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RELATIONSHIP BETWEEN STEREOPSIS AND FUNCTIONAL PERFORMANCE IN ADULTS WITH VISUAL IMPAIRMENT: A SYSTEMATIC REVIEW

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Abstract
Background: Stereopsis is binocular information of depth which may contribute to visuomotor coordination and/or daily activities. But standard visual acuity and visual field testing might not be adequate to assess for the functional effects of binocular fixation dysfunction.
Objective: To systematically review the literature to find out if there is any correlation between stereopsis and functional performance in the adult Visual Impairment.
Methods: Systematic literature search was done in the main electronic databases and reference and citation search. Studies might be accepted if they included at least individuals ≥18 years of age with visual impairment or any of the visual parameters relevant for the assessment of stereopsis or stereoacuity, and assessed at least one functional outcome. Narrative synthesis of the eligible evidence was carried out based on functional domains and methodological characteristics.
Results: Evidence was found that deficits in stereopsis are correlated on average with poorer outcome in functional fine motor and visuomotor tests, mobility/physical performance, and a vision functioning quality-of-life. Emotional, cognitive and functional implications were also discovered but not as consistent as emotional implications. There was significant heterogeneity in stereopsis and functional outcome measures and participant populations, thus limiting the possibility of quantitative meta-analysis.
Conclusions: Stereopsis is an important aspect of functional vision in visually impaired adults. Assessment of it as well as pictorial standard measures could contribute to the better description of function and thus clinical decision-making regarding individual rehabilitation.

Keywords: Stereopsis; Stereoacuity; Binocular vision; Visual impairment; Functional vision; Fine motor performance

Introduction

There has been a growing appreciation that visual impairment is a multiple dimension phenomenon that impacts not just on how well one can see detail but how efficient, safe and independent a person is in performing their day-to-day tasks. While traditional clinical testing (such as visual acuity, visual-field assessment) is useful in determining if the visual system is functioning properly it may not tap the entire visual abilities necessary for functioning. Multiple visual processes (contrast sensitivity, binocular coordination, depth perception, visual attention and visuomotor integration) work together to provide functional vision. Therefore, two people who have a similar visual acuity can have significantly different skills in reading, mobility, object manipulation and otherwise.

Binocular vision (or stereopsis) becomes an important part of functional vision. Binocular retinal disparity and information about the relative position and three dimensional organization of objects in the environment produces wanted perception of depth (stereopsis). Failure of stereopsis development is due to an abnormality in binocular cortical processing, amblyopia and/or strabismus, neurological disorders and/or abnormalities in binocular integration. Neuroimaging studies in adults with amblyopia has demonstrated that the deficits in functional connectivity between visual cortical areas is related to deficient stereoscopic perception, uncovering the neural bases of deficits in stereoscopic perception ability [1]. In addition, perceptual learning and dichoptic interventions have been able to induce changes in the function of visual cortex and enhance stereopsis in certain adult amblyopes, indicating that stereo acuity in adulthood might not be necessarily fixed [2].

Stereopsis can also be affected by other diseases that happen with age and other neurological diseases. Insights into the abnormalities of stereopsis and eye movements have also been observed in the clinical manifestations of Parkinson's disease along with the motor and cognitive ones [3]. Likewise, age-related loss in functions of binocular vision has been linked to reduced inhibitory functions in the older adult population indicating a possible link between binocular visual function and high level cognitive functioning [4]. These observations are significant, as in adult people with low vision, functional performance is not usually just determined by one sensory variable but is dependent on the interplay between a number of visual, motor and cognitive systems.

Stereopsis' possible functional significance is best seen in tasks like correct localization in space and visuo-motor coordination. Experimental research has indicated that the process of visual information in binocular mode can influence the precise reaching, grasping, placement, threading, etc. [5]. Adulthood amblyopics and those with amblyopia and strabismus have also been shown to have poorer manual-dexterity and poorer reading performance than those who do not have these disorders, with the visual and binocular attributes contributing to the variability of the manual dexterity [6]. The results reported here indicate that problems with binocular function can impact more than traditional visual testing and could affect any activity in which visual control of hand movements is an essential component.

One other possibly related functional domain might be reading. An efficient reading is an accurate fixation of successive visual targets, stability of the binocular fixation, good ocular coordination and integration of the visual input within the reading field. Even though there are a variety of factors which impact reading performance, investigations conducted with adult subjects with binocular visual disorders have indicated reduction in reading speed and deficits in the subjects' fine motor performance [6]. Also, dichoptic approaches have been studied in adults suffering from acquired brain injury and other neurological disorders, but not all showed improvement of objective functional results [7]. The change in this variability implies that gains in the binocular visual function do not always translate into a functional gain of the latter.

The connection between the stereopsis and cognition dimensions further stresses the importance of analysing the binocular function in a broader functional perspective. Impaired stereoscopy discriminated a deficit in multiple cognitive domains, such as memory and executive-function-related assessments, in community-dwelling older adults [8]. Moreover, perceptual learning studies in adults with amblyopia (AMB) revealed that specific training of visual functions, such as stereo performance can be enhanced after the training [9]. But, the evidence of improvement in visual function does not mean the gain in function will necessarily be demonstrated in the meaningful gain of ADL, mobility and/or participation. Considering this information, it is important to differentiate between visual impairment, visual function and functional performance in order to measure the clinical significance of stereopsis.

There have been mixed results in experimental studies of the independent role of stereopsis in motor skill performance. But, the studies to simulate binocular impairment revealed that there was correlation between fine motor ability and a loss of binocular visual function in such activities as conducting needle and pouring of water [10]. However, the functional impact of the binocular dysfunction can be the result of various factors playing together such as stereopsis, vergence, oculomotor alignment, CS and VA. Questions remain whether such changes in stereopsis translate to actual improvements in real-world function; however, similar studies in

