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Subjective versus objective methods for visual acuity measurement in children: A systematic review

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Abstract

Recent advancements have enhanced the evaluation of vision in children. The review aimed to assess the techniques and instruments used for measuring visual acuity (VA) in children, assisting pediatric ophthalmologists and optometrists in choosing an effective and fast screening approach. The authors used PRISMA 2020-guidelines to assess the vision measurement techniques in childhood, from PubMed, Medline, Web of Science, Google Scholar, Cochrane Library (Wiley interface), and ResearchGate, excluding articles that were non-childhood, non-English, case studies, and incomplete texts. The review found subjective VA tests in children with variant challenges due to communication limits and risk of overestimation. They require diverse and age-appropriate methods. Meanwhile, objective VA measurement aids in diagnosis but challenged by cost and accuracy issues. Visual evoked potential is a non-invasive tool for visual assessment, effective in children and amblyopia, yet face non-standardization and low accuracy conditions. In addition, optokinetic nystagmus assesses visual function through eye-tracking, integrating objective and subjective methods. In conclusion, assessing children's vision requires a multi-instrumental approach, balancing subjective tests with objective, technology-based methods for accurate, parent-informed evaluations, and effective treatment of vision impairments.

Introduction

The prevalence of low vision is a significant global concern, with myopia affecting 22.9% of the population in 2000 and projected to rise to 49.8% by 2050.[1] Approximately 18.9 million children under 15 years who experience visual impairment[2] and require vision correction to preserve their visual and cognitive development.[3,4] Among children with learning disabilities, around 5.6% also have vision impairments, excluding specific learning difficulties like dyslexia.[5] Amblyopia, affecting 3–5% of children with low vision globally, is characterized by a deficit in visual system stimulation, arising from insults during the critical maturation period (4 months to 3 years of age).[6,7] Recent modalities have identified abnormalities in photoreceptor structures and ocular axis.[7] Amblyopes complain of reduced contrast sensitivity and delayed development of stereo acuity,[8-18] leading to a decline in local contrast sensitivity and increased spatial pooling, resulting in vernier acuity loss.[19-22] Despite adapting to using their unaffected eye, they face a lower quality of life and fear losing vision in the non-amblyopic eye.[23,24] The review aims to assess the efficacy, challenges, and pitfalls of methods, for visual acuity (VA) measurement in children.

Materials and Methods

This systematic review was conducted as per the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews).[25]

Eligibility criteria

Studies were eligible if they (1) investigated the properties, functionality, and pitfalls of VA measurements methods and (2) been utilized and deployed on the children. Reasons for exclusion as shown on the flowchart, reason 1: Studies conducted among adults, reason 2: Non-full text articles (only abstract), and reason 3: Non-English articles.

Information source

Articles were retrieved from, PubMed, Medline, Web of Science, Google Scholar, Cochrane Library (Wiley interface), and research gate.

Search strategy

The authors reviewed the literature for available data on the methods of VA measurement in children as well as any advancement and Pitfalls of these tools. Then, the first author removed 13 duplicated articles and sorted studies independently as eligible, or ineligible, possibly eligible based on aforementioned criteria. The search strategy was created using controlled data terms (below mentioned) and was matched for each of the databases. Any discrepancies that arose during the process were reviewed by the author J. T and a further 12 articles were excluded. Books and clinical trials were also retrieved and examined for eligibility using the exact sort out way. Out of the initial 190 records, 81 studies met the inclusion criteria and search terms for analysis [Figure 1].

Results

VA measurement by subjective tests

Approaching young children often encounters significant challenges, particularly when using subjective methods such as the cover test, refraction, Hirschberg test, or Bruckner reflex. This complexity arises because neonates lack advanced communication skills and do not easily cooperate with the examiners.[26] When screening children aged between 18 and 24 months, vision screeners commonly use preliterate figures, such as Allen cards or LEA symbols. These symbols are advantageous as children, especially those with speech difficulties can more easily match them. The ease of matching these shapes helps in identifying amblyopes, particularly Allen's pictures with crowding bars around isolated figures.[27-29] However, when utilizing preliterate figures or symbols, caution is necessary as there is a tendency for vision screeners to overestimate the VA in amblyopic individuals. Amblyopic individuals often recognize single shapes more effortlessly than a sequence of figures, a phenomenon known as the crowding effect.[27,28] Additional

