pediatric and Young Adult Populations (≤25 years): A Systematic Review and Meta-Analysis

Ana Roque[1]
Amélia Fernandes Nunes[2]
Henrique Nascimento[1]
Clara Martinez-Perez[3]

1. Instituto Superior de Educação e Ciências de Lisboa (ISEC Lisboa), Alameda das Linhas de Torres, 179, 1750-142 Lisboa, Portugal. ana.roque@iseclisboa.pt; henrique.nascimento@iseclisboa.pt
2. Center for Research in Health Sciences (CICS), University of Beira Interior, Covilhã, Portugal. amnunes@ubi.pt
3. Applied Physics Department (Optometry Area), Facultade de Óptica e Optometría, Universidade de Santiago de Compostela, 15705 Santiago de Compostela, Spain

Corresponding author: Clara Martínez Pérez (clara.perez@iseclisboa.pt)

Funding: The authors did not receive support from any organization for the submitted work.

Running title: Refraction Accuracy in Children and Young Adults

Competing interests: The authors have no relevant financial or non-financial interests to disclose.

Ethics approval: This study is a meta-analysis of previously published studies and does not involve any new studies with human participants or animals performed by any of the authors.

Consent to participate: Not applicable.

Consent to publish: Not applicable.

Data availability: All data supporting the findings of this study are available from the corresponding author upon reasonable request. All data were extracted from previously published articles.

Authors' contributions: Concept and design: AR, AFN, HN, and CMP. Data collection: AR, and CMP. Data analysis: AR, and CMP. Data interpretation: AR and CMP. Drafting the initial manuscript: AR and CMP. Critical revision of the manuscript: AR, AFN, HN, and CMP. All authors have read and approved the final version of the manuscript.

Abstract

Background: Accurate refractive assessment in children and young adults is critical to prevent amblyopia and strabismus, conditions that may arise from uncorrected hyperopia. Although non-cycloplegic autorefractors and photoscreeners are increasingly used for vision screening due to their practicality and high testability, residual accommodation often introduces systematic measurement bias. The debate regarding the necessity of cycloplegia has intensified, particularly in large-scale epidemiological studies and screening programs, highlighting the need for an evidence-based synthesis.

Methods: This systematic review and meta-analysis, conducted according to PRISMA and AMSTAR-2 standards and registered in PROSPERO (CRD420251134665), synthesized data from 54 comparative studies, with 24 included in quantitative analyses.

Results: Compared with cycloplegic reference methods, non-cycloplegic autorefractors and photoscreeners consistently underestimated refractive error, showing pooled mean differences of -0.65 D (95% CI: -0.84 to -0.45; 95% PI: -1.50 to +0.20 D) and -0.78 D (95% CI: -1.12 to -0.44; 95% PI: -1.70 to +0.10 D), respectively. These prediction intervals illustrate the wide variability expected across future studies and populations. The bias was most pronounced in younger children and hyperopic eyes, reflecting the impact of accommodative tone. Despite device-specific differences, no method fully corrected this systematic error. Testability exceeded 95% across most devices, reinforcing their feasibility for population-level screening. However, the certainty of evidence was rated as low due to heterogeneity and observational design limitations.

Conclusions: Non-cycloplegic methods systematically underestimate hyperopia and therefore cannot replace cycloplegia for definitive diagnosis or spectacle prescription in pediatric populations. Cycloplegic assessment remains essential to detect amblyogenic refractive errors accurately. Non-cycloplegic methods may be integrated into large-scale screening programs for initial case detection, but positive or borderline cases must undergo cycloplegic confirmation to ensure safe and effective clinical management.

Keywords: Cycloplegia; Autorefraction; Photoscreener; Pediatric refractive error; Spherical equivalent; Vision screening; Meta-analysis; Amblyopia; Hyperopia; Instrument-based refraction

1.Introduction

The visual system undergoes a prolonged maturation throughout childhood, a period particularly vulnerable to the adverse effects of uncorrected ocular conditions such as amblyopia, which can affect up to 2% of children if untreated in time.[1] Epidemiological data indicate that nearly one-third of childhood visual impairment is preventable, mainly through timely detection and correction of refractive errors.[2] This underscores the importance of precise refractive assessment in pediatric populations, as uncorrected refractive errors remain a leading cause of amblyopia and may contribute to the development of strabismus. [3,4]

Cycloplegic retinoscopy has long been considered the gold standard for pediatric refractive assessment. [3] Accurate measurement in young children is complicated by accommodation, and complete relaxation is required to uncover latent hyperopia. Several approaches, distant fixation, fogging, Mohindra retinoscopy, and pharmacological cycloplegia, have been described, with agents such as cyclopentolate or tropicamide proving most effective.[5–8] In addition, non-pharmacological methods such as the School Bus Accommodation-Relaxing Skiascopy (SBARS) technique described by Schaafsma et al.[9] have shown promising results in partially reducing accommodative tone and improving agreement with cycloplegic refraction. Cycloplegic retinoscopy continues to be the reference in both clinical and research contexts, especially in preschool-aged children, to avoid underestimation of hyperopia and amblyogenic errors.[3,4]

Technological innovations have introduced handheld autorefractors and photoscreeners that facilitate rapid, instrument-based estimation of refractive error.[3,10,11] These devices are increasingly used by non-specialist health professionals in schools and community screening programs. [12] The Welch-Allyn Spot Vision Screener, for instance, has shown sensitivities of 60.9–89.8% and specificities of 70.4–94.9% for amblyopia risk factors, while handheld autorefractors often achieve even higher values.[13–16] Despite their practicality, accuracy remains limited for hyperopia detection in non-cycloplegic conditions due to residual accommodation, leading to systematic underestimation of hyperopia.[11,14–17]

Cycloplegic autorefraction is generally reported as the most reliable objective method, followed by non-cycloplegic autorefraction, subjective refraction, and retinoscopy.[18–20] However, cycloplegia is not always well accepted, as it causes transient photophobia, discomfort, and blurred near vision, sometimes leading to parental reluctance, especially in large-scale studies. This has fueled debate about its necessity in older children and young adults, with some studies suggesting it may not always be required, while others report significant discrepancies, especially for hyperopia or in highly myopic cohorts.[5,7,21,22]

Photorefraction has emerged as an alternative, particularly for less experienced examiners or when cooperation is limited.[19] Devices such as Plusoptix simultaneously measure refraction, pupil size, and ocular alignment, but several studies report systematic underestimation of hyperopia even under cycloplegia.[11,17,23] These instruments use fixation targets that can modify accommodative tone, and they are primarily designed to detect insufficiently relaxed hyperopia, which represents the clinically relevant amblyopia risk factor, rather than full latent hyperopia.[12,15,24] Plusoptix may fail to provide valid readings when pupils are widely dilated under cycloplegia, and SureSight has shown variable performance outside the controlled conditions of the Vision in Preschoolers (VIPS) study.[12,25,26] The choice of cycloplegic agent and dosing protocol also affects outcomes, with tropicamide alone still insufficiently studied.[27]

At a public health level, refractive error constitutes a major global burden, associated with comorbidities and reduced quality of life.[4,17,19,20,28] Misclassification of refractive status due to absence of cycloplegia can distort epidemiological data and resource planning.[29] For example, large-scale Chinese studies demonstrated that non-cycloplegic refraction can markedly

overestimate myopia and underestimate hyperopia, with the magnitude of error varying with underlying prevalence.[22,30]

In light of these challenges, this study systematically compares cycloplegic and non-cycloplegic refractive assessment methods in pediatric and young adult populations, with particular focus on diagnostic performance, limitations, and the clinical role of contemporary instrument-based screening devices. By synthesizing evidence from diverse clinical and epidemiological settings, the review aims to inform best practices and refine protocols for refractive error assessment and vision screening in children and adolescents. This review builds upon previous evidence by including newer generations of autorefractors and photoscreeners, extending the analysis to young adult populations, and proposing a practical framework to guide both clinical and public health screening strategies.

2. Methods

2.1. Research Question and PICOS Framework

This systematic review and meta-analysis was registered in PROSPERO (CRD420251134665; available at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD420251134665) and conducted in accordance with the PRISMA guidelines[31] and AMSTAR-2 methodological standards [32] (see Figure 1). A completed PRISMA 2020 checklist is provided as Supplementary Material (Additional file 1). The last literature search was performed on 15 August 2025. Minor deviations from the registered protocol included the addition of sensitivity analyses for highly heterogeneous outcomes and a slight extension of the upper age limit to 25 years to better capture young adult populations.

The research question was developed using the PICOS framework to ensure methodological rigor and clinical relevance. Specifically, we aimed to determine whether children and adolescents undergoing non-cycloplegic refractive assessment (Population and Intervention/Exposure) show significant differences in spherical equivalent refraction (Outcome) compared to those assessed with cycloplegic reference methods, including retinoscopy, subjective refraction, or autorefraction (Comparator). All included studies were observational in design (Study design), encompassing cross-sectional, prospective, and retrospective comparisons of at least two refractive techniques, with explicit reporting of cycloplegic status.

The primary outcome was the mean difference in spherical equivalent refraction between non-cycloplegic and cycloplegic measurements. Secondary analyses explored device type (handheld vs. tabletop; autorefractor vs. photoscreener), patient age, refractive status (myopia, hyperopia), testability rates, and the influence of methodological heterogeneity across studies. By systematically synthesizing evidence on the accuracy and agreement of different refraction methods, this review aims to inform clinical decision-making for pediatric refractive assessment, identify sources of bias and variability, and highlight areas for future research and guideline development.

2.2. Eligibility Criteria

Studies were excluded if they were case reports, case series, or lacked a comparative group; systematic or narrative reviews; duplicate reports from the same dataset; or if they exhibited a high risk of bias or insufficient methodological rigor. Additional exclusion criteria included studies with non-comparable or incomplete demographic data, those employing inadequate or unspecified refractive assessment protocols, studies not reporting relevant refractive outcomes (such as spherical equivalent or cylinder), and those lacking sufficient statistical data (e.g., means, standard deviations, or confidence intervals) required for meta-analytic synthesis.

2.3. Information Sources

A comprehensive literature search was conducted using three major electronic databases: PubMed, Web of Science, and Scopus. The search strategy was systematic and exhaustive, with no restrictions on publication date or language. Additionally, the reference lists of all articles meeting the inclusion criteria were manually reviewed to identify any relevant studies that may have been missed during the initial database search.

2.4. Search Methods for Identification of Studies

The search strategy combined controlled vocabulary and free-text terms relevant to cycloplegic and non-cycloplegic refractive assessment, including: ("cycloplegic refraction" OR "cycloplegia" OR "cyclopentolate" OR "atropine" OR "tropicamide") AND (retinoscopy OR skiascopy OR "manual refraction") AND (autorefractometry OR autorefractor OR "automatic refractometer" OR "auto refract*"). Complete search strategies for each database are provided in Additional file 2. Two reviewers (A.R. and C.M.P) independently assessed study eligibility at both the title/abstract screening and full-text review stages. Disagreements were resolved through discussion and consensus. No language restrictions were applied, and studies published in languages other than English were translated and included when relevant data were available

2.5. Data Extraction and Data Items

Two authors (A.R. and C.M.P.) independently extracted data from all eligible studies. For each included study, the following key characteristics were collected: first author's name, year of publication, country or region, study design, sample size, mean age of participants, refractive assessment methods (including details of cycloplegic and non-cycloplegic protocols), and the specific devices or instruments used. Discrepancies in data extraction or study inclusion were resolved through discussion and consensus. Record management, including duplicate removal and tracking of study eligibility, was performed using Microsoft Excel.

The primary variables extracted included mean and standard deviation of spherical equivalent refraction (SER) for each comparison group, as well as cylinder values where available. Additional data items included the type of refractive device (e.g., handheld or tabletop autorefractor, photoscreener), cycloplegic agent and protocol, population characteristics (age range, refractive status), and testability or cooperation rates. These variables were recorded to enable subgroup and sensitivity analyses, and to assess potential sources of methodological heterogeneity across studies.