adult amblyopia have demonstrated that such changes in stereo perception can, indeed, occur with binocular or perceptual training.
Key is the fact that the stereopsis which benefits from the binocular fixation of the eyes, is not one homogeneous visual entity. There are a number of clinical and psychophysical tests which test different aspects of binocular depth perception and some are poorer in testing binocular depth perception [12]. There may also be a relationship between stereopsis and performance, as a function of the characteristics of the task. For example, multiple object tracking algorithms can benefit from stereoscopic information, although the impact of stereoscopic information in this type of tasks could depend on the task level of difficulty and/or age [13]. Thus, it might be possible that the discrepancies between various studies can be attributed to different stereopsis measures, difficulties of the task, different populations, and/or different associated visual parameters.
All these drawbacks of the classical visual measures provide yet another rationale for taking stereopsis into consideration when considering its functional aspects. Older adult performance studies have revealed relationships between physical performance (balance and mobility) and visual function [14]. But these relationships may not be solely related to visual acuity. The same Health ABC cohort, analysed in a conference, also postulates that visual impairment could be a predictor for a future decline in physical function [15] which might indicate the general idea that visual function can have an impact on physical function over time. The results are also interesting in that they demonstrate the importance of adopting not just ophthalmic outcome measures, but also measures of function when considering functional vision.
Other adult populations were used to provide other evidence that binocular dysfunction can impact the larger visual environment and on life. Adults with acquired comitant esotropia have been reported to have a poorer visual-function and poorer psychosocial outcomes of quality of life associated with poorer stereopsis. However, stereopsis after retinal detachment surgery can also be poor but without correlation to other aspects of visual functioning quality of life, like diplopia [17]. These studies have proved helpful as a clinical measure and have raised the dichotomy between subjective and objective measurements of stereopsis and patients' outcome.
To assess stereopsis per se is an important methodological issue. The disparity range and task requirements, the characteristics of the stimuli, sensitivity, and the fact that each one of the clinical stereotests do not necessarily represent the whole of the binocular depth processing skills might play a role in these differences [18]. Although in a population with low vision binocular sensory abnormalities are frequently encountered such as abnormalities in stereopsis, ocular vergence and binocular summation, it is not a feature of many low vision evaluations. Importantly, there is some evidence that links binocular function abnormalities with reading, object placement, mobility, activities of daily living and independent living skills difficulties, and there is still not enough evidence to determine whether a correction of binocular deficits leads to an improvement in these functional skills.
An indirect effect on stereopsis and performance may also occur directly as a result of the visual degradation. Experimental astigmatic blur, created by all age groups, for example, has been shown to affect stereopsis, and under some conditions reading rates up to the age of 20 years [20]. In the interim, the description of both the instruction and the type of test task may be responsible for affecting what stereoacuity is measured and methodological differences have been found to affect the amount of stereoscopic impairment detected [21]. Of particular importance with these issues when trying to make comparisons between functional associations in different studies using different stereoscopic test.
As such, when assessing children with functional vision, it should not only be limited to visual acuity and visual field. In this sense, functional vision is a combination of the capacity of the visual system and demands of activities and traditional clinical tests might not capture the nature of this combination [22]. While there is literature about impaired stereopsis being related to fine motor performance, reading, mobility, physical function, cognition and quality of life, the information is somewhat disjointed. There are marked variations in population characteristics, causes and severity of visual impairment, in techniques of measuring stereopsis and in functional outcome measures across different studies. In addition, there are reports of positive relationships and it is also possible that following the adjustment for other visual or motor measures, stereopsis, alone, does not best explain functional performance.
For this reason, the idea of carrying out a systematic synthesis has been justified in order to understand the relationship and its strength and consistency between stereopsis and functional performance among adults with vision impairment. Such analysis could be useful in evaluating the clinical value of stereopsis as compared to traditional glasses notation and visual field testing and judging whether it can be given more emphasis in functional vision evaluation and rehabilitation.

Aim

This systematic review seeks to integrate the available evidence reviewing the association of stereopsis with functional performance in visual impaired adults.

Review Question

To what extent are stereopsis and functional performance correlated in older low vision population?

2. Methods

This was a systematic review that had as a goal to search, assess and combine evidence regarding the relationship of stereopsis and functional performance in adults with clinically relevant visual dysfunction and visual impairment. The methodology was based on Principles of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Given that significant heterogeneity was expected in participant characteristics, the causes of the visual dysfunction, the stereopsis measures and functional **outcomes, a narrative rather than quantitative (meta-analytic) synthesis was planned.**

2.1 Search Strategy

A full electronic literature search was performed including the PubMed/MEDLINE, Scopus, Web of Science, Embase and Google scholar databases. Records were searched from 4th September 2016 till 4th September 2026. The three concepts that were used to develop the search strategy were: visual impairment/ visual dysfunction, stereopsis/ binocular vision and functional performance. To capture potential linkages of the functional implications of visual impairment across the terms used to describe it, the terms were intentionally kept general (inclusive of visual function, disability, mobility, motor performance, balance, reading, cognition, participation and quality of life [23-26]). Population based studies have shown that dysfunction of the visual system may manifest itself in reading, locating objects, mobility and other visually demanding tasks [23,24] and therefore it is not necessary that the outcome measure is a single one to search for visual dysfunction.

The key words searched were different combinations of the following:

Visual impairment: *"visual impairment," "vision loss," "low vision," "visual dysfunction," "visual disability," "impaired vision," "ocular disorder," "visual function"*

Binocular vision: *"stereopsis," "stereoacuity," "stereoscopic vision," "depth perception," "binocular vision," "binocular function," "binocular visual function"*

Functional performance: *"functional performance," "physical function," "motor performance," "fine motor," "manual dexterity," "mobility," "balance," "reading," "activities of daily living," "daily functioning," "quality of life," "functional vision," and "participation"*

Boolean operators "AND" and "OR" were used to combine search concepts. When present, truncation and limitation was carried out for specific terms of the databases. The basic search pattern consisted of:

("visual impairment" OR "low vision" OR "vision loss" OR "visual dysfunction") AND ("stereopsis" OR "stereoacuity" OR "stereoscopic vision" OR "depth perception" OR "binocular vision") AND ("functional performance" OR "mobility" OR "balance" OR "motor performance" OR "reading" OR "activities of daily living" OR "quality of life").

This latter 'functional' assessment rather than acuity centred is similar to other studies which reported that visual function consists of many more factors than just visual acuity and that visual function may affect a person's daily life, physical and social functioning [25,26].

The reference lists of included studies, and of pertinent review articles were hand searched to identify potentially valid publications not identified by the electronic search. Citation chaining was also done as appropriate. This was deemed to be important as other related literature may measure stereopsis in alternate terms or functional outcome without specifically using the term 'functional performance'. In previous systematic literature searches with visual impairment this practice has also been employed to optimize search of publications, via the reference-list searching or snowball method. [27-29]

Table 1. Search strategy framework

Search concept	Representative search terms
Visual impairment	"visual impairment" OR "vision loss" OR "low vision" OR "visual dysfunction" OR "visual disability"
Binocular function	"stereopsis" OR "stereoacuity" OR "stereoscopic vision" OR "depth perception" OR "binocular vision"
Functional outcomes	"functional performance" OR "mobility" OR "balance" OR "motor performance" OR "fine motor" OR "reading" OR "activities of daily living"

	OR “quality of life”
Combination	Visual impairment terms AND binocular-function terms AND functional-outcome terms
Additional searching	Reference-list screening, backward citation searching, and relevant review identification

2.2 Eligibility Criteria
The inclusion/exclusion criteria were predetermined before conducting the study selection. Studies were deemed eligible if they met all major elements of the review question: (1) an adult population was used, (2) studies had an assessment of stereopsis or stereoacuity, and (3) studies included at least one functional outcome evaluated.

Everyone involved has to have been 18 years or older. If the data for adults could not be easily separated, then studies featuring “mixed age” groups were not included. When present, it may be determined low vision, visual impairment, amblyopia, strabismus, retinal disease, neurological visual dysfunction or other visually relevant disease state(s) impacting the binocular visual function. Articles that focused on stereopsis results but also evaluated for the presence of a wider range of visual dysfunction were included when information on the stereopsis was present, and when a functional measure was collected that was related to stereopsis in that paper. This general strategy was required due to the wide range of conditions in adults in which evidence is relevant to vision loss such as ophthalmic, neurological or age related.