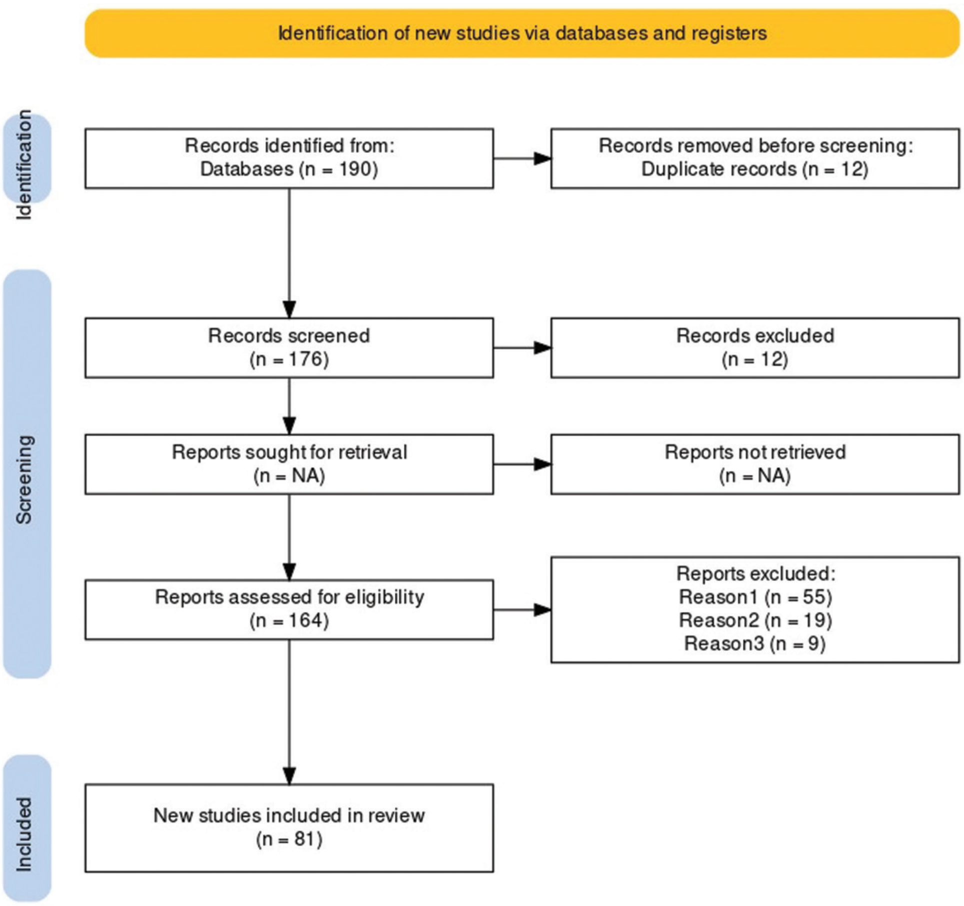

Figure 1: Methods of systemic review and studies selection. (Reason 1): Studies conducted among adults. (Reason 2): Non-full text articles (only abstract). (Reason 3): Non-English articles

subjective tests such as HOTV or LEA symbols are adept at detecting amblyopes and refractive errors in children aged 3–5 years, while the KM chart is deemed suitable for 6 years. It is crucial to employ these tests simultaneously and not relying exclusively on a single method could lead to inaccuracies in VA calculations.[30-32] There are also challenges in accurately gauging VA in preverbal children, individuals with functional visual impairments, or those with intellectual disabilities in which subjective techniques can impede the reliable assessment of VA.[33,34]

VA measurement by objective tests

Introduction

Objective measurement of VA is especially beneficial for patients with cognitive, attentional, or language challenges and cannot follow the vision screener guidelines. These tests could evaluate visually impaired patients before and after surgery and assist in diagnosing amblyopia in young children with a short consultation time.[35] The introduction of computer-operated machines such as autorefractors and photo-screeners marks a significant advancement in identifying refractive errors. These devices provide rapid and efficient results by recording precise refractive data for both eyes in a few seconds.[36] Photo-screening tools have become an alternate method for early amblyopia detection, refractive error diagnosis, and identifying conditions of ocular misalignment.[37] However, the EUSCREEN project Country Reports highlight some limitations in cost-effectiveness compared to traditional chart-based VA screenings. In addition, there is limited evidence that photo-screening services could reduce the incidence of amblyopia or strabismus or enhance prognosis.[38] Further progress is seen as these instruments have been enhanced with eccentric photorefraction methods and calibrated for additional diagnostic functions, similar to retinoscopy, in eyes without cycloplegia.[39-42] It is essential to acknowledge that inaccurate myopic readings and an increase in over referrals may occur due to the impact of proximal accommodation in young children based on Johnson's book.