2.6. Risk of Bias Assessment

The methodological quality and risk of bias of the included observational studies were independently assessed by two reviewers using the Methodological Index for Non-Randomized Studies (MINORS) developed by Slim et al.[33] (Additional file 3). The MINORS tool evaluates key aspects of study design, such as the clarity of study objectives, consecutive inclusion of participants, appropriateness of inclusion criteria, objectivity of outcome assessments, and adequacy of follow-up.

For comparative studies, the total MINORS score ranges from 0 to 24, with studies classified as very low quality (0–6), low quality (7–10), moderate quality (11–15), or high quality (16–24). Only comparative (cross-sectional, cohort, or case-control) studies were included in this review. Any disagreements in quality assessment were resolved through discussion and consensus.

In addition, the overall methodological rigor of the review process was verified using the AMSTAR-2 framework, in accordance with current international standards for systematic reviews. Given that most included studies evaluated agreement between refractive methods rather

than diagnostic accuracy per se, the MINORS tool was considered more appropriate than QUADAS-2 or QUADAS-C for individual study appraisal.

2.7. Assessment of Results

For continuous outcomes measured on the same scale, mean differences (MD) with 95% confidence intervals (CI) were calculated. When outcomes were reported using different measurement scales, standardized mean differences (SMD) were used to enable comparability across studies. For dichotomous outcomes, odds ratios (OR) with 95% CI were computed. Statistical heterogeneity among studies was assessed using the I^2 statistic and interpreted as low (<25%), moderate (25–50%), or high (>50%) heterogeneity. A fixed-effects model was applied when heterogeneity was not significant ($I^2 \leq 50\%$), while a random-effects model was used in cases of substantial heterogeneity. Missing or incomplete data were addressed according to methodological recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions.[34] All statistical analyses and figure generation were performed using Review Manager (RevMan) version 5.4.1. When outcomes were reported per eye rather than per participant, study-level summary statistics were used, assuming minimal within-subject correlation, as individual paired data were not available. This approach is consistent with prior ophthalmic meta-analyses. Potential sources of heterogeneity were pre-specified, including participant age, device type (open- vs. closed-field), refractive category, and cycloplegia protocol or timing. Random-effects models were fitted using the DerSimonian–Laird method, which provides results comparable to restricted maximum likelihood (REML) estimators. Prediction intervals were examined to illustrate the expected range of effects across studies.

The sign convention for spherical equivalent refraction (SER) followed standard ophthalmic practice, with negative values indicating myopia and positive values indicating hyperopia. Between-study heterogeneity was further quantified using the Q statistic, τ^2, and I^2 for each pooled comparison, as reported in the corresponding forest plots and Supplementary Figures. Outcomes involving cylindrical power and axis orientation were analyzed descriptively as agreement measures (limits of agreement, LoA) rather than pooled as mean differences, due to the directional and vectorial nature of these variables.

Diagnostic accuracy indicators (sensitivity, specificity, and AUC) were summarized descriptively as reported in the primary studies, since heterogeneous cut-offs precluded pooled bivariate or HSROC modeling.

2.8. Publication Bias

Potential publication bias was assessed through visual inspection of funnel plots generated using Review Manager (RevMan) version 5.4.1. Asymmetry in the funnel plot was interpreted as a possible indication of publication bias, reflecting the potential non-publication of smaller studies with null or inconclusive results. This assessment was performed for each main comparison group, including cycloplegic versus non-cycloplegic refractive methods. Given the high heterogeneity and the limited number of studies ($k < 10$) in some comparisons, small-study effects and funnel plot asymmetry were interpreted with caution.

2.9. Additional Analyses

Sensitivity analyses were performed to evaluate the robustness of the pooled results by sequentially removing studies identified as highly influential within each outcome domain. These analyses allowed assessment of the impact of individual studies on overall effect estimates and contributed to a better understanding of sources of heterogeneity, particularly for key outcomes such as spherical equivalent refraction, cylinder, and testability rates. All analyses were conducted

using Review Manager (RevMan) version 5.4.1, applying a random-effects model when significant heterogeneity was present. Furthermore, the certainty of evidence for each outcome was evaluated using the GRADE approach, considering factors such as risk of bias, inconsistency among studies, imprecision of effect estimates, and potential publication bias. [35] All assessments were performed independently by two reviewers, and any discrepancies were resolved through discussion and consensus.

3. Results

3.1. Systematic Review

3.1.1. Study selection

A total of 274 records were initially retrieved from PubMed (n=90), Web of Science (n=96), and Scopus (n=88) (Figure 1). After removal of duplicates and screening of titles and abstracts, 107 records were excluded. Exclusion criteria at this stage included studies that did not report spherical equivalent refractive error, did not compare at least two of the following methods (retinoscopy, autorefraction, or subjective refraction), did not specify cycloplegic status, were case reports, or were review articles. Subsequently, 167 full-text articles were assessed for eligibility. Of these, 115 were excluded due to non-comparative data, dissimilar demographics, incomplete data, high risk of bias, or non-shared data. Additionally, two relevant studies were identified through manual review of reference lists. In total, 54 studies met the inclusion criteria and were included in the qualitative synthesis, [17,19,20,23–26,28,29,36–80] of which 24 were included in the meta-analysis.[17,19,20,29,37,38,41,43,44,46–48,50,52,54,61,63,65,70,72,76–79]

The 54 included studies originated from 22 countries across five continents, most frequently from Turkey (n = 11), the United States (n = 11), China (n = 6), Germany (n = 4), and India (n = 4). Additional studies were conducted in Australia (n = 2), and in countries including Sweden, Malaysia, the United Kingdom, Spain, Thailand, Portugal, Vietnam, Taiwan, Slovenia, the Democratic Republic of Congo, the Netherlands, France, Croatia, Singapore, Italy, Iran, and Greece (each n = 1). Among the 24 studies included in the meta-analysis, most were conducted in Asia and Europe.

3.1.2. Study characteristics

The main characteristics of the studies included in this review are summarized in Additional file 4. The 54 studies, conducted between 1997 and 2025, encompassed a wide range of countries and clinical settings across Europe, Asia, North America, Australia, and Africa. Study designs were predominantly cross-sectional (n = 40) or prospective (n = 10), with sample sizes ranging from 28 to 4,040 participants and ages spanning from infancy to adulthood; 46 studies (85.2%) focused primarily on pediatric populations.

Across these studies, the most frequently compared refraction methods were autorefraction (47 studies, 87.0%), retinoscopy (42, 77.8%), photoscreening or photorefraction (17, 31.5%), and subjective refraction (12, 22.2%). A smaller number of studies also evaluated wavefront aberrometry (4, 7.4%) or other hybrid comparison techniques (3, 5.6%). Cycloplegia protocols varied, with cyclopentolate 1% used in 32 studies (59.3%), tropicamide 1% or 0.5% in 11 (20.4%), combined regimens in 8 (14.8%), and homatropine or atropine in 3 (5.5%).

Twenty-six studies (48.1%) included both cycloplegic and non-cycloplegic measurements, while 28 (51.9%) focused exclusively on one condition. The studies were conducted in hospital-based (n = 22), school-based (n = 18), and population-based (n = 14) settings, addressing different combinations of refraction methods under varied cycloplegia protocols. A detailed breakdown of refraction methods, devices, and cycloplegic agents for each study is provided in Additional file

4 (Summary table of study characteristics). None of the included studies declared conflicts of interest.

3.2. Meta-analysis

3.2.1. Non-cycloplegic Autorefractor vs. Cycloplegic Reference Methods

This meta-analysis evaluated the performance of non-cycloplegic autorefractors compared with cycloplegic reference methods, including retinoscopy, autorefraction, and subjective refraction, across 15 studies (Figure 2). The pooled analysis demonstrated a consistent myopic bias with non-cycloplegic measurements, confirming that these instruments systematically underestimate hyperopia and overestimate myopia in pediatric and young adult populations.

When non-cycloplegic autorefractors were compared with cycloplegic retinoscopy (10 studies), the pooled mean difference was –0.81 D (95% CI: –1.28 to –0.33; $p<0.00001$). Although heterogeneity was high ($I^2=97\%$), stratification by age revealed that children aged 7–12 years showed more consistent results ($I^2=0\%$), with a pooled mean difference of –1.04 D. This highlights the influence of both age and accommodative behavior on measurement variability.

For non-cycloplegic versus cycloplegic autorefraction (11 studies), the overall mean difference was –0.58 D (95% CI: –0.82 to –0.34), again confirming a systematic myopic shift. Heterogeneity remained considerable ($I^2=96\%$), reflecting differences in device type, cycloplegia regimen, and study population. In children aged 7–12 years, the pooled mean difference was –0.73 D, whereas in adults over 20 years it was –0.41 D, indicating that the bias decreases with age but persists into young adulthood.

Two studies compared non-cycloplegic autorefractor and cycloplegic subjective refraction, reporting a pooled mean difference of –0.47 D (95% CI: –0.73 to –0.22). This again confirmed the tendency of non-cycloplegic measurements to yield more myopic values, with moderate heterogeneity ($I^2=87\%$). Across all comparisons, the global pooled effect was –0.65 D (95% CI: –0.84 to –0.45), reinforcing the presence of a systematic myopic bias associated with residual accommodation.

Importantly, testability rates for modern autorefractors were consistently high (>95%), with handheld devices such as Retinomax, SureSight, and QuickSee achieving >98% even in preschool children.[24,40,59,64,71] This underscores their value in field and community-based screening where cooperation is limited.

Despite this advantage, a recurring finding is the systematic underestimation of hyperopia. Mean differences between non-cycloplegic autorefraction and cycloplegic retinoscopy ranged from –0.3D to –1.5D, with the largest discrepancies in hyperopic children or when photoscreening devices were used.[39,51,55,56,60,64,66,67,71] For instance, Paff et al.[64] found that Retinomax K-plus2 underestimated hyperopia by –2.11D post-cycloplegia compared with retinoscopy, while Plusoptix S08 underestimated by –1.13D, with sensitivity as low as 33% for detecting high hyperopia. Similarly, SureSight detected only 18–33% of cases within 0.5D of retinoscopy.[39,71]

Tabletop closed-field autorefractors, such as Topcon KR-800, also tended toward more myopic readings without cycloplegia, whereas open-field devices like Shin-Nippon NVision-K 5001 performed closer to retinoscopy, particularly for hyperopia and oblique astigmatism.[51,57] Comparisons of portable devices like QuickSee and 2WIN reported mean differences of –0.97D and –1.34D, respectively, further demonstrating the limitations of non-cycloplegic measures.[53,59]

Cycloplegia consistently produced a hyperopic shift across instruments. Kaiser et al.[53] reported a median shift of +0.25D with cyclopentolate, while Kirschen et al.[56] found an increase of 1.03D in hyperopia post-cycloplegia. Agreement between autorefraction and retinoscopy improved dramatically under cycloplegia, with intraclass correlation coefficients >0.9 for spherical equivalent and J0 components.[51,55,57]

Cylinder and axis measurements were more reproducible than sphere, even without cycloplegia. Büchner et al.[39] found that 82% of SureSight cylinder values were within 0.5 D and 67% of axis values were in close agreement with cycloplegic retinoscopy. QuickSee and similar handhelds showed moderate-to-good correlations, though oblique astigmatism remained variable, with open-field devices performing better.[51,57,59]

Clinically, handheld autorefractors are valuable in mass screenings due to portability, speed, and cooperation.[24,40,59,64,71] However, tabletop autorefractors with fogging and eye-tracking mechanisms (e.g., Marco ARK-560A) still fail to neutralize accommodation fully without cycloplegia.[53,56,74] Wavefront-based autorefraction showed strong correlations but tended to overestimate myopia by nearly 1.0D.[55] Open-field autorefractors consistently provided better agreement with retinoscopy than closed-field devices.[51,57]

Sensitivity for detecting myopia and astigmatism was generally high, but hyperopia detection without cycloplegia remained poor, often <35%.[60,64,67,69] With cycloplegia, Retinomax sensitivity for high hyperopia exceeded 80%. Optimized referral criteria and repeated screenings improved specificity and efficiency.[64,66,69]

Recent studies highlight strategies to mitigate bias. Abrahamsson et al.[36] confirmed significant cycloplegic vs. non-cycloplegic differences, sometimes extreme (up to 16D), reinforcing the need for cycloplegia. Gopalakrishnan et al.[45] found that using a cutoff of –0.75D instead of –0.50D for non-cycloplegic data aligned myopia prevalence estimates with cycloplegic values, suggesting epidemiological corrections. Ocak et al.[62] showed that anesthesia failed to relax accommodation adequately, underestimating hyperopia compared with pharmacological cycloplegia. Rajavi et al.[28] reported systematic underestimation with Plusoptix and Topcon RM800, with improved sensitivity at lower hyperopia thresholds but reduced specificity.