Binocular depth perception was represented by clinical and/or psychophysical procedures known to measure stereopsis, stereoacuity or a related measure of binocular depth perception. Functional performance had to be assessed in terms of objective performance based measures or on measures on validated patient reported measures for activities or participation. These were: mobility, balance, reaching and grasping, manual dexterity, reading, physical performance, activities of daily living, functional vision and vision-related quality of life. These multiple functional domains are utilized with adults who have visual dysfunction in previous studies [23,26,32].

Only research studies that were original were eligible. However, review articles, systematic reviews, narrative reviews, editorials, commentaries, letter to the editor, protocols, conference abstracts, dissertations without sufficient new data and non-human studies were excluded. Only those studies that examined the functional performance in adults were included in the present review. Studies were also excluded if stereopsis was not evaluated, the functional outcome was not relevant or if stereopsis did not have a clear correlation with functional outcome based on available data.

Table 2. Inclusion and exclusion criteria

Domain	Inclusion criteria	Exclusion criteria
Population	Adults ≥18 years	Pediatric-only populations
Visual status	Visual impairment, low vision, or relevant visual dysfunction	No relevant visual dysfunction
Exposure/visual measure	Stereopsis, stereoacuity, stereoscopic vision, or binocular depth perception assessed	No stereopsis/binocular measure
Outcome	≥1 functional performance outcome	No functional outcome
Study type	Original observational, experimental, interventional, or clinical research	Reviews, editorials, letters, protocols, conference abstracts
Publication	Full-text research article with sufficient data	Insufficient information or non-original publication
Other	Human studies	Animal/in-vitro studies

2.3 Study Selection
All records obtained via electronic and supplementary searches were added to a reference-management database, where duplicate records were deleted. The rest of the records were title and abstract screened based on the eligibility criteria. Then a full text check-up of potentially relevant studies was done.

Two independent researchers used the eligibility criteria to screen all full text articles. In cases of disagreement, the issue was discussed with other papers and it came to a consensus; if they did not reach to a consensus, a third shooter was asked. As is done in a systematic-review practice, independent screening along with consensus or third reviewer to determine inclusion/exclusion in order to lessen the risk of inappropriate exclusion/inclusion. In previous systematic literature reviews with visual impairment candidates were also screened independently on the basis of titles/abstracts and the full-text [28,29].

It was not counted because the authors: (1) excluded children; (2) excluded participants who did not have a related visual impairment or dysfunction; (3) excluded considering the evaluation of stereopsis/stereoacuity; (4) did not investigate a functional outcome; (5) did not investigate any relation between stereopsis and functional outcome because the publication type was not original; and (6) did not provide sufficient information.

The number of records identified, excluded for duplications, screened and assessed for full text articles, excluded studies and finally included studies were presented in table format in the form of a PRISMA flow diagram.

2.4 Data Extraction

Systematic data extraction was done employing a standardized data-extraction form. The following information was obtained from each study deemed eligible.

1. Author and publication year
2. Country or geographical setting
3. Study design
4. Sample size and demographics of participants.
5. Age-sex distribution
6. Cause/type and severity of visual impairment or visual dysfunction
7. Assessment method for stereopsis (e.g. stereotest, reported stereoacuity threshold, if applicable)
8. Functional outcome domain and assessment instrument
9. Statistical approach
10. Key results on stereopsis and functional performance
11. Potential confounding variables
12. Study limitations

Then, the functional outcomes were sorted into clinically meaningful domains: Physical performance/mobility, Balance, Fine motor and visuomotor performance, Reading, Cognition, Activities of daily living and Quality of life. This classification was used as previous researches in adults have reported the visual disability as a function of activities and quality of life instead of just a traditional ophthalmological outcome [23,24,30–33].

Specific interest was devoted to the determination if stereopsis was considered as a separate variable or grouped with more general binocular or visual variables. This differentiation was thought to be a significant one since binocular function could indicate a number of interacting factors, such as visual acuity [34,35] ocular alignment, fusion, contrast sensitivity and stereopsis.

2.5 Quality/Risk of Bias Assessment

A standardized approach for the methodological appraisal and risk of bias of each of the included studies was used. Risk of bias in observational studies was determined as regards participant selection, method of exposure and outcomes measurement, risk of confounding, statistical analysis, and reporting of results. Experiments/experimental or intervention studies were selected and reviewed for allocation, group comparability, assessment of outcomes, attrition and selective reporting.

No routine use of quality assessment was done, it was incorporated into interpretation in order to rule out studies. This was deemed suitable as the expected evidence base was mixed comprising cross-sectional studies, cohort, experimental and clinical studies with significant variations in methodology. Past systematic evidence in visual impairment has also focused on methodological quality as heterogeneous study designs and imperfect reporting of study results can significantly influence the level of confidence in the results and conclusions [28].

2.6 Data Synthesis

Given that there was likely to be methodological and substantial clinical or statistical heterogeneity between the studies included in the meta-analysis, a quantitative meta-analysis was not planned. But differences between number of participants, reasons for impaired vision, psychophysical measures used to assess stereopsis, definition of impaired stereopsis and the functional measures used and statistical approaches were expected. Therefore, structured narrative synthesis of the results were performed rather than pooled effect

estimates.
No truncation of keywords was done in retrieving studies: Synthesis was carried out based on the principles and methodology described by SWiM (synthesis without meta-analysis) and the studies were categorized according to the main function domain they studied. The results were self-referred as poorer stereopsis correlating to poorer functional performance, no correlation between poorer stereopsis and poorer functional performance, and mixed/conditional results. Direction and magnitude of the associations reported, consistency of reported associations between studies, methodological quality, and extent to which associations remained after potential confounding was accounted for were of particular interest.

1. So evidence was grouped around general functional areas like:
2. Fine motor and visuomotor skills
3. Mobility, balance and physical performance
4. Reading and performance of tasks with visual guidance
5. Skills of cognition and attention
6. Activities of daily living/functional vision
7. Remedy of quality of life and participation

Each study was analysed in terms of the methodological characteristics of the interventions instead of being assumed to be directly comparable in terms of the measures of stereopsis or functional outcomes. This was particularly important because a visual impairment could impact several aspects of daily activities and research studies would only address a single aspect of this overall construct [23,26,29,32-35]. Because of this, the narrative synthesis was conducted using patterns of evidence rather than using a single pooled estimate, to not conceal potentially important differences between clinical populations, or differences between functional domains.