Visual evoked potential (VEP)

Visual Evoked Potential (VEP) is considered to be one of the psychophysical or electrophysiological methods, it is a non-invasive electrophysiological technique for evaluating the human visual system's function. VEP works by presenting visual stimuli to subjects and measuring the resulting electrical activity from the visual cortex, which does not require conscious focus or awareness.[43-45] Experimentally, the invisibility degree of visually evoked responses to stimuli of varying contrast levels and sensitivity is significant. These observations aid in assessing VA, amblyopia, and refractive errors.[46-49] Standards for using VEPs in children highlight the importance of establishing normal age-related benchmarks. For infants, a sweep duration of at least 500 post-stimulus is recommended to capture the complete waveform. By 6 months, the distinct positive peak in pattern-reversal VEPs (1 checks) usually approaches within 10% of adult levels.[50] Previous suggestions have been made regarding the variability in VA testing using EEG and VEP methods, including comparisons between different VEP types such as sweep VEPs (sVEPs), steady-state VEPs (SSVEPs), and pattern VEPs (PVEPs).[51] Odom *et al*. 2010 have described that the VEP's ability to linearly measure the decline in contrast sensitivity with spatial frequency makes it a non-invasive diagnostic tool for assessing VA in non-verbal infants through basic electrophysiological labs.[52] Simon *et al*. studied 122 children and showed a 94% successful completion rate of the test, including participation from infants as young as 5 months. The study also noted low VEP response magnitude in amblyopic eyes across all spatial frequencies, except for one false-negative case.[53] In addition to the diagnostic support, Nakamura *et al*. 2001 employed VEP in identifying six malingered individuals who might exaggerate symptoms for compensation. They found a superiority of VEP results than subjective VA measurement.[54] Even when patients feigned VA levels between 20/60 and no light perception on the ETDRS chart, their VEP responses to pattern-induced stimulation under maximum contrast and constant luminance were normal.[55] In contrast, Jeon *et al*. used the PVEP to affirm legally blind status in non-malingering head trauma patients without obvious optic[56] disc pallor or other signs.[56] They identified a VEP amplitude over 5.77 μV as significant ($P < 0.0001$) when they correlated the VEP-estimated VA among patients with amblyopia and optic neuritis to their logMAR Snellen VA.[57] An advanced version of VEP, sVEP, measures the response to continuously varied visual stimuli instead of a fixed value.[57-59] It employs a series of stimuli with changing grating pattern widths and contrasts. The VEP curve's highest spatial frequency response at the visual system's threshold is zero, allowing VA measurement by plotting a regression line on the amplitude-spatial frequency function for each frequency.[60,61] Validation studies are crucial for confirming the reliability and effectiveness of the logMAR sVEP method. Vesely investigated an adult through logMAR sVEP who had no eye diseases nor refractive errors, showing a significant positive correlation ($P < 0.05$, r = 0.72) between logMAR sVEP measurements and Snellen values. Moreover, a t-test comparing average sVEP and Snellen values was significant ($P < 0.01$), and significant correlations were found between repeated sVEP measurements in 32 normal adults ($P < 0.05$, r = 0.69).[61] Ridder and Rouse concluded that sVEP acuity is an accurate prediction of post-amblyopia therapy Snellen acuity ($P < 0.00001$), with an interclass correlation coefficient of 0.73. The average difference in sVEP acuity estimate and final Snellen VA was +0.002 ± 0.123 logMAR acuity lines.[62] Dotto *et al*. published 2 articles about usage a new digital sVEP system confirming visual impairment in children with brain tumors and West syndrome. The patients were unable to undergo subjective recognition acuity tests, such as Teller grating acuity, though researchers validated the sVEP system with a cutoff value of 0.10 logMAR, based on variations in grating visual acuities among 10 healthy children with a normal VA of 0.00 logMAR; children with conditions showed decreased contrast sensitivity using sVEP.[63,64] Furthermore, Chang *et al*. 2007 noted a decrease in contrast sensitivity in 14 children with neurofibromatosis type 1.[65] Vernier acuity, the ability to perceive misalignments or separations of lines, dots, segments, edges, or gratings, can also be studied using psychophysical or electrophysiological methods like VEP.[66,67] Hou *et al*. have validated that the reduction of vernier and optotype acuities in amblyopes who do not use both eyes did show reduced making vernier acuity measurement important in their follow-ups and evaluations.[68] There is a significant correlation between sVEP Vernier and grating acuities with their respective psychophysical acuities ($P < 0.001$) when measured with swept-parameter VEPs.[69] Supporting the accuracy of sVEP in estimating VA, Kasikci *et al*. 2022 compared normal and amblyope children using the smallest pattern size; they elicited that a response to estimate sVEP showed only a ±0.11 logMAR difference between best corrected VA and mean sVEP VA.[69] However, Hamilton's review documented how scientists and since 1970 have been improving the VEP functionality and developing standardized protocols for VA measurement.[70] Apart from some recent guidelines, there is a lack of standardization which remains a challenge.[71,72] VEP pitfalls have been claimed by researchers at University Medical Center Freiburg who compared the Freiburg VA with SSVEP in amblyopic eyes found that the latter overestimated psychophysical acuity by more than 0.3 logMAR in most cases, making it unreliable for amblyopic eyes.[73] Another investigation by Strasser *et al*. analyzed two sVEP recording systems finding both overestimated predicted VA for low subjective visual acuities and underestimated it for high subjective visual acuities.[74] Lauritzen *et al*. 2004 have detected a variability during examining infants with the sVEP system, and it showed multiple thresholds because the mean of several acuity thresholds was less variable than a single best threshold.[75] A retrospective analysis of 141 patients was conducted by Hamurcu, it showed a weak positive correlation ($r = 0.267$, $P < 0.001$) between Snellen chart VA and sVEP-measured VA.[76] Zheng *et al*. concluded that behavioral acuity was more accurate than VEP acuity for patients with macular, optic nerve, or cerebral diseases.[77] Similarly, Greenstein *et al*. 1998 estimated a decrease in VEP responses in chromatic contrast and luminance contrast conditions among 15 patients with open angle glaucoma.[78] Heinrich *et al*. found that acuity estimates in a 1-second condition were about twice as high as in a 0.1-s standard, equivalent to a 3-line increase in VA estimates. Extending the presentation duration to 10 s has improved the VA.[79]