Rauscher et al.[68] observed that cycloplegic SER was on average 0.55D more hyperopic than non-cycloplegic, with higher variability in sphere without cycloplegia. Tuncer et al.[73] confirmed underestimation by handheld Retinomax compared with retinoscopy, although device agreement was good once cycloplegia was applied. Finally, Wang et al.[80] proposed a predictive model combining non-cycloplegic refraction, biometry, and visual acuity, achieving high accuracy ($R^2 \approx 0.93$), offering potential correction for epidemiological studies lacking cycloplegia.

In summary, non-cycloplegic autorefractors show high feasibility and reproducibility for myopia and astigmatism, but consistently underestimate hyperopia, limiting their role in clinical prescription. Cycloplegic refraction remains essential for accurate diagnosis, while predictive models may help adjust non-cycloplegic data in large-scale surveys.

3.2.2. Non-cycloplegic Photoscreener vs. Cycloplegic Reference Methods

Figure 3 presents the pooled analysis of spherical equivalent refraction (SER) measured by non-cycloplegic photoscreeners compared to cycloplegic reference methods across ten studies, grouped into two subcategories: (1) non-cycloplegic photoscreener versus cycloplegic retinoscopy, and (2) non-cycloplegic versus cycloplegic photoscreener.

For the comparison with cycloplegic retinoscopy (nine studies, 2,537 eyes), the pooled mean difference was –0.76D (95% CI: –1.07 to –0.44; p<0.00001), showing that non-cycloplegic devices consistently yielded more myopic (or less hyperopic) results. Heterogeneity was high (I^2=82%), reflecting variability in study design, populations, and devices. Subgroup analysis by age confirmed this pattern: in children ≤6 years, the pooled mean difference was –0.58D (95% CI: –0.90 to –0.26; I^2=73%), and in those aged 7–12 years, –0.80D (95% CI: –1.32 to –0.29; I^2=79%).

For non-cycloplegic versus cycloplegic photoscreeners (four studies, 598 eyes), the pooled mean difference was –0.85D (95% CI: –1.77 to 0.07; p=0.07), again indicating a systematic myopic

bias without cycloplegia, with very high heterogeneity (I^2=95%). The overall pooled effect across all 3,135 eyes confirmed a significant bias of –0.78D (95% CI: –1.12 to –0.44; p<0.00001), with total heterogeneity of I^2=91%.

These findings highlight a consistent underestimation of hyperopia by non-cycloplegic photoscreeners, an issue of particular concern in pediatric populations where accommodative tone is strong. Dahlmann-Noor et al.[42] reported that the Plusoptix Vision Screener underestimated mean spherical equivalent (MSE) by an average of 1.9D compared to cycloplegic retinoscopy, with only 19% of measurements within ±0.50D. This discrepancy was most pronounced in children with hyperopia or strabismus, illustrating the risk of missing amblyogenic refractive errors.

Kulp et al.[25], analyzing >4,000 preschoolers in the Vision In Preschoolers (VIP) Study, confirmed that while non-cycloplegic instruments (SureSight, Retinomax) showed high discriminatory power for refractive errors (AUCs 0.92–0.93), hyperopia detection was weaker (AUC 0.85 for SureSight vs 0.98 for Retinomax). Device-specific differences were particularly relevant for hyperopic error detection, despite high testability and strong performance for myopia and astigmatism (AUCs ≥0.97).

Yan et al.[26] evaluated Plusoptix and SureSight against cycloplegic retinoscopy in Chinese preschoolers. Agreement was generally good (limits >93%), but hyperopia detection efficiency remained low (Youden index 0.60 for Plusoptix, 0.83 for SureSight). Adjusting referral criteria improved performance but did not resolve the underlying limitation.

In a clinical study of 142 children, Racano et al.[23] showed that Plusoptix A12R under non-cycloplegic conditions had a sensitivity of only 33.3% for hyperopia, although specificity was high (95.9%). Both Plusoptix and 2Win refractometer correlated well with cycloplegic references for astigmatism but consistently underestimated hyperopia.

Yakar [75], testing the Spot Vision Screener in 150 Turkish children, found 59% sensitivity and 94% specificity for significant refractive errors. Again, SER was systematically underestimated, with underestimation correlating with ocular biometry such as anterior chamber depth and axial length.

Overall, the evidence shows robust and consistent myopic bias with non-cycloplegic photoscreeners. While practicality and testability are strong advantages, the underestimation of hyperopia substantially reduces sensitivity, increasing the risk of false negatives in vision screening. Device-specific patterns exist (SureSight more sensitive for hyperopia, Plusoptix for myopia), but none fully overcome the absence of cycloplegia. These results emphasize the need for careful interpretation of non-cycloplegic data, especially where undetected hyperopia may contribute to amblyopia or visual deficits.

3.2.3. Non-cycloplegic Retinoscopy vs. Cycloplegic Retinoscopy

Figure 4 presents the pooled analysis of SER measured by non-cycloplegic retinoscopy compared to cycloplegic retinoscopy. Data from five studies, including a total of 681 eyes, were analyzed to assess systematic differences between these two methods.

The pooled mean difference was –0.28D (95% CI: –0.64 to 0.09; p=0.14), indicating a trend for non-cycloplegic retinoscopy to yield slightly more myopic (or less hyperopic) values compared to cycloplegic retinoscopy, although this difference did not reach statistical significance. There was substantial heterogeneity among the studies (I^2=86%), which may reflect differences in study populations, retinoscopy protocols, or examiner experience.

Individual study mean differences ranged from –0.96 to +0.04D. Three of the five studies reported small or negligible differences between non-cycloplegic and cycloplegic retinoscopy, while two studies showed a more pronounced myopic bias without cycloplegia. When stratifying by age, in the subgroup of children aged 7 to 12 years, the pooled mean difference was –0.37D (95% CI: –

1.00 to 0.25), with substantial heterogeneity (I^2=80%). In participants over 20 years of age, the pooled mean difference was –0.14 diopters (95% CI: –0.54 to 0.26; I^2=86%), again with considerable heterogeneity.

3.2.4. Non-cycloplegic Subjective Refraction vs. Cycloplegic Reference Methods

Figure 5 presents the pooled analysis of SER measured by non-cycloplegic subjective refraction compared to three cycloplegic reference methods: cycloplegic subjective refraction, cycloplegic retinoscopy, and cycloplegic autorefraction. Data from five studies, were included and analyzed in three subgroups.

For the comparison between non-cycloplegic subjective refraction and cycloplegic subjective refraction (2 studies), the pooled mean difference was –0.08D (95% CI: –0.17 to 0.00; p=0.06), indicating a very small, non-significant tendency for non-cycloplegic subjective refraction to yield more myopic (or less hyperopic) values. Heterogeneity was negligible (I^2=0%).

For the comparison between non-cycloplegic subjective refraction and cycloplegic retinoscopy (2 studies), the pooled mean difference was –0.02D (95% CI: –0.11 to 0.07; p=0.64), again showing minimal and non-significant difference between the two methods, with no heterogeneity detected (I^2=0%).

In the comparison between non-cycloplegic subjective refraction and cycloplegic autorefraction (six studies, 605 eyes), the pooled mean difference was 0.10D (95% CI: 0.04 to 0.16; p=0.0008), suggesting a slight but statistically significant bias toward more hyperopic (or less myopic) values with non-cycloplegic subjective refraction. Heterogeneity was low (I^2 = 0%).

The overall pooled effect across all comparisons (976 eyes) showed a mean difference of –0.02D (95% CI: –0.12 to 0.09; p=0.77) between non-cycloplegic subjective refraction and cycloplegic reference methods, indicating no significant systematic bias. Moderate heterogeneity was observed across subgroups (I^2=67%), likely reflecting the inclusion of multiple reference methods and variations in study populations and protocols.

3.2.5. Cycloplegic Autorefractor vs. Cycloplegic Reference Methods

Figure 6 shows the pooled analysis of spherical equivalent refraction (SER) measured by cycloplegic autorefractors compared with cycloplegic subjective refraction and cycloplegic retinoscopy. Twelve studies (3,204 eyes) were included, grouped into two subgroups.

For cycloplegic autorefractor versus subjective refraction (five studies, 551 eyes), the pooled mean difference was –0.20D (95% CI: –0.26 to –0.14; p<0.00001), indicating a slight myopic bias of autorefractors. No heterogeneity was observed (I^2=0%). For cycloplegic autorefractor versus retinoscopy (13 studies, 2,653 eyes), the pooled mean difference was –0.18D (95% CI: –0.22 to –0.13; p<0.00001), again showing a small but significant bias, with low heterogeneity (I^2=42%). Subgroup analysis by age showed a pooled mean difference of –0.18D (95% CI: –0.39 to 0.03) in children ≤6 years (I^2=55%) and –0.10D (95% CI: –0.30 to 0.11) in those aged 7–12 years (I^2=36%). Overall, across all comparisons, the pooled effect was –0.19D (95% CI: –0.22 to –0.15; p<0.00001), with low total heterogeneity (I^2=20%). These results confirm a small but consistent myopic shift of cycloplegic autorefractors compared to reference methods. Notably, recent studies have shown that certain accommodation-relaxing techniques, such as open-field or optical methods, can achieve comparable accuracy under non-pharmacological conditions.[24,57]

Harvey et al.[49] evaluated the handheld Nikon Retinomax in 47 children (11–93 months) under cycloplegia, comparing with retinoscopy and subjectively refined retinoscopy. Retinomax showed good reproducibility (mean deviation 0.43D). Agreement with retinoscopy was close (mean bias –0.31D after working distance correction), suggesting only slight underestimation of hyperopia. Mean absolute differences were 0.82D with retinoscopy and 1.03D with subjective

refinement, supporting Retinomax as a reliable alternative in young children when subjective methods are unfeasible.

Honglertnapakul et al.[51] compared cycloplegic retinoscopy (CR), cycloplegic autorefraction (CA, Topcon KR-800), and subjective/non-cycloplegic refraction in 44 children (6–15 years). CA produced slightly more myopic values than CR (median difference 0.38D, $p<0.001$), but differences were not clinically meaningful. In hyperopes, CA and CR were closer (median difference 0.25D). The study confirmed that cycloplegic autorefraction and retinoscopy are largely interchangeable, though small biases persist.

Kurent[58] compared cycloplegic refraction from a handheld 2WIN, a table-mounted Nidek ARK-1, and streak retinoscopy in 57 children with poor vision and/or strabismus. The Nidek ARK-1 closely matched retinoscopy (mean difference 0.04D; narrow limits of agreement –0.37 to 0.45D). In contrast, the 2WIN substantially underestimated SE by more than 1D compared with both retinoscopy and Nidek, especially in higher refractive errors, raising concern for under-detection in amblyogenic cases.

Taken together, these studies show that table-mounted cycloplegic autorefractors demonstrate excellent agreement with retinoscopy, with minimal mean differences (<0.1–0.4D). Handheld autorefractors vary: Retinomax shows good reproducibility and clinically acceptable agreement (bias ~–0.3D), while 2WIN shows clinically significant underestimation of refractive error, especially in children with higher ametropia. Both handheld and table-mounted devices exhibit a general myopic bias relative to retinoscopy, but the magnitude is small and often clinically acceptable, except for certain handheld devices.

3.2.6. Cycloplegic Photoscreener vs Cycloplegic Retinoscopy

Figure 7 presents the pooled analysis of spherical equivalent refraction measured by cycloplegic photoscreeners compared to cycloplegic retinoscopy. Data from four studies, involving a total of 763 eyes, were included.