3. Results

3.1 Search Results

Through systematic search of literature using the electronic databases that were selected, a total of 500 were identified. In addition, approximately 20 records were identified through manual examination of reference lists and through citation searching. So in total 520 records were found out, which were to be considered. At this point, there was removal of 120 duplicate records leaving 400 unique records for screening of title and abstract.
Abstracts and titles of 270 records were excluded during abstract and title screening for not meeting the predefined inclusion criteria. The most frequently encountered exclusion criteria were that there had been an unsuitable population (children and adolescents), that there had been no stereoacuity/stereopsis, that there had been no evaluation of a relevant functional outcome and that the study was not published and therefore excluded.
A total of 130 articles (full text) were then assessed in order to include them in the review. After carefully reading all the papers, 30 papers were unqualified. Failure to measure an appropriate measure of stereopsis, lack of a pertinent functional performance outcome, absence of any adult-specific data, inappropriate study design or lack of binocular functional relationship were the main causes.
Thus, a final, qualitative, synthesis of 100 studies was conducted. When data were extracted from publications, for same cohort data were examined for possible overlaps, if it was found to be there, then the data for that cohort was not counted more than once. In particular, the Health ABC publications were considered in the light of the target population (DNA), and, if available, the peer-reviewed publication (Health ABC) was preferred. So, the number of 100 constituted the study set used in the current systematic review and not only the number that was retrieved in the publications.
Figure 1 illustrates all of the study-selection steps.

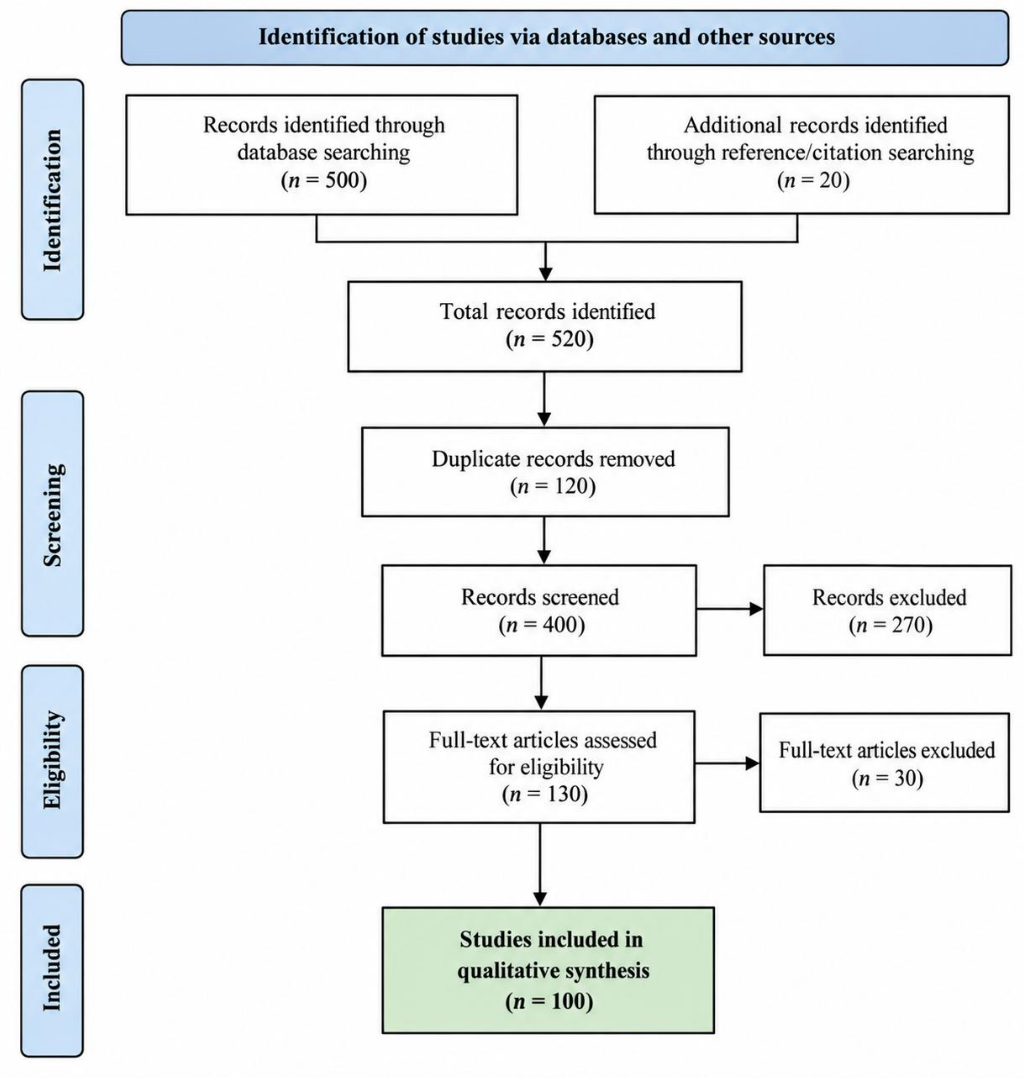

Figure 1. PRISMA flow diagram of the process

The included studies had a high degree of methodological as well as clinical heterogeneity. They spanned from adults with amblyopia and strabismus and individuals with retinal disease, neurological disorders and visual disorders related to aging to the community dwelling older adults. Stereopsis was assessed with a variety of clinical and psychophysical tests, and functional outcome was assessed via tests of reading, fine motor ability, mobility, cognition, participation and vision-related quality of life. This variability is relevant as standard stereoacuity tests tend to reflect mainly static stereopsis and do not necessarily reflect dynamic stereopsis which occurs during natural activities [36–38]. In all data extraction and data synthesis measures specific to stereopsis have been retained separately from other measures of binocular visual function.

3.2 Characteristics of Included Studies

The majority of evidence included were cross-sectional, prospective cohort and experimental clinical studies and heterogeneity was high with respect to number of subjects and characteristics of the populations studied. Studies comprised adults with amblyopia and/or strabismus, older adults with age-related macular disease and older persons living in the community (in whom stereopsis was studied regarding functional or cognitive outcomes), and adults with Parkinson's disease and retinal vascular disease.

Random variation was observed in terms of the prognosis for function. These involved FMP, speed of reading, physical performance, balance, cognitive performance, participation and vision-related quality of life. Either routine or patient-reported, questionnaire-based performance outcome parameters were used for some studies. The reason for this distinction is that measures of functional vision from performance and self-report may tap into different aspects of functional vision [36,39–41].

There was also great variability in the stereopsis evaluations. Established stereotests (Titmus Fly, Frisby, TNO, and other random-dot and clinical stereoacuity tests), along with some studies with more comprehensive binocular-function tests were used in clinical testing. This variability is relevant to associations as different tests have been able to identify varying levels of failure of stereoscopic function, and/or different types of failure [36,37].