Optokinetic nystagmus (OKN)

OKN is an involuntary eye movement phenomenon, typically observed in mammals, triggered by moving patterns or stimuli. It leads to a repetitive cycle of eye movement, where the eye follows a moving visual feature and then resets (saccade) to a new segment of the stimulus OKN.[80-82] It is also known as optokinetic response or reflex, is detected through an eye-tracking system that records a sequence of slow phases where the eyes track a moving stimulus feature and quick phases where the eyes rapidly move in the opposite direction.[83] Millodot and Harper 1969 was an early investigator who addressed the benefits of eye movement in VA assessment.[84] Cheng and Outerbridge 1975 have compared OKN-based VA (an objective method) with subjective measurement techniques in children, like the Teller cards.[85] Han *et al*. 2011 have investigated 71 patients with different ocular diseases, and they used the computerized objective VA test using the OKN.[86] They concluded that subjective VA and objective VA (OKN induction and suppression) had a significant association.[86] Among all age groups as well, Aleci *et al*. 2019 found the OKN as a worthwhile objective method to assess VA in non-cooperating individuals with cataract or macular degeneration.[87] Hu Zongzi's patent aimed to integrate the eye-tracking technology with systems that correlate objective and subjective vision measurements and it was beneficial for young children and patients who struggle with cognitive, attentional, and linguistic skills, or those unable to follow standard test instructions.[88] Turuwhenua *et al.* deployed a simple and cheap technology that had a 93% accuracy rate in detection the presence and direction of OKN. They used a limbal masking strategy to estimate limbal velocity.[89] With the acknowledgment of OKN as a marker of visual function/response in humans, substantial progress has been made in evaluating children's visual function and retinal sensitivity.[90,91] That comparison is crucial for early detection and improved treatment outcomes for visual impairments in amblyopic children.[92] In addition, OKN techniques offer a rapid and reliable assessment of VA in young children and adults with various disabilities or dysfunctions in cognitive, neurological, and visual systems or due to substance intoxication.[92-95] One way to stimulate OKN involves displaying a series of visual stimulus patterns, such as striped shapes with a specific spatial frequency, moving horizontally or vertically.[94,95] To measure OKN-related VA, the width or area of the moving stimulus is decreased until there is a noticeable reduction in OKN gain.[96,97] Boop *et al*. 1987 utilized Catford drum, employing monitors with various stimulus shapes beyond the standard vertical stripes, including dots.[98] Data extraction is being advanced by observing the subject's gaze or using electro-oculographic recordings through a camera, noting that changes in the target's size, shape, contrast, velocity, or application can affect the reflex.[99-101] Eye-tracking systems now enable the recording and analysis of optokinetic responses, including the components, presence, and strength of OKN.[102] There are two primary techniques for recording VA using OKN:

- The induction method begins by showing patterns (typically stripes or dots) to the patient, gradually reducing the pattern's brightness, and increasing the spatial frequency until OKN ceases when patterns become undetectable under normal conditions. The VA is calculated using the highest spatial frequency and the smallest pattern size that elicits an OKN response.
- The suppression method involves displaying moving patterns that inhibit OKN. Initially, patterns with a spatial frequency above the threshold, insufficient to evoke optokinetic responses, are used. In contrast to the induction method, VA is gauged based on the lowest spatial frequency and minimal

size or brightness of patterns (dots/stripes) that suppress the OKN response.[103]

Hyon *et al*. suggested using the induction method for patients with poor vision, while the suppression method seems more effective for those with better VA.[83] The induction method is influenced by the central and peripheral retina, but the suppression depends mainly on the central retina. Therefore, combining both methods offers a satisfactory means of objective VA assessment.[86,104] Aleci *et al*. developed a novel stimulator method, Oktotype, using symbols in a linear periodic pattern moving horizontally to stimulate the optokinetic reflex, illustrating that the induction OKN method provides a broader insight into the visual system compared to the suppression method.[90] These approaches, combining biology, engineering, and optics, aim to refine VA measurement techniques in young amblyopic children or those at risk of amblyopia. They involve adjusting the contrast and frequency of visual stimuli to identify the threshold where OKN is absent or falls below a certain level. Subsequently, an image processing system analyzes the footage to determine the presence or strength of OKN.[105] Despite some uncertainty surrounding the variability of OKN components, Waddington and Harris discovered a significant correlation between the initiation, termination, and amplitude of OKN phases, recorded using a binocular head-mounted limbus tracker.[80]

Discussion

This systematic review delves into the methods and challenges of measuring VA in children, it underscored the importance of early detection of vision impairments. The thoughtful integration of objective and subjective methods is pivotal in enhancing early detection and thereby improving overall outcomes and quality of life for visually impaired children. Subjective methods are crucial in their role but rely on the participation of examinees and are hampered by inaccuracies and overestimations, particularly in young or non-verbal children. Objective methods, on the other hand, leverage technological advancements to offer more reliable and efficient evaluations. From a technical perspective, VEP remains an objective vision measurement method, but examiners need to consider factors like optimal retinal image quality for better VA recordings during longer viewing periods or other technical settings/variables. A notable example is OKN, which employs eye-tracking systems to record involuntary eye movements in response to moving stimuli. This technique is efficient for young children and those with cognitive or linguistic limitations.

Conclusion

There are many strengths of subjective and objective methods, but the review reveals that neither approach is flawless, with the precision of objective methods, they still face challenges, such as standardization issues and the risk of over-referrals, can be moderated with subjective assessments. This finding underscores the importance of an integrated approach that synergizes subjective and objective methodologies, providing a holistic and accurate measuring of pediatric VA.

Conflict of Interest

The authors declare no conflict of interest related to the content of the systemic review.

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