The pooled mean difference was –0.28D (95% CI: –1.43 to 0.86; $p=0.63$), indicating no significant difference between cycloplegic photoscreener and cycloplegic retinoscopy measurements. There was substantial heterogeneity among the studies ($I^2=97\%$), suggesting considerable variation in the degree and direction of differences across study populations and devices.

Individual study mean differences ranged from –1.77 to +1.06D. While two studies showed the photoscreener tending to yield less hyperopic or more myopic values than cycloplegic retinoscopy, the other two studies reported a slight hyperopic bias or near equivalence.

3.2.7. Sensitivity analysis

A sensitivity analysis was conducted by excluding specific studies identified as major contributors to heterogeneity in refractive error outcomes (Additional file 5). For the comparison between non-cycloplegic autorefractor and cycloplegic retinoscopy, the studies by Ciuffreda & Rosenfield[41] [Retinomax-3 and Topcon KR-1W] and Payerols et al.[17] [Retinomax] were excluded due to their outlier values and methodological differences. After their removal, the pooled mean difference was –0.96D (95% CI: –1.13 to –0.80), which remained statistically significant. Importantly, this adjustment reduced heterogeneity dramatically from 97% to 0%, indicating high consistency across the remaining studies.

Similarly, for the comparison between non-cycloplegic autorefractor and cycloplegic subjective refraction, exclusion of Choong et al.[19] [Retinomax K plus] and Ciuffreda & Rosenfield [41] [Topcon KR-1W] resulted in a pooled mean difference of –0.39 (95% CI: –0.47 to –0.30), with heterogeneity decreasing from 87% to 0%.

Another sensitivity analysis was conducted by excluding studies identified as major contributors to heterogeneity in the comparison between non-cycloplegic photoscreener and cycloplegic retinoscopy (Additional file 6). Specifically, the studies by Huang et al.[52] and Yalçın et al.[76] [2WIN] were excluded due to their methodological differences and outlier values. After their removal, the pooled mean difference was –0.70D (95% CI: –0.96 to –0.44), which remained statistically significant. Notably, this adjustment reduced heterogeneity from 82% to 45%, indicating a substantial increase in consistency across the remaining studies. These findings confirm that the systematic myopic bias observed with non-cycloplegic photoscreeners is robust and not driven by these influential studies.

A sensitivity analysis was conducted by excluding Mukash et al.[61], which was identified as a major contributor to heterogeneity in the comparison between non-cycloplegic retinoscopy and cycloplegic retinoscopy (Additional file 7). After excluding this study, the pooled mean difference was –0.10D (95% CI: –0.33 to 0.14), which remained non-significant. Importantly, this adjustment reduced heterogeneity from 86% to 56%, indicating a notable increase in consistency among the remaining studies. These results confirm that while the overall estimate was not substantially affected, the exclusion of this influential study improved the reliability and interpretability of the pooled analysis.

3.2.8. Publication bias

Publication bias was evaluated using funnel plots across all outcome domains (Additional file 8). Comparisons of cycloplegic photoscreener versus retinoscopy showed symmetrical distributions, though few studies limited power to detect asymmetry. For cycloplegic autorefractor versus reference methods, minor asymmetry suggested small studies tended to report more extreme effects, but the overall pattern remained centered, indicating moderate risk. Non-cycloplegic subjective and retinoscopy comparisons appeared symmetric, showing minimal bias. In contrast, photoscreener and autorefractor non-cycloplegic groups displayed some scatter and mild asymmetry, consistent with small-study effects. Overall, no substantial publication bias was identified, though cautious interpretation remains warranted.

3.2.9. GRADE

The GRADE summary of findings (Additional file 9) rated the certainty of evidence as low across all refractive comparisons, including non-cycloplegic autorefractor, photoscreener, and subjective refraction versus cycloplegic reference methods. This reflects reliance on non-randomized designs and concerns regarding bias, inconsistency, and imprecision, though none were judged severe enough to downgrade further. Effect estimates consistently showed moderate to large differences, with systematic myopic bias against cycloplegic standards. However, substantial heterogeneity and wide confidence intervals, particularly for photoscreeners, limit reliability. These results highlight the need for high-quality randomized studies to strengthen the evidence and better guide clinical practice.

4. Discussion

This meta-analysis provides strong evidence that non-cycloplegic instrument-based refractive assessment systematically introduces a myopic bias, consistently documented across comparison groups and confirmed internationally. In addition, this review expands upon previous syntheses by incorporating modern device generations, a broader age range including young adults, and practical implications for evidence-based screening protocols. Non-cycloplegic autorefractors universally underestimate hyperopia and overestimate myopia, particularly in children, aligning with Padhy et al.[81], who reported small mean differences but wide limits of agreement, making

these devices unreliable for individual diagnosis. Foundational studies such as Rajavi et al.[28], Kirschen et al.[56], and the meta-analysis by Wilson et al.[82] emphasize that this discrepancy is most pronounced in younger children and those with latent hyperopia. Device type (handheld or tabletop, open- or closed-field) modulates but does not eliminate the bias. Open-field devices like Grand Seiko show slightly better agreement, yet hyperopia detection remains inadequate, as reinforced by Büchner et al.[39] and Paff et al.[64]

Our meta-analysis extends prior work by Wilson et al.[82] by including a broader age range (up to 25 years), more studies, and diverse devices, including autorefractors, photoscreeners, retinoscopy, and subjective refraction. We also examined testability, age/device subgroups, and certainty of evidence using GRADE, offering a comprehensive overview of instrument-based refraction and implications for clinical practice.

For non-cycloplegic photoscreeners, the pattern is equally robust: Dahlmann-Noor et al.[42], the Vision In Preschoolers study (Kulp et al.[25]), and Yan et al.[26] consistently reported high specificity but poor sensitivity for hyperopia, risking missed amblyogenic errors. Racano et al.[23] and Yakar[75] confirmed that adjusting cutoffs improves efficiency but cannot resolve the systematic underestimation. Device variability exists (SureSight is more sensitive for hyperopia, Plusoptix for myopia) but the underlying bias persists, restricting photoscreeners to preliminary screening rather than diagnostic confirmation. The SureSight device, although included in several studies, is no longer commercially available. When active, it featured separate adult and child screening modes, with the latter automatically applying a +1.00 D offset to compensate for accommodative tone.

In adults, the bias persists but is clinically smaller. Vilaseca et al.[83] found modest differences among double-pass, autorefraction, retinoscopy, and subjective refraction in healthy adults (retinoscopy more hyperopic by –0.51±0.50D; autorefraction more myopic by 0.24±0.49D), consistent with our subgroup findings. Hashemi et al.[84] reported poor agreement between non-cycloplegic autorefraction and subjective refraction in young adults with cataract, particularly for spherical components, though cylinder agreement was better.

Non-cycloplegic versus cycloplegic retinoscopy usually shows small mean differences (<0.5D), as in Przekoracka-Krawczyk[85] and Abrahamsson [36], but discrepancies occur in strabismus or poor cooperation. Thus, non-cycloplegic retinoscopy may be reliable in experienced hands and cooperative adults but less so in pediatric hyperopia. Non-cycloplegic subjective refraction shows minimal differences from cycloplegic methods,[79,84] but this applies mainly to older children or adults; in latent hyperopia or symptomatic patients, cycloplegia remains essential.[86]

By contrast, cycloplegic autorefractors demonstrate high agreement with cycloplegic retinoscopy, particularly tabletop models, with mean differences around –0.2D and narrow limits of agreement.[49,51,58] Handheld cycloplegic devices may introduce slightly greater bias, especially in children at risk of amblyopia.[58] Cycloplegic photoscreeners compared with cycloplegic retinoscopy show small, nonsignificant differences, though heterogeneity persists,[58,75] suggesting potential interchangeability with local validation.

Overall, non-cycloplegic autorefractors and photoscreeners, despite advantages of speed, portability, and high testability (as noted by Arnold et al.[87], Seymen et al. [88]), consistently introduce systematic bias that cannot be fully corrected by adjusting cutoffs or statistical models. Cycloplegia remains indispensable for accurate detection of hyperopia and prevention of missed amblyogenic errors, as reinforced by recent systematic reviews. Variability across studies reflects age, device, examiner experience, and prevalence, but the underlying myopic bias is universal.

Limitations of this meta-analysis include high heterogeneity due to age, refractive profiles, device technologies, and cycloplegic protocols. Most primary studies used observational designs, with risks of selection and reporting bias. Lack of standardized definitions, masking, and subgroup

data (e.g., developmental delay, high astigmatism) further limit interpretation. Additionally, subgroup analyses by race or country could not be performed because most studies did not provide stratified data by ethnicity or geographic region. Some devices analyzed are outdated, reducing generalizability. Publication bias cannot be excluded, as null results may be underreported. Although subgroup and sensitivity analyses were conducted to explore potential sources of heterogeneity, the available data did not allow for formal meta-regression or Hartung–Knapp adjustment. These advanced models are acknowledged as promising approaches for future work when sufficient information becomes available.

Future research should prioritize large, prospective multicenter studies with standardized protocols, blinding, and detailed subgroup analyses. Special attention is needed for underrepresented populations (infants, strabismus, amblyopia, diverse ethnicities). Longitudinal studies should clarify the real-world impact of misclassification on amblyopia outcomes. Innovative strategies such as biometry-integrated models or machine learning corrections warrant exploration when cycloplegia is impractical. Comparative studies on cost, feasibility, and patient acceptance would further guide public health policy.

In conclusion, non-cycloplegic methods are efficient for detecting myopia and astigmatism in large-scale screening but cannot replace cycloplegia for diagnosis or prescribing, particularly in children at risk for amblyopia. Clinical protocols must ensure that all positive or borderline screening cases undergo cycloplegic confirmation, with programmatic pathways to guarantee follow-up. Device selection should consider local needs and performance, while education is needed to ensure evidence-based use of refractive technologies in pediatric care. A proposed screening-to-referral pathway by age group and device type is presented in Additional file 10, illustrating practical thresholds for cycloplegic confirmation across screening contexts.

5. Conclusions

This systematic review and meta-analysis confirm that non-cycloplegic autorefractors and photoscreeners systematically underestimate hyperopia and overestimate myopia, particularly in younger children and hyperopic eyes. Although highly practical and with excellent testability for large-scale screening, their limited sensitivity for hyperopia detection prevents use as standalone diagnostic tools. Cycloplegic assessment remains essential for accurate refractive evaluation, amblyopia prevention, and spectacle prescription. Open-field autorefractors show closer agreement with cycloplegic measures, but no device eliminates accommodative bias. The pooled mean differences were –0.65 D (95% CI: –0.84 to –0.45; 95% PI: –1.50 to +0.20 D) for autorefractors and –0.78 D (95% CI: –1.12 to –0.44; 95% PI: –1.70 to +0.10 D) for photoscreeners, confirming substantial between-study variability. Non-cycloplegic methods may serve for initial screening of myopia and astigmatism, but positive or borderline cases require cycloplegic confirmation, supported by clear clinical pathways.