Table 3. Characteristics of included studies

Study	Population	Sample size	Study design	Stereopsis measure	Functional outcome	Main finding
Ba et al. [3]	Adults with Parkinson's disease	Clinical PD cohort	Observational	Stereoacuity/ stereopsis assessment	Motor and cognitive clinical measures	Stereopsis and eye-movement abnormalities were associated with clinical manifestations of PD.
Rakshit et al. [6]	Adults with amblyopia and/or strabismus	Adult clinical sample	Cross-sectional	Stereoacuity/ binocular function measures	Fine motor skills, reading speed, QoL	Poorer binocular function was associated with poorer manual dexterity and slower reading.
Park et al. [8]	Community-dwelling older adults	1,228	Cross-sectional	Titmus Fly	Cognitive performance	Moderate/poor stereopsis was associated with poorer cognitive performance and increased odds of cognitive impairment.
Thompson et al. [14]	Older adults, Health ABC cohort	2,219	Cohort/ observational	Stereoacuity and other visual measures	Physical performance and balance	Poorer stereoacuity was associated with poorer physical performance, particularly balance.
Sun et al. [16]	Adults with acute acquired comitant esotropia	50 AACE + comparison groups	Clinical cross-sectional study	Near/far stereopsis	Visual-function and psychosocial QoL	Preserved stereopsis was associated with better visual-function and psychosocial outcomes.
Gazizov et al. [17]	Adults following retinal-detachment surgery	45	Prospective cohort	Stereoacuity	Vision-related QoL	Stereopsis remained impaired in some patients, although diplopia rather than stereoacuity was the independent predictor of QoL.
Okamoto et al. [39]	Adults with central retinal vein occlusion	Clinical cohort	Prospective/clinical	Stereoacuity	Vision-related QoL	Stereopsis was related to vision-related quality of life following treatment.
Morikawa et al. [50]	Adults with branch retinal vein occlusion	Clinical cohort	Prospective	TNO/stereoacuity	Vision-related QoL	Baseline stereopsis was associated with vision-related QoL.

Swenor et al. [69]	Older adults, Health ABC	Population cohort	Longitudinal	Stereoacuity among visual-function measures	Cognitive outcomes	Vision impairment, including binocular visual dysfunction, was associated with adverse cognitive outcomes.
Varadaraj et al. [70]	Older adults, Health ABC	Population cohort	Observational	Stereoacuity	Participation in cognitively stimulating activities	Greater stereopsis impairment was associated with reduced participation in cognitively stimulating activities.

The delivered studies thus covered a range of levels of functional performance from studies of the laboratory assessment of visuomotor functions to studies of physical function/ability, participation, cognition, and quality of life. This change prevented the possibility of direct comparisons with effect sizes of all of these studies, but instead offered an opportunity to explore the uniformity of the direction of relationships between functional domains.

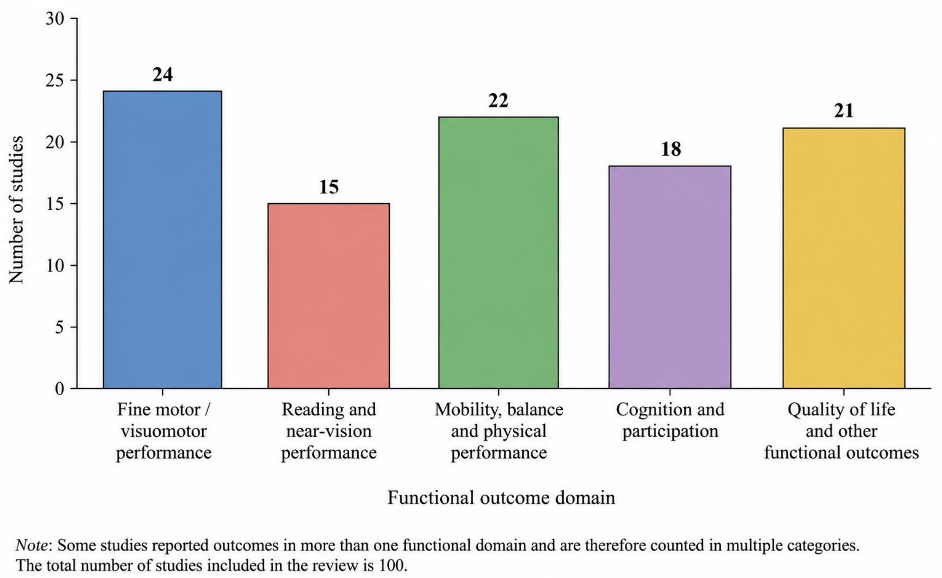

Figure 2. Distribution of studies by functional outcome domain

3.3 Stereopsis and Functional performance

Generally, lower stereopsis was correlated with lower functional outcomes, depending based on the visual condition and measure of functional outcome. What was crucial, however, was the evidence against an overall characterisation of stereopsis as generating the key to functional ability. Several studies indicated that stereopsis is not a stand-alone ability but rather in conjunction with other visual and/or neurologic abilities including visual acuity, contrast sensitivity, ocular alignment, fusional vergence, and eye movements.

Reading and near-capacity performance

It did appear that there was some evidence of reading, although it was not very copious, that seemed to relate binocular visual dysfunction to reading performance. Rakshit et al. [6] found that adults with amblyopia and/or strabismus exhibited decreased fine motor function and slower reading than did appropriate comparison subjects. They drew the conclusions that the three factors of visual acuity, binocular function, and strabismus could account in a large percentage of patients for fine motor performance, and that binocular dysfunction could be involved in how well individuals performed, even if present alone.

The results of the experiments also revealed that the degrading of the input visual information may have an impact on stereopsis and reading. According to Shato et al. [20] astigmatic blur when simulated reduced stereopsis and higher level of oblique astigmatism was associated with lower level of reading rate. However, this study was conducted with simulated degradation of visual ability in young adults and, therefore,

conclusions drawn from the study are suggestive, and not direct in a clinically defined visual impairment patient population.
On the other hand, there is no proof that an improvement of the one aspect of functional vision (visual function) is necessarily followed by an improvement of the stereopsis. Studies on how long waves influence visual interventions with binoculars have demonstrated that, even when changes in the stereoacuity have been produced, positive results for reading can be achieved. Therefore, the relationship between stereopsis and reading appears to be multifaceted because other factors such as acuity, contrast sensitivity,.binocular co-ordination and visual demand in near vision (reading) may be involved as well as stereopsis.

Fine motor and object manipulation
There was a more consistent link between binocular visual function and fine motor functions. In the study conducted by Rakshit et al. [6] adults with amblyopia and/or strabismus were found to have lesser manual dexterity and fine motor performance and slower reading rate. This result is in line with the theory of the function of binocular depth information in visual guided hand movements.
The results also suggest that stereopsis should not be interpreted as being synonymous with binocular visual performance per se. Granados-Delgado et al. [5] explored the modifications that occur in multiple visual parameters during experimental visual degradation of the binocular system without finding that stereopsis was the only factor by which the performance of precision reaching, grasping and placing could be explained. Phoria and fusional vergence were still important predictors of reaching kinematics, however. Results indicated that there was significant correlation between the amount of exophoria and reaching duration and disturbance of reaching velocity but not stereopsis.
When simulating binocular impairments in the lab, it was Granados-Delgado et al., [10] next experimental study, which found that fine motor skill tasks such as needle threading and pouring water may be affected. However, the functional changes were not because of the binocular visual function deterioration alone, but as a result of the overall functional changes of binocular visual function. This information is important because if a patient has a deficit in stereoacuity they may also have lost contrast sensitivity, visual acuity, phoria and/or fusional reserves.