References

1. Friedman DS, Repka MX, Katz J, Giordano L, Ibironke J, Hawse P, et al. Prevalence of amblyopia and strabismus in white and African American children aged 6 through 71 months: The Baltimore Pediatric Eye Disease Study. *Ophthalmology*. 2009;116(11):2128–2134.e2. doi: 10.1016/j.ophtha.2009.04.034.
2. Kızıltunç PB, İdil A, Atilla H, Topalkara A, Alay C. Results of screening in schools for visually impaired children. *Turk Oftalmol Derg*. 2017;47(4):216–220. doi: 10.4274/tjo.82246

3. Donahue SP, Arthur B, Neely DE, Arnold RW, Silbert D, Ruben JB. Guidelines for automated preschool vision screening: A 10-year, evidence-based update. *J AAPOS*. 2013;17(1):4–8. doi: 10.1016/j.jaapos.2012.09.012.
4. Repka MX, Kraker RT, Holmes JM, Summers AI, Glaser SR, Barnhardt CN, et al. Atropine vs patching for treatment of moderate amblyopia: Follow-up at 15 years of age of a randomized clinical trial. *JAMA Ophthalmol.* 2014;132(7):799–805. doi: 10.1001/jamaophthalmol.2014.392.
5. Sanfilippo PG, Chu BS, Bigault O, Kearns LS, Boon MY, Young TL, et al. What is the appropriate age cut-off for cycloplegia in refraction? *Acta Ophthalmol*. 2014;92(6):e458–e462. doi: 10.1111/aos.12388.
6. Chen J, Xie A, Hou L, Su Y, Lu F, Thorn F. Cycloplegic and noncycloplegic refractions of Chinese neonatal infants. *Invest Ophthalmol Vis Sci*. 2010;52(5):2456–2461. doi: 10.1167/iovs.10-5441.
7. Fotouhi A, Morgan I, Iribarren R, Khabazkhoob M, Hashemi H. Validity of noncycloplegic refraction in the assessment of refractive errors: The Tehran Eye Study. *Acta Ophthalmol*. 2010;90(4):380–386. doi: 10.1111/j.1755-3768.2010.01983.x.
8. Kauser F, Gupta Y, Amitava A, Saxena J, Raza S, Masood A, et al. Do all children need a cycloplegic refraction? A comparison of Mohindra's versus cycloplegic refraction. *Indian J Ophthalmol.* 2020;68(11):2458–2461. doi: 10.4103/ijo.IJO_229_20.
9. Schaafsma JD, Arnold RW. Pre-cycloplegic exam benefit of photoscreening and accommodation-relaxing skiascopy. *Clin Ophthalmol.* 2024;18:833–846. doi: 10.2147/OPTH.S454430.
10. Ying GS, Maguire M, Quinn G, Kulp M, Cyert L. ROC analysis of the accuracy of noncycloplegic retinoscopy, Retinomax autorefractor, and SureSight Vision Screener for preschool vision screening. *Invest Ophthalmol Vis Sci*. 2011;52(13):9658–9664. doi: 10.1167/iovs.11-8559.
11. Won J, Shin H, Kim SY, Lee Y. A comparison of the Plusoptix S09 with an autorefractometer of noncycloplegics and cycloplegics in children. *Medicine (Baltimore)*. 2016;95(35):e4596. doi: 10.1097/MD.0000000000004596.
12. Harvey EM, Dobson V, Miller JM, Clifford-Donaldson CE, Green TK, Messer DH, et al. Accuracy of the Welch Allyn SureSight for measurement of magnitude of astigmatism in 3- to 7-year-old children. *J AAPOS*. 2009;13(5):466–471. doi: 10.1016/j.jaapos.2009.08.013.
13. Forcina BD, Peterseim MM, Wilson ME, Cheeseman EW, Feldman S, Marzolf AL, et al. Performance of the Spot Vision Screener in children younger than 3 years of age. *Am J Ophthalmol.* 2017;178:79–83. doi: 10.1016/j.ajo.2017.03.014.
14. Yakar K. Clinical performance of the Spot Vision Photo Screener before and after induction of cycloplegia in children. *J Ophthalmol*. 2019;2019:1–7. doi: 10.1155/2019/5329121.
15. Barugel R, Touhami S, Samama S, Landre C, Busquet G, Vera L, et al. Evaluation of the Spot Vision Screener for children with limited access to ocular health care. *J AAPOS*. 2019;23(3):153.e1–153.e5. doi: 10.1016/j.jaapos.2018.09.012.
16. Yalinbas D, Kara C, Sarı S, Dursun D, Bozali E. Comparison of photoscreeners and hand-held autorefractometer with cycloplegic autorefraction as a vision screening tool for children with newly diagnosed attention deficit hyperactivity disorder. J AAPOS. 2021;25(4). doi:10.21203/rs.3.rs-178270/v2
17. Payerols A, Eliaou C, Trezeguet V, Villain M, Daien V. Accuracy of PlusOptix A09 distance refraction in pediatric myopia and hyperopia. *BMC Ophthalmol*. 2016;16:24. doi: 10.1186/s12886-016-0247-8.

18. McCullough SJ, Doyle L, Saunders KJ. Intra- and inter-examiner repeatability of cycloplegic retinoscopy among young children. *Ophthalmic Physiol Opt.* 2017;37(1):16–23. doi: 10.1111/opo.12341.
19. Choong YF, Chen AH, Goh PP. A comparison of autorefraction and subjective refraction with and without cycloplegia in primary school children. *Am J Ophthalmol.* 2006;142(1):68–74. doi: 10.1016/j.ajo.2006.01.084.
20. Prabakaran S, Dirani M, Chia A, Gazzard G, Fan Q, Leo SW, et al. Cycloplegic refraction in preschool children: Comparisons between the hand-held autorefractor, table-mounted autorefractor and retinoscopy. *Ophthalmic Physiol Opt*. 2009;29(4):422–426. doi: 10.1111/j.1475-1313.2008.00616.x.
21. Morgan IG, Iribarren R, Fotouhi A, Grzybowski A. Cycloplegic refraction is the gold standard for epidemiological studies. *Acta Ophthalmol*. 2015;93(6):581–585. doi: 10.1111/aos.12642.
22. Hu YY, Wu JF, Lu TL, Wu H, Sun W, Wang XR, et al. Effect of cycloplegia on the refractive status of children: The Shandong Children Eye Study. *PLoS One*. 2015;10(2):e0117482. doi: 10.1371/journal.pone.0117482
23. Racano E, Alessi S, Pertile R. Comparison of 2Win and plusoptiX A12R refractometers with Retinomax handheld autorefractor keratometer. *J AAPOS*. 2019;23(5):276.e1–276.e5. doi: 10.1016/j.jaapos.2019.05.017.
24. Levitt AH, Martin SJ, Arnold RW. Performance of glow fixation GoCheck Kids and 2WIN photoscreeners and Retinomax to uncover hyperopia. *Clin Ophthalmol*. 2020;14:2237–2244. doi: 10.2147/OPTH.S256991.
25. Kulp MT, Ying GS, Huang J, Maguire M, Quinn G, Ciner EB, et al. Accuracy of noncycloplegic retinoscopy, Retinomax autorefractor, and SureSight Vision Screener for detecting significant refractive errors. *Invest Ophthalmol Vis Sci*. 2014;55(3):1378–1385. doi: 10.1167/iovs.13-13433.
26. Yan Q, Li R, Qian Y, Lin X, Zhu H, Wang Y, et al. Instrument referral criteria for PlusoptiX and SureSight based on 2021 AAPOS guidelines: A population-based study. *Front Public Health.* 2022;10:959757. doi: 10.3389/fpubh.2022.959757.
27. Twelker J, Mutti D. Retinoscopy in infants using a near noncycloplegic technique, cycloplegia with tropicamide 1%, and cycloplegia with cyclopentolate 1%. *Optom Vis Sci*. 2001;78(4):215–222. doi: 10.1097/00006324-200104000-00010.
28. Rajavi Z, Sabbaghi H, Baghini A, Yaseri M, Sheibani K, Norouzi G, et al. Accuracy and repeatability of refractive error measurements by photorefractometry. *J Ophthalmic Vis Res*. 2015;10(3):221–228. doi: 10.4103/2008-322X.170360
29. Zhu D, Wang Y, Yang X, Yang D, Guo K, Guo Y, et al. Pre- and postcycloplegic refractions in children and adolescents. *PLoS One*. 2016;11(12):e0167628. doi: 10.1371/journal.pone.0167628.
30. Guo K, Yang DY, Wang Y, Yang XR, Jing XX, Guo YY, et al. Prevalence of myopia in schoolchildren in Ejina: The Gobi Desert Children Eye Study. *Invest Ophthalmol Vis Sci*. 2015;56(3):1769–1774. doi: 10.1167/iovs.14-15737.
31. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi: 10.1136/bmj.n71.
32. Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, et al. AMSTAR 2: A critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ*. 2017;358:j4008.

33. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (MINORS): Development and validation of a new instrument. *ANZ J Surg*. 2003;73(9):712–716. doi: 10.1046/j.1445-2197.2003.02748.x.
34. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al. Cochrane Handbook for Systematic Reviews of Interventions. Cochrane. 2019.
35. Guyatt GH, Thorlund K, Oxman AD, Walter SD, Patrick D, Furukawa TA, et al. GRADE guidelines: 13. Preparing Summary of Findings tables and evidence profiles – Continuous outcomes. *J Clin Epidemiol*. 2013;66(2):173–183. doi: 10.1016/j.jclinepi.2012.08.001
36. Abrahamsson M, Ohlsson J, Björndahl M, Abrahamsson H. Clinical evaluation of an eccentric infrared photorefractor: The PowerRefractor. *Acta Ophthalmol Scand*. 2003;81(6):605–611. doi: 10.1046/j.1600-0420.2003.0149.x.
37. Arslantürk Eren M, Nalcı Baytaroğlu H, Atilla H. Comparison of Spot Vision Screener and tabletop autorefractometer with retinoscopy in the pediatric population. *Turk J Ophthalmol*. 2024;54(2):56–62. doi: 10.4274/tjo.galenos.2024.93607.
38. Ayse YK, Onder U, Suheyla K. Accuracy of Plusoptix S04 in children and teens. *Can J Ophthalmol.* 2011;46(2):153–157. doi: 10.3129/i10-110.
39. Büchner TF, Schnorbus U, Grenzebach UH, Stupp T, Busse H. Untersuchung von kindergartenkindern auf refraktionsanomalien: Erste erfahrungen mit einem handgehaltenen autorefraktometer. *Ophthalmologe*. 2003;100:971–978. doi: 10.1007/s00347-003-0860-9.
40. Ciner EB. Comparison of the Retinomax and Palm-AR auto-refractors: A pilot study. *Optom Vis Sci*. 2011;88(7):830–836. doi: 10.1097/OPX.0b013e3182192658
41. Ciuffreda KJ, Rosenfield M. Evaluation of the SVOne: A handheld, smartphone-based autorefractor. *Optom Vis Sci*. 2015;92(12):1133–1139. doi: 10.1097/OPX.0000000000000726.
42. Dahlmann-Noor AH, Comyn O, Kostakis V, Misra A, Gupta N, Heath J, et al. Plusoptix vision screener: The accuracy and repeatability of refractive measurements using a new autorefractor. *Br J Ophthalmol.* 2009;93(3):346–349. doi: 10.1136/bjo.2008.138123.
43. Demirci G, Arslan B, Özsütçü M, EliaçIk M, Gulkilik G. Comparison of photorefraction, autorefractometry and retinoscopy in children. *Int Ophthalmol*. 2014;34(4):739–746. doi: 10.1007/s10792-013-9864-x.
44. Iuorno JD, Grant WD, Noël LP. Clinical comparison of the Welch Allyn SureSight handheld autorefractor versus cycloplegic autorefraction and retinoscopic refraction. *J AAPOS*. 2004;8(2):123–127. doi: 10.1016/j.jaapos.2003.10.006
45. Gopalakrishnan A, Hussaindeen JR, Sivaraman V, Swaminathan M, Wong YL, Armitage JA, et al. The Sankara Nethralaya Tamil Nadu Essilor Myopia (STEM) study—Defining a threshold for non-cycloplegic myopia prevalence in children. *J Clin Med*. 2021;10(6):1300. doi: 10.3390/jcm10061215.
46. Gole GA, Schluter PJ, Hall J, Colville D. Comparison of the Retinomax autorefractor with hand-held retinoscopy in 1-year-old infants. *Clin Exp Ophthalmol*. 2003;31(4):341–347. doi: 10.1046/j.1442-9071.2003.00668.x.
47. Gu F, Gao HM, Zheng X, Gu L, Huang J, Meng J, et al. Effect of cycloplegia on refractive error measure in Chinese school students. *Ophthalmic Epidemiol*. 2022;29(6):629–639. doi: 10.1080/09286586.2021.1999986
48. Guha S, Shah S, Shah K, Hurakadli P, Majee D, Gandhi S. A comparison of cycloplegic autorefraction and retinoscopy in Indian children. *Clin Exp Optom*. 2017;100(1):73–78. doi: 10.1111/cxo.12375.

49. Harvey EM, Miller JM, Wagner K, Dobson V. Reproducibility and accuracy of measurements with a hand held autorefractor in children. *Br J Ophthalmol*. 1997;81(11):941–948. doi: 10.1136/bjo.81.11.941.
50. Hernandez-Moreno L, Vallelado-Alvarez A, Martin R. Repeatability of ARK-30 in a pediatric population. *Indian J Ophthalmol*. 2018;66(9):1262–1267. doi: 10.4103/ijo.IJO_266_18.
51. Honglertnapakul W, Jindarak P, Praneeprachachon P, Pukrushpan P. The difference of refraction between the cycloplegic retinoscopy and non-cycloplegic subjective refraction in children aged 6 to 15 years. J Med Assoc Thai. 2020;103:566–571.
52. Huang D, Chen X, Zhang X, Wang Y, Zhu H, Ding H, et al. Pediatric vision screening using the Plusoptix A12C photoscreener in Chinese preschool children aged 3 to 4 years. *Sci Rep*. 2017;7(1):2041. doi: 10.1038/s41598-017-02246-6.
53. Kaiser KP, Lwowski C, Nazir F, Kohnen T, Wenner Y. A comparison of cycloplegic effect of cyclopentolate 0.5% versus 1.0% eye drops with five different refraction measurement modalities in young adults. *Graefes Arch Clin Exp Ophthalmol*. 2025;263(4):1135–1146. doi: 10.1007/s00417-024-06658-9.
54. Khan HA, Tran H, Naduvilath TJ, Tahhan N, Ha T, Sankaridurg P. Comparison between cycloplegic and noncycloplegic refraction in young adult myopes. *Optom Vis Sci*. 2024;101(7):470–476. doi: 10.1097/OPX.0000000000002169
55. Kinori M, Gomi CF, Ondeck CL, Schanzlin DJ, Robbins SL, et al. Usefulness of refractive measurement of wavefront autorefraction in patients with difficult retinoscopy. *J AAPOS*. 2016;20(6):493–495.e1. doi: 10.1016/j.jaapos.2016.08.010.
56. Kirschen D, Isenberg SJ. The effectiveness of an autorefractor with eye-tracking capability in pediatric patients. *J AAPOS*. 2014;18(3):217–221. doi: 10.1016/j.jaapos.2013.12.019.
57. Kuo YC, Wang JH, Chiu CJ. Comparison of open-field autorefraction, closed-field autorefraction, and retinoscopy for refractive measurements of children and adolescents in Taiwan. *J Formos Med Assoc*. 2020;119(8):1251–1258. doi: 10.1016/j.jfma.2020.04.009.
58. Kurent A. Comparison of the cycloplegic refractive measurements with handheld, table-mounted refractometers and retinoscopy in children. Ophthalmol J. 2022;7:200–207.
59. Loayza A, Lewis A, Trivedi RH, Gouvea L, Bowsher JD, Wolf B, et al. Evaluation of the QuickSee portable autorefractor system in a pediatric population. *J AAPOS*. 2025;29(3):104228. doi: 10.1016/j.jaapos.2025.104228.
60. Lowry EA, Lui R, Enanoria W, Keenan J, De Alba Campomanes AG. Repeat Retinomax screening changes positive predictive value. *J AAPOS*. 2014;18(1):45–49. doi: 10.1016/j.jaapos.2013.11.004
61. Mukash SN, Kayembe DL, Mwanza JC. Agreement between retinoscopy, autorefractometry and subjective refraction for determining refractive errors in Congolese children. *Clin Optom*. 2021;13:129–136. doi: 10.2147/OPTO.S303286
62. Ocak OB, Inal A, Tülü Aygün B, Kırmacı Kabakci A, Kemer Atik B, Yurttaser Ocak S, et al. Refraction under general anesthesia in children, using cycloplegic refraction only as a reference. *Strabismus*. 2020;28(2):73–78. doi: 10.1080/09273972.2020.1714669.
63. Oral Y, Gunaydin N, Ozgur O, Arsan AK, Oskan S. A comparison of different autorefractors with retinoscopy in children. *J Pediatr Ophthalmol Strabismus*. 2012;49(6):370–377. doi: 10.3928/01913913-20120821-04.
64. Paff T, Oudesluys-Murphy AM, Wolterbeek R, Swart-Van Den Berg M, De Nie JM, Tijssen E, et al. Screening for refractive errors in children: The Plusoptix S08 and the Retinomax K-plus2 performed by a lay screener compared to cycloplegic retinoscopy. *J AAPOS*. 2010;14(6):478–483. doi: 10.1016/j.jaapos.2010.09.015.

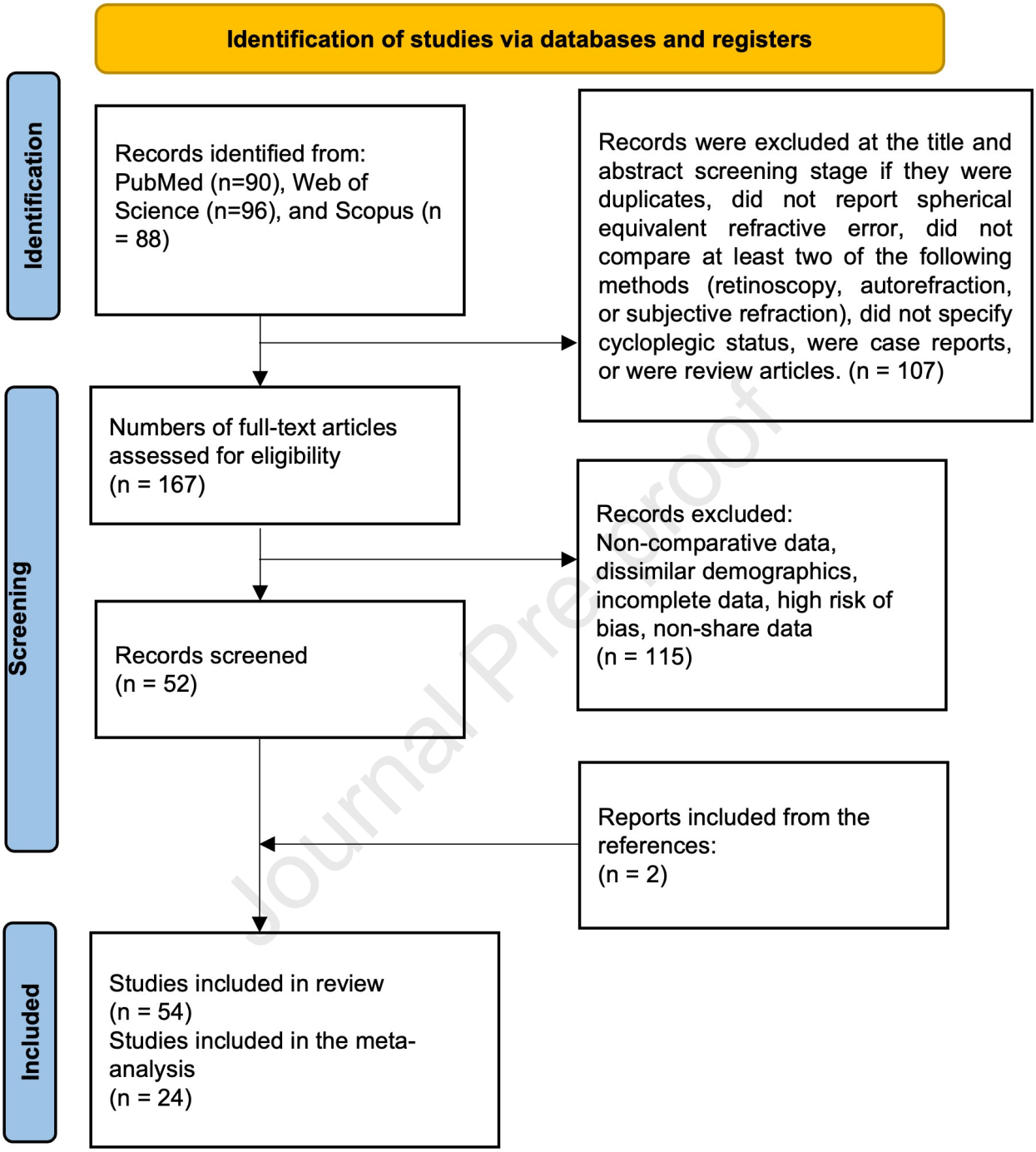
65. Peng MY, Matta N, Silbert D, Tian J, Singman E. Accuracy of the Retinomax K-plus3 in measuring refractive error in a pediatric population. *J AAPOS*. 2014;18(4):327–331. doi: 10.1016/j.jaapos.2014.02.017.
66. Pokupec R, Mrazovac D, Popović-Suić S, Mrazovac V, Kordić R, Petricek I. Comparison between refractometer and retinoscopy in determining refractive errors in children—false doubt. *Coll Antropol*. 2013;37:205–208.
67. Rao DP, Negiloni K, Gurunathan S, Velkumar S, Sivaraman A, Baig AU, et al. Validation of a simple-to-use, affordable, portable wavefront aberrometry-based auto refractometer in a paediatric population. *Clin Ophthalmol*. 2022;16:4281–4291. doi: 10.1186/s12886-022-02684-5.
68. Rauscher FG, Lange H, Yahiaoui-Doktor M, Tegetmeyer H, Sterker I, Hinz A, et al. Agreement and repeatability of noncycloplegic and cycloplegic wavefront-based autorefraction in children. *Optom Vis Sci*. 2019;96(11):879–889. doi: 10.1097/OPX.0000000000001444
69. Rotsos T, Kokkolaki A, Manios N. A comparison of manifest refractions, cycloplegic refractions and retinoscopy on the RMA-3000 autorefractometer in children aged 3 to 15 years. *Clin Ophthalmol*. 2009;3:429–431. doi: 10.2147/opth.s5145
70. Saini V, Raina UK, Gupta A, Goyal JL, Anjum R, Saini P, et al. Comparison of Plusoptix S12R photoscreener with cycloplegic retinoscopy and autorefraction in pediatric age group. *Indian J Ophthalmol*. 2019;67(10):1555–1559. doi: 10.4103/ijo.IJO_1465_18.
71. Schimitzek T, Wesemann W. Clinical evaluation of refraction using a handheld wavefront autorefractor in young and adult patients. *J Cataract Refract Surg*. 2002;28(9):1655–1670. oi: 10.1016/s0886-3350(02)01426-8.
72. Yassa ET, Ünlü C. Comparison of autorefraction and photorefraction with and without cycloplegia using 1% tropicamide in preschool children. *J Ophthalmol*. 2019;2019:1487013. doi: 10.1155/2019/1487013.
73. Tuncer I, Zengin MO, Karahan E. Comparison of the Retinomax hand-held autorefractor versus table-top autorefractor and retinoscopy. *Int J Ophthalmol*. 2014;7(3):491–495. doi: 10.3980/j.issn.2222-3959.2014.03.19
74. Vasudevan B, Ciuffreda KJ, Meehan K, Grk D, Cox M. Comparison of objective refraction in darkness to cycloplegic refraction: A pilot study. *Clin Exp Optom*. 2016;99(2):168–172. doi: 10.1111/cxo.12367.
75. Yakar K. Anterior chamber depth and axial length affect clinical performance of Spot Vision Screener. *Arq Bras Oftalmol*. 2020;83(1):43–47. doi: 10.5935/0004-2749.20200009.
76. Yalçın E, Sultan P, Yılmaz S, Pallikaris IG. A comparison of refraction defects in childhood measured using Plusoptix S09, 2WIN photorefractometer, benchtop autorefractometer, and cycloplegic retinoscopy. *Semin Ophthalmol*. 2017;32(4):422–427. doi: 10.3109/08820538.2015.1118135.
77. Yalçınkaya G, Ocak OB, Çakır İ, İnal A, Gökyiğit B. Comparison of two different photorefractors with skiascopy measurements in healthy children. *J Acad Res Med.* 2021;11:206–210.
78. Wei X, Li L, Jiang L, Lu H, Huang H, Zhong D, et al. Comparison of the new self-contained darkroom refractive screener versus table-top autorefractor and cycloplegia retinoscopy in detecting refractive error. *BMC Ophthalmol*. 2023;23:487. doi:10.1186/s12886-023-03231-6
79. Jorge J, Queiros A, González-Méijome J, Fernandes P, Almeida JB, Parafita MA. The influence of cycloplegia in objective refraction. *Ophthalmic Physiol Opt*. 2005;25(4):340–345. doi: 10.1111/j.1475-1313.2005.00277.x.