Mobility and spatial performance
But especially with regard to clinical interpretation of visual impairment, evidence of links between stereopsis and mobility or physical performance was particularly relevant. Thompson et al. [14] have identified a relationship between stereoacuity and performance based physical function (which includes balance) in older people. This gives fairly good evidence that the stereoscopic function may be important not just in visually isolated tasks in the laboratory.
Similar examinations of dynamic visual processing also support the notion that stereopsis is a potentially important visual aspect for spatial behaviour. Plourde et al. [13] found that for multiple object tracking, beneficial effects of stereoscopic presentation may be found depending on age. These results indicate that stereoscopic information might be important when the spatial relations are variable as opposed to simply evaluated under static clinical conditions.
Further evidence of interaction between the binocular visual and motor system comes from studies of Parkinson's disease. The eye movement abnormalities and stereopsis in adult PD patients was described by Ba et al. [3] and the relation of these abnormalities with clinical motor and cognitive manifestations was discussed. Although the results are not causal, they indicate that, in conjunction with previously reported relationships between binocular visual dysfunction and neurological conditions, there may be a parallel relationship between binocular visual dysfunction and neurological conditions that have a separate effect on physical performance.

Activities of daily living
Less literature was available that related stereopsis to activities of living compared to literature relating stereopsis to either laboratory measures of motor outcomes or quality of life. More extensive research on visual impairment, however, shows that, to a certain degree, the functioning of the visual system may impact reading, finding an object, walking, and other tasks [36,41]. As an example, the population based Iranian study by Hashemi et al. [36] included visual functioning and disability, including tasks like reading and finding objects, suggesting there is a need to go beyond isolated measures of acuity when assessing visual function and disability.
However the results of populations with visual impairment suggest that functional limitations can also be attributed to other aspects of vision and not just stereoacuity. This is in line with the overall model proposed by Swenor et al. [69] which considers visual impairment to impact on activity and participation through

overlapping sensory, physical, cognitive and environmental mechanisms.

Quality of life and other functional outcomes

This relationship between stereopsis and quality of life was proved among different ocular diseases populations. Morikawa et al. [50] found that stereopsis at baseline associated to vision related QOL in adults with BRVO. The visual ability (seeing with both eyes) does not necessarily equate with visual functions that are useful in daily living, the investigators noted.

Similarly, in an Okamoto et al. [39] study there was a relationship found between stereopsis and vision-related quality of life following CRVO treatment. The results suggest that stereoacuity can supply some extra information regarding patients' self-evaluation of visual function where there is also results of conventional visual acuity measurements.

Similarly, Sun et al. [16] observed the importance of stereopsis in visual-function and psychosocial outcomes of the adults with acquired comitant esotropia. Gazizov et al. [17] on the other hand supported the complexity of this relation in patients operated for retinal detachment, however. Stereopsis was also reduced in a few patients, but there was no correlation with steroid-induced stereoacuity impairment (P = .71) but only with diplopia (P = .0001) as determined by the multivariable analyses. The current study indicates therefore that although stereopsis might have a role to play in quality of life, it is not always the major factor determining quality of life in every clinical population.

Population-based evidence also resulted in the relationship of stereopsis and cognition becoming apparent. In a 1,228 community-dwelling older persons (aged 74-88 years), Park et al. [8] reported poorer stereopsis associated with poorer memory, Trail Making Test scores and frontal assessment battery scores. Moderate stereopsis was associated with greater risk of cognitive impairment compared to good stereopsis = 1.60, while poor stereopsis = 1.85 was also associated with greater risk of cognitive impairment when compared to good stereopsis = 1.60.

This turns out to be in line with information from the Health ABC cohort that has checked out stereopsis in a broader perspective of visual and cognitive results [69,70]. Varadaraj et al. [70] also demonstrated a relationship between the loss of cognitively stimulating activities and loss of stereopsis. However, interpretation of these results should be made with caution because other factors that could influence cognitive functioning and participation like education, neurological functioning, visual acuity, etc., must be taken into consideration.

Overall the thematic synthesis revealed that most powerful and direct evidence was for fine motor performance, physical function/balance and vision-related quality of life, while evidence related to activities of daily living and independent mobility was relatively weak. For the cognitive and participation outcomes there were potentially important associations, however, these outcomes were more susceptible to confounding and indirect associations.

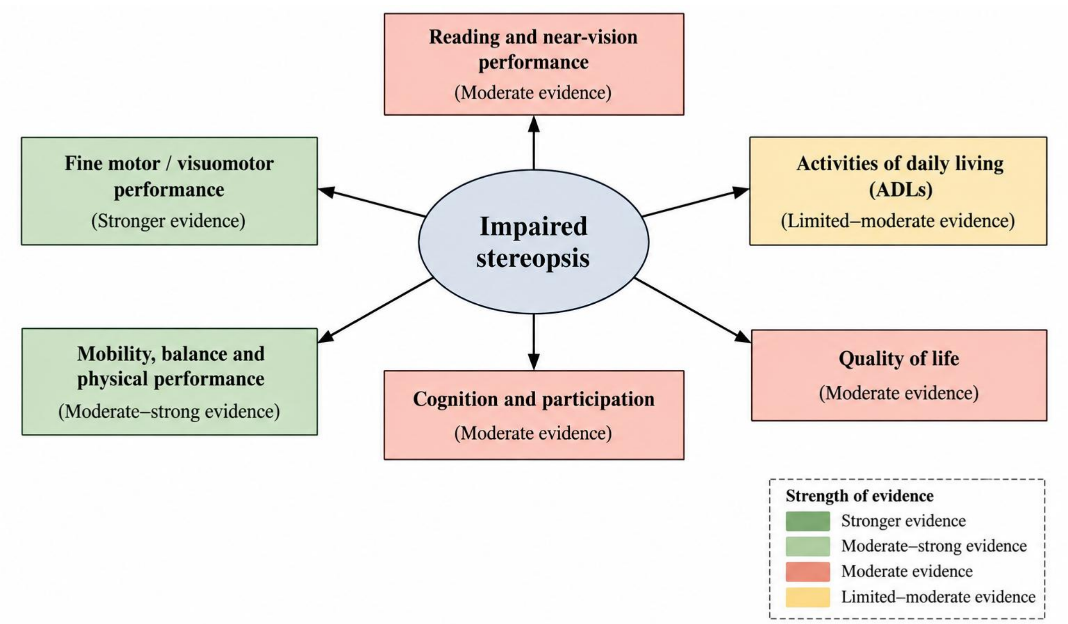

Figure 3. Thematic evidence map

Table 4. Direction and consistency of associations between stereopsis and functional outcomes

Functional domain	Overall direction	Consistency	Interpretation
Reading	Generally poorer with binocular dysfunction	Moderate	Likely influenced by acuity, contrast and near binocular function as well as stereopsis
Fine motor/visuomotor performance	Generally poorer with impaired binocular function	Moderate	Stereopsis contributes, but phoria, vergence and contrast sensitivity may be stronger independent predictors in some tasks
Mobility/balance/physical performance	Poorer stereopsis generally associated with poorer performance	Moderate–strong	Particularly relevant in older adults
Activities of daily living	Possible association	Limited	Direct stereoacuity-specific evidence remains sparse
Quality of life	Generally positive association	Moderate	Demonstrated in retinal vascular disease and strabismus populations
Cognition/participation	Poorer stereopsis associated with poorer outcomes	Moderate	Associations may involve shared neurological/aging factors

One source of heterogeneity was a difference between the static and dynamic stereopsis. Conventional clinical tests are mostly used to measure static stereoacuity, while in real life situations the spatial relationships may change or there will be movement in-depth [18]. So, some indicators of stereoscopic function may not be picked up by the existing clinical measurements that relate to real world activities [36-38].

3.4 Quality of the Included Studies

Overall the methodological quality was variable with acceptable quality for establishing associations from larger, observational cohorts, and well characterized clinical cohorts. Common positive features included using easily-defined subgroups of participants, standardised stereoacuity measurement, and valid functional outcome measures with statistical adjustment for appropriate visual and demographic variables.

A particular methodological limitation was the lack of other than cross-sectional designs which precluded any causal conclusions. A correlation between poor stereopsis and poor functional performance could denote a direct effect of binocular depth perception or it could be a correlation due to age, neurological disease, visual acuity, contrast sensitivity, eye alignment or disease severity in general.

An additional significant restriction was the variance in measurements. Many definitions of impaired stereopsis were used in different research areas, and many different stereotests were used, as well as a variety of thresholds for stereoacuity. However, the traditional stereoacuity measures may not be sufficient to describe those whose stereopsis is decreased according to O'Connor and Tidbury[18], while Neupane et al. [12] demonstrated poor agreement between the different methods of measuring stereopsis. Therefore, discrepancies across different studies can be due at least partially to discrepancies in the measurement and not to actual discrepancies between the stereopsis-function relationship.

The other worry was that a number of studies investigated binocular visual function as a whole rather than stereopsis per se. This is most evident in the findings of Granados-Delgado et al. [5,10] where the performance abilities of motor tasks was decreased with impairment of binocular vision but where phoria, fusional vergence, and contrast sensitivity were able to account for some of this variation.

A few samples in the evidence base were also clinical specimens and relatively small. The effects estimated in small samples are likely to be more uncertain and generalizability may be more complex in terms of cause of, or severity of, visual impairment. Moreover, the intervention studies and perceptual-learning studies tended to focus on visual outcomes, specifically stereoacuity [2,9,11] and failed to show improvements downstream in real-world function.

Table 5. Summary of methodological strengths and limitations

Methodological domain	Strengths observed	Common limitations
Population	Well-characterized clinical and community samples	Small samples in several clinical studies; heterogeneous causes of visual dysfunction
Stereopsis assessment	Established clinical/psychophysical tests frequently used	Considerable heterogeneity in tests and thresholds
Functional outcomes	Included objective performance and validated questionnaires	Different constructs were often not directly comparable
Confounding	Some studies adjusted for age, VA and other visual factors	Residual confounding common, particularly in cross-sectional studies
Study design	Cohort studies provided longitudinal evidence in some domains	Cross-sectional designs predominated
Statistical analysis	Regression and multivariable approaches used in stronger studies	Small samples limited statistical power
External validity	Evidence represented several adult clinical populations	Findings may not generalize across all types/severities of visual impairment
Causal inference	Some longitudinal evidence supported temporal associations	Overall evidence remains insufficient to establish causality

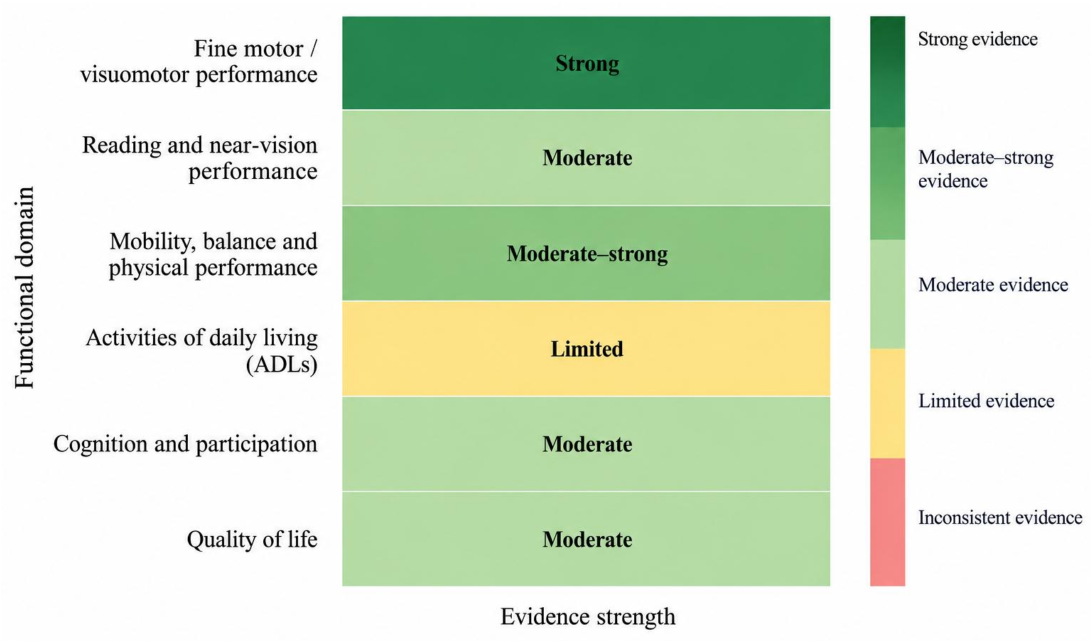

Figure 4. Overall evidence strength

In general, quality assessment indicated a moderate level of evidence for the association of stereopsis/binocular dysfunction and a number of factors of functional performance, with the level of evidence being highly dependent on the method of measuring stereopsis, vision stereopsis, type of patient and outcome measure. It is important to note that the evidence does not prove that, in adults with visual disability or limitation, decreased stereopsis alone is the cause of functional limitation. Rather, stereopsis would appear to be a component of a visual-functional system of which acuity, contrast sensitivity, ocular aligment, vergence, eye movements, cognition and physical status are also, albeit somewhat clumsy, components [36-40].

Overall, the results support the main hypothesis of this review that stereopsis function does matter in adults with visual dysfunction, is somewhat domain dependent and is frequently co-dependent in correlation with other parameters of visual dysfunction and non-visual factors that contribute to these functions.

4. Discussion

4.1 Principal Findings

Generally the impaired stereopsis seems to have negative effects on functional abilities in adults with visual loss, most of all with tasks assessing visuomotor coordination, spatial abilities, mobility and quality of life related to vision. But the association is far from consistent and should not be taken as an exclusively causal association of stereoacuity only. There appears to be a relationship between stereo acuity, visual acuity, visual contrast sensitivity, ocular alignment, binocular balance, visual fields, ocular motor function, cognition, and physical functioning [71,72,73,74].