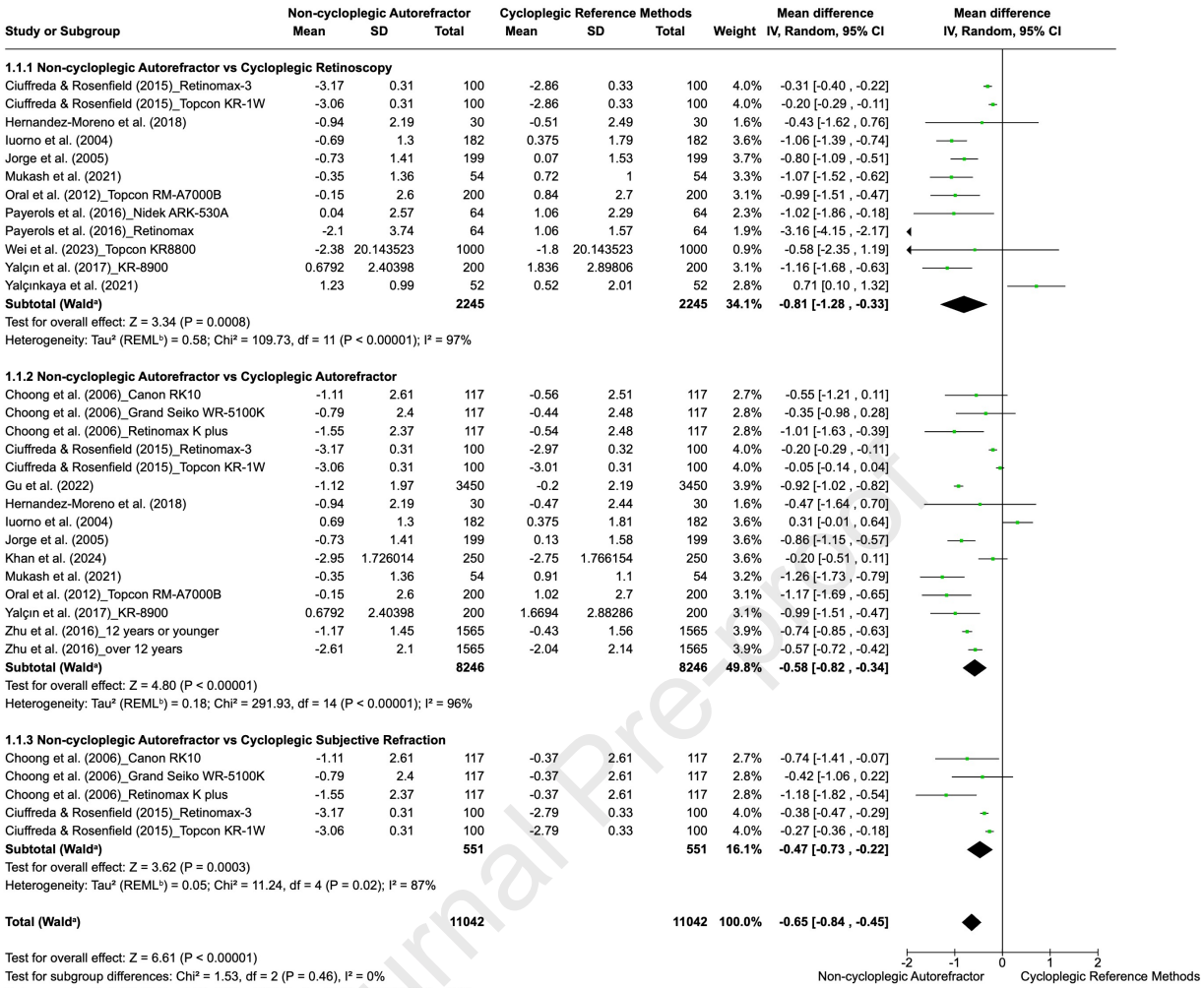
80. Wang J, Wang X, Gao HM, Zhang H, Yang Y, Gu F, et al. Prediction for cycloplegic refractive error in Chinese school students: Model development and validation. *Transl Vis Sci Technol*. 2022;11(1):15. doi: 10.1167/tvst.11.1.15
81. Padhy D, Bharadwaj S, Nayak S, Rath S, Das T. Does the accuracy and repeatability of refractive error estimates depend on the measurement principle of autorefractors? *Transl Vis Sci Technol*. 2021;10(1):2. doi: 10.1167/tvst.10.1.2
82. Wilson S, Ctori I, Shah R, Suttle C, Conway M. Systematic review and meta-analysis on the agreement of non-cycloplegic and cycloplegic refraction in children. *Ophthalmic Physiol Opt*. 2022;42(6):1276–1288. doi: 10.1111/opo.13022.
83. Vilaseca M, Arjona M, Pujol J, Peris E, Martínez V. Non-cycloplegic spherical equivalent refraction in adults: Comparison of the double-pass system, retinoscopy, subjective refraction and a table-mounted autorefractor. *Int J Ophthalmol*. 2013;6(5):618–625. doi: 10.3980/j.issn.2222-3959.2013.05.12
84. Hashemi H, Jamali A, Mortazavi A, Hashemi A, Khabazkhoob M. Auto-refraction versus subjective refraction in different phakic and pseudophakic conditions: The Tehran Geriatric Eye Study (TGES). *Int J Ophthalmol*. 2023;16(8):1309–1316. doi: 10.18240/ijo.2023.08.18
85. Przekoracka-Krawczyk A, Brenk-Krakowska A, Wojtczak-Kwaśniewska M. Accuracy of refractive error measurements in children with strabismus comparing cycloplegic autorefractometry to dry monocular Mohindra retinoscopy. *PLoS One*. 2025;20(5):e0323750. doi: 10.1371/journal.pone.0323750.
86. Mimouni M, Zoller L, Horowitz J, Wygnanski-Jaffe T, Morad Y, Mezer E. Cycloplegic autorefraction in young adults: Is it mandatory? *Graefes Arch Clin Exp Ophthalmol.* 2016;254(2):395–398. doi: 10.1007/s00417-015-3246-1.
87. Arnold SL, Arnold AW, Sprano JH, Arnold RW. Performance of the 2WIN photoscreener with "CR" strabismus estimation in high-risk patients. Am J Ophthalmol. 2019;207:195–203. doi: 10.2147/OPTH.S251451
88. Seymen Z. Handyref-K: Comparison of the latest handheld autorefractokeratometer in patients younger than three years of age with Retinomax and PlusOptix. *Beyoglu Eye J.* 2019;4(1):32–37. doi: 10.14744/bej.2018.20591.

Figure legends

Figure 1. PRISMA flow diagram of study selection.

Figure 2. Forest plot of spherical equivalent refraction between non-cycloplegic autorefractor and cycloplegic reference methods (retinoscopy, autorefraction, and subjective refraction).
Figure 3. Comparison of Non-cycloplegic Photoscreeners Versus Cycloplegic Reference Methods for Spherical Equivalent Refraction.
Figure 4. Forest plot of Non-cycloplegic Retinoscopy versus Cycloplegic Retinoscopy for Spherical Equivalent Refraction.
Figure 5. Forest plot of Non-cycloplegic Subjective Refraction versus Cycloplegic Reference Methods for Spherical Equivalent Refraction.
Figure 6. Forest plot of Cycloplegic Autorefractor versus Cycloplegic Reference Methods for Spherical Equivalent Refraction.
Figure 7. Forest plot of Cycloplegic Photoscreener versus Cycloplegic Retinoscopy for Spherical Equivalent Refraction



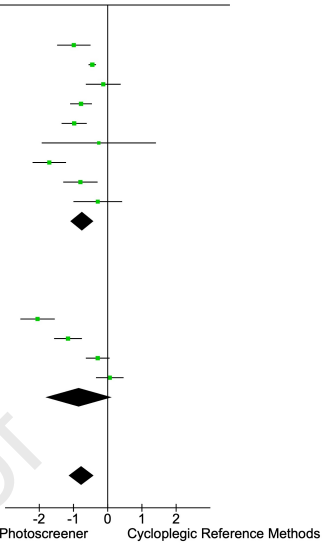


Footnotes

[a]CI calculated by Wald-type method.

[b]Tau² calculated by Restricted Maximum-Likelihood method.

Study or Subgroup	Non-cycloplegic Photoscreener Mean	SD	Total	Cycloplegic Reference Methods Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI
1.1.1 Non-cycloplegic Photoscreener vs Cycloplegic Retinoscopy								
Ayse et al. (2011)	1.15	1.65	128	2.14	2.29	128	7.9%	-0.99 [-1.48 , -0.50]
Huang et al. (2017)	0.72	0.64	357	1.17	0.84	357	9.3%	-0.45 [-0.56 , -0.34]
Oral et al. (2012)_Plusoptix S08	0.71	2.5	200	0.84	2.7	200	7.7%	-0.13 [-0.64 , 0.38]
Saini et al. (2019)_3-7years	0.72	1.52	200	1.5	1.73	200	8.7%	-0.78 [-1.10 , -0.46]
Saini et al. (2019)_8-15years	0.28	1.75	200	1.26	2	200	8.4%	-0.98 [-1.35 , -0.61]
Wei et al. (2023)_YD-SX-A	-2.06	17.887449	1000	-1.8	20.143523	1000	2.9%	-0.26 [-1.93 , 1.41]
Yalçın et al. (2017)_2WIN	0.13	2.01983	200	1.836	2.89806	200	7.9%	-1.71 [-2.20 , -1.22]
Yalçın et al. (2017)_Plusoptix S09	1.038	2.17508	200	1.836	2.89806	200	7.8%	-0.80 [-1.30 , -0.30]
Yalçınkaya et al. (2021)	0.23	1.68	52	0.52	2.01	52	6.7%	-0.29 [-1.00 , 0.42]
Subtotal (Wald[a])			**2537**			**2537**	**67.1%**	**-0.76 [-1.07 , -0.44]**
Test for overall effect: Z = 4.69 (P < 0.00001)								
Heterogeneity: Tau² (REML[b]) = 0.16; Chi² = 38.93, df = 8 (P < 0.00001); I² = 82%								
1.1.2 Non-cycloplegic Photoscreener vs Cycloplegic Photoscreener								
Ayse et al. (2011)	1.15	1.65	128	3.2	2.39	128	7.8%	-2.05 [-2.55 , -1.55]
Tan Yassa & Unlu (2019	0.61	1.03	70	1.77	1.4	70	8.3%	-1.16 [-1.57 , -0.75]
Yalçın et al. (2017)_2WIN	1.038	2.17508	200	1.3295	1.25482	200	8.5%	-0.29 [-0.64 , 0.06]
Yalçın et al. (2017)_Plusoptix S09	0.13	2.01983	200	0.0693	2.09824	200	8.3%	0.06 [-0.34 , 0.46]
Subtotal (Wald[a])			**598**			**598**	**32.9%**	**-0.85 [-1.77 , 0.07]**
Test for overall effect: Z = 1.82 (P = 0.07)								
Heterogeneity: Tau² (REML[b]) = 0.83; Chi² = 51.50, df = 3 (P < 0.00001); I² = 95%								
Total (Wald[a])			**3135**			**3135**	**100.0%**	**-0.78 [-1.12 , -0.44]**
Test for overall effect: Z = 4.46 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.04, df = 1 (P = 0.85), I² = 0%								
Heterogeneity: Tau² (REML[b]) = 0.32; Chi² = 91.77, df = 12 (P < 0.00001); I² = 91%								



Footnotes

[a]CI calculated by Wald-type method.

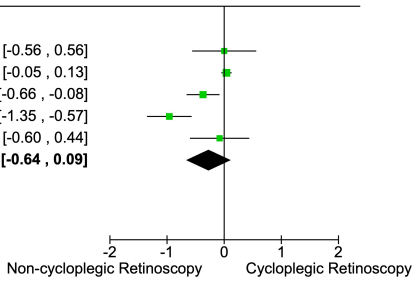
[b]Tau² calculated by Restricted Maximum-Likelihood method.

Study or Subgroup	Non-cycloplegic Retinoscopy Mean	SD	Total	Cycloplegic Retinoscopy Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI
4.1.1 Non-cycloplegic Retinoscopy vs Cycloplegic Retinoscopy								
Ayse et al. (2011)	2.14	2.29	128	2.14	2.29	128	16.1%	0.00 [-0.56 , 0.56]
Ciuffreda & Rosenfield (2015)	-2.82	0.32	100	-2.86	0.33	100	25.1%	0.04 [-0.05 , 0.13]
Jorge et al. (2005)	-0.3	1.41	199	0.07	1.53	199	22.1%	-0.37 [-0.66 , -0.08]
Mukash et al. (2021)	-0.24	1.07	54	0.72	1	54	19.8%	-0.96 [-1.35 , -0.57]
Oral et al. (2012)	0.76	2.6	200	0.84	2.7	200	16.9%	-0.08 [-0.60 , 0.44]
Subtotal (Wald[a])			**681**			**681**	**100.0%**	**-0.28 [-0.64 , 0.09]**

Test for overall effect: Z = 1.46 (P = 0.14)

Heterogeneity: Tau² (REML[b]) = 0.14; Chi² = 29.39, df = 4 (P < 0.00001); I² = 86%

Test for subgroup differences: Not applicable

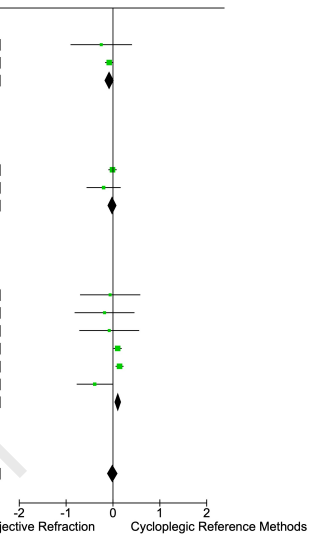


Footnotes

[a]CI calculated by Wald-type method.

[b]Tau² calculated by Restricted Maximum-Likelihood method.

Study or Subgroup	Non-cycloplegic Subjective Refraction Mean	SD	Total	Cycloplegic Reference Methods Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI
1.1.1 Non-cycloplegic Subjective Refraction vs Cycloplegic Subjective Refraction								
Choong et al. (2006)	-0.62	2.51	117	-0.37	2.61	117	2.2%	-0.25 [-0.91 , 0.41]
Ciuffreda & Rosenfield (2015)	-2.87	0.31	100	-2.79	0.33	100	19.9%	-0.08 [-0.17 , 0.01]
Subtotal (Wald[a])			**217**			**217**	**22.1%**	**-0.08 [-0.17 , 0.00]**
Test for overall effect: Z = 1.85 (P = 0.06)								
Heterogeneity: Tau² (REML[b]) = 0.00; Chi² = 0.25, df = 1 (P = 0.61); I² = 0%								
1.1.2 Non-cycloplegic Subjective Refraction vs Cycloplegic Retinoscopy								
Ciuffreda & Rosenfield (2015)	-2.87	0.31	100	-2.86	0.33	100	19.9%	-0.01 [-0.10 , 0.08]
Mukash et al. (2021)	0.52	0.93	54	0.72	1	54	5.8%	-0.20 [-0.56 , 0.16]
Subtotal (Wald[a])			**154**			**154**	**25.7%**	**-0.02 [-0.11 , 0.07]**
Test for overall effect: Z = 0.47 (P = 0.64)								
Heterogeneity: Tau² (REML[b]) = 0.00; Chi² = 0.99, df = 1 (P = 0.32); I² = 0%								
1.1.3 Non-cycloplegic Subjective Refraction vs Cycloplegic Autorefractor								
Choong et al. (2006)_Canon RK10	-0.62	2.51	117	-0.56	2.51	117	2.3%	-0.06 [-0.70 , 0.58]
Choong et al. (2006)_Grand Seiko WR-5100K	-0.62	2.51	117	-0.44	2.48	117	2.3%	-0.18 [-0.82 , 0.46]
Choong et al. (2006)_Retinomax K plus	-0.62	2.51	117	-0.54	2.48	117	2.3%	-0.08 [-0.72 , 0.56]
Ciuffreda & Rosenfield (2015)_Retinomax-3	-2.87	0.31	100	-2.97	0.32	100	20.0%	0.10 [0.01 , 0.19]
Ciuffreda & Rosenfield (2015)_Topcon KR-1W	-2.87	0.31	100	-3.01	0.31	100	20.1%	0.14 [0.05 , 0.23]
Mukash et al. (2021)	0.52	0.93	54	0.91	1.1	54	5.4%	-0.39 [-0.77 , -0.01]
Subtotal (Wald[a])			**605**			**605**	**52.2%**	**0.10 [0.04 , 0.16]**
Test for overall effect: Z = 3.35 (P = 0.0008)								
Heterogeneity: Tau² (REML[b]) = 0.00; Chi² = 8.36, df = 5 (P = 0.14); I² = 0%								
Total (Wald[a])			**976**			**976**	**100.0%**	**-0.02 [-0.12 , 0.09]**
Test for overall effect: Z = 0.29 (P = 0.77)								
Test for subgroup differences: Chi² = 13.27, df = 2 (P = 0.001), I² = 84.9%								
Heterogeneity: Tau² (REML[b]) = 0.01; Chi² = 22.86, df = 9 (P = 0.007); I² = 67%								

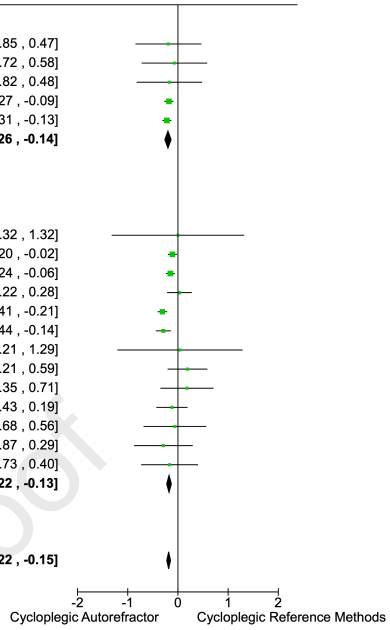


Footnotes

[a]CI calculated by Wald-type method.

[b]Tau² calculated by Restricted Maximum-Likelihood method.

Study or Subgroup	Cycloplegic Autorefractor Mean	SD	Total	Cycloplegic Reference Methods Mean	SD	Total	Weight	Mean difference IV, Fixed, 95% CI
1.1.1 Cycloplegic Autorefractor vs Cycloplegic Subjective Refraction								
Choong et al. (2006)_Canon RK10	-0.56	2.51	117	-0.37	2.61	117	0.3%	-0.19 [-0.85 , 0.47]
Choong et al. (2006)_Grand Seiko WR-5100K	-0.44	2.48	117	-0.37	2.61	117	0.3%	-0.07 [-0.72 , 0.58]
Choong et al. (2006)_Retinomax K plus	-0.54	2.48	117	-0.37	2.61	117	0.3%	-0.17 [-0.82 , 0.48]
Ciuffreda & Rosenfield (2015)_Retinomax-3	-2.97	0.32	100	-2.79	0.33	100	17.4%	-0.18 [-0.27 , -0.09]
Ciuffreda & Rosenfield (2015)_Topcon KR-1W	-3.01	0.31	100	-2.79	0.33	100	17.9%	-0.22 [-0.31 , -0.13]
Subtotal			**551**			**551**	**36.3%**	**-0.20 [-0.26 , -0.14]**
Test for overall effect: Z = 6.25 (P < 0.00001)								
Heterogeneity: Chi² = 0.54, df = 4 (P = 0.97); I² = 0%								
1.1.2 Cycloplegic Autorefractor vs Cycloplegic Retinoscopy								
Arslantürk Eren et al. (2024)	1.7	4.3	62	1.7	3.7	88	0.1%	0.00 [-1.32 , 1.32]
Ciuffreda & Rosenfield (2015)_Retinomax-3	-2.97	0.32	100	-2.86	0.33	100	17.4%	-0.11 [-0.20 , -0.02]
Ciuffreda & Rosenfield (2015)_Topcon KR-1W	-3.01	0.31	100	-2.86	0.33	100	17.9%	-0.15 [-0.24 , -0.06]
Demirci et al. (2014)	-0.12	1.41	235	-0.15	1.31	235	2.3%	0.03 [-0.22 , 0.28]
Gole et al. (2003)	1.26	0.82	654	1.57	0.93	654	15.6%	-0.31 [-0.41 , -0.21]
Guha et al. (2017)	-0.156	0.9	294	0.134	0.96	294	6.2%	-0.29 [-0.44 , -0.14]
Hernandez-Moreno et al. (2018)	-0.47	2.44	30	-0.51	2.49	30	0.1%	0.04 [-1.21 , 1.29]
Mukash et al. (2021)	0.91	1.1	54	0.72	1	54	0.9%	0.19 [-0.21 , 0.59]
Oral et al. (2012)_Topcon RM-A7000B	1.02	2.7	200	0.84	2.7	200	0.5%	0.18 [-0.35 , 0.71]
Peng et al. (2014)	1.21	2.78	622	1.33	2.83	622	1.5%	-0.12 [-0.43 , 0.19]
Prabakaran et al. (2009)_Canon FK-1	1.03	1.64	51	1.09	1.58	51	0.4%	-0.06 [-0.68 , 0.56]
Prabakaran et al. (2009)_Retinomax	0.8	1.43	51	1.09	1.58	51	0.4%	-0.29 [-0.87 , 0.29]
Yalçın et al. (2017)_KR-8900	1.6694	2.88286	200	1.836	2.89806	200	0.4%	-0.17 [-0.73 , 0.40]
Subtotal			**2653**			**2679**	**63.7%**	**-0.18 [-0.22 , -0.13]**
Test for overall effect: Z = 7.39 (P < 0.00001)								
Heterogeneity: Chi² = 20.52, df = 12 (P = 0.06); I² = 42%								
Total			**3204**			**3230**	**100.0%**	**-0.19 [-0.22 , -0.15]**
Test for overall effect: Z = 9.66 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.29, df = 1 (P = 0.59), I² = 0%								
Heterogeneity: Chi² = 21.35, df = 17 (P = 0.21); I² = 20%								

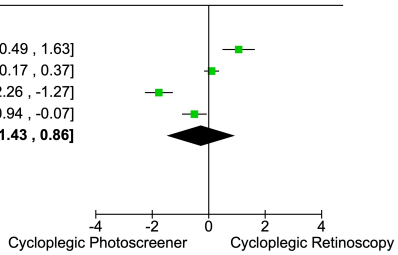


Study or Subgroup	Cycloplegic Photoscreener Mean	SD	Total	Cycloplegic Retinoscopy Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI
1.1.1 Cycloplegic Photoscreener vs Cycloplegic Retinoscopy								
Ayse et al. (2011)	3.2	2.39	128	2.14	2.29	128	24.4%	1.06 [0.49 , 1.63]
Demirci et al. (2014)	-0.05	1.61	235	-0.15	1.31	235	25.7%	0.10 [-0.17 , 0.37]
Yalçın et al. (2017)_2WIN	0.0693	2.09824	200	1.836	2.89806	200	24.8%	-1.77 [-2.26 , -1.27]
Yalçın et al. (2017)_Plusoptix S09	1.3295	1.25482	200	1.836	2.89806	200	25.1%	-0.51 [-0.94 , -0.07]
Subtotal (Wald[a])			**763**			**763**	**100.0%**	**-0.28 [-1.43 , 0.86]**

Test for overall effect: Z = 0.48 (P = 0.63)

Heterogeneity: Tau² (REML[b]) = 1.31; Chi² = 63.69, df = 3 (P < 0.00001); I² = 97%

Test for subgroup differences: Not applicable



Footnotes

[a]CI calculated by Wald-type method.

[b]Tau² calculated by Restricted Maximum-Likelihood method.

Funding: The authors did not receive support from any organization for the submitted work.

This systematic review and meta-analysis was registered in PROSPERO (registration number: [CRD420251134665])

Competing interests: The authors have no relevant financial or non-financial interests to disclose.