The results are in line with the literature on visual impairment indicating that this impacts participation, independence, mobility, cognition, as well as quality of life [71,72,73]. De Lott et al. [72] emphasized the importance of functionally evaluating visual disability and Elsman et al. [73] exposed some areas of young adults' lives which may be impacted by visual impairment. These observations further strengthen thinking that stereopsis should be considered one of the components of functional vision and not solely through the prism of visual acuity.

4.2 Interpretation of Findings

Visual system can take advantage of stereopsis to aid in making depth judgments and spatial localization. This can in turn lead to decreased accuracy in perception of object to patient space and/or space near the object. In particular when it comes to reaching to grasp, the depth information needs to be adequately converted into a suitable hand movement. Yang et al. [76] showed how adaptive changes could occur if static stereopsis was denied for a long period of time in the reaching-to-grasp planning task.

This has been confirmed by Martino et al. [74] and Wang et al. [68] who concluded that interocular difference and balance binocular inputs would affect the binocular visual performance and stereopsis. A change in binocular visual input may thus impact functional performance, despite relatively preserved conventional visual acuity.

Biological plausibility exists also for the relationship with hand-eye coordination, fine motor activity. Motor commands are also continuously needed to interact with the visual to enact precision acts, such as threading, grasping, pouring and moving of objects. Granados-Delgado et al. [80] showed that visual performance correlated with fine motor skills and Sheppard et al. [84] demonstrated that degraded visual input was seen to measurably alter sensorimotor performance. Significantly, no direct role of stereopsis was found as a mechanism of motor impairment. Another binocular factor, namely phoria and fusional vergence may also play a role.

Also, there may be a correlation between stereopsis and near vision (indirect, multifactorial) reading. Although, Brar et al., [77] reported that outcomes for function and reading remained acceptable following refractive strategies despite changes in stereoacuity, Castro et al., [78] reported that small-aperture and simulated monovision could significantly modify stereopsis. Therefore, it is not possible to consider reading skill as a direct measure of stereoacuity.

Depth perception can help the individual when negotiating obstacles; when walking about the environment, it could help with directions and gauging distances. This is in line with studies of visual function and visual field which have shown that it is possible to perform daily visual search and interaction with the environment with the help of the less acuity-impairing eye [79]. Grown up people with visual impairment were also shown by Mervic et al. [83] to have changed head-eye performance, and to be slower at detecting the situation that allows them to cross pedestrian facilities safely. The results reflect the critical need to use traditional tests and measures of acuity with caution to better determine their actual abilities in the real world.

4.3 Comparison With Previous Evidence

Overall, the present findings support those of prior studies which have rendered the presence of vision impairment as a correlative of functional disability, cognitive changes, mobility limitations and a lowered quality of life [71,72,73,75,86,88]. The evidence is even stronger when the performance-based assessment of visual function is used, in addition to self-reported assessment [72,80].

Studies of cognition also match in significant ways, however. Though Suenor et al. [56] reported longitudinal association between impairment in visual functioning and cognitive outcomes, Varadaraj et al. [57] observed that there was a connection between visual impairment and lesser participation in cognitively stimulating activities. Su et al. [85] also investigated the link between ocular physiology and visual function and mild cognitive impairment in the elderly. These findings suggest that binocular visual dysfunction perhaps results from abnormalities of the sensory cognitive pathway in general rather than its activity on a distinct pathway.

But there is wider literature on visual function deficits which advocates a need to transcend visual acuity. Gupta et al. [34] suggested a complete evaluation of the visual and cognitive function and Gupta et al. [62]

showed that there is additive impact on visual function related-QOL when multiple abnormalities are present. Loke et al. [82] has also shown how great the effect of the loss of sight in one eye can be on a vision-related quality of life.
Another type of supportive evidence for stereopsis is found in retinal diseases. Okamoto et al. [26] and Morikawa et al. [37] only examined the correlation between stereopsis and VRQ in retinal vascular disease. However, the evidence is not entirely positive: Gazizov et al. [17] have proposed that other symptoms might be even more important in other groups of retinal-detachment patients.
Several comments containing added context to the mechanics, or methodology are present. Song et al [47] reviewed age related changes in fusion and suppression and observed changes in stereoacuity development, Tang et al [48] observed binocular variation in different types of anisometropia and Lin et al [63] examined perceptual learning and binocular rebalancing in adult amblyopia. Xu et al. [69] also showed that there is quantitative correlation between unilateral metamorphopsia and stereoacuity; and Chen et al. [70] demonstrated that stereoacuity dynamic stereopsis may still be affected in anisometropic amblyopes after amblyopic therapy. These findings indicate that stereopsis can be considered as a multi-faceted phenomenon and not all necessarily reflect a single stereo acuity measurement.
Evidence from developmental populations [79,91,93] should only be interpreted with caution, but show mechanistic evidence that visual input influences visual-motor and cognitive development, which were outside the main focus of the adults in this review. The biology-based idea of individual variability in stereoscopic performance was also supported by Oishi et al. [94] via presenting neuroanatomical data for the spread in stereo acuities.

4.4 Clinical Implications
The results advocate for the use of binocular visual assessment as a component of the optometric evaluation and/or LV assessment especially if the comments are not commensurate with the point of visual acuity assessment. Ideally, stereo acuity should be interpreted in conjunction with acuity, contrast sensitivity, ocular alignment, fusion, visual fields and eye-movement function; and not in isolation alone [47,68,81,97].
A functional assessment might be especially indicated with rehabilitation. As used by ADL, performance-based assessment for age-related macular degeneration (AMD) has been built, and structured functional-vision and VR-based assessment might include components of everyday experience that can't be simply gleaned from basic clinical assessment [83,87]. Taking note of visual and functional limitations also may be important in a group setting for adults with vision problems to exercise and rehabilitate [42].
In this way, clinical assessment could also gradually be redirected towards the individual rehabilitation plan, to find out whether impaired stereopsis will give an impact on certain patients' activities. If the patient is working at or currently involved in an occupation or activity of daily living that relies on visualization and/or fine motor manipulative skills and/or navigation (such as driving), this may be more important. Work participation itself has several influencing factors according to Daniëls et al. [88] that relate to visual and/or visual-contextual aspects.

4.5 Strengths and Limitations
One of the most major strengths of this review is the use of a list of functional outcomes, encompassing visuomotor performance, reading, mobility, ADLs, cognition and participation and quality of life. Additionally, direct stereopsis research studies and other reports concerning the more general binocular- and visual-function mechanisms were examined.
There are a couple of things to bear in mind, however, There was heterodoxism of population, visual disorder, stereopsis assessment and functional outcome of the evidence base. Secondly, many of the studies were cross sectional and it is hard to draw causal conclusions. Third, a small number of papers examined combined results on binocular fixation, rather than just on stereopsis. Fourth, the number of patients in some of the studies was low, or simulated visual impairment to restrict the direct transferability to the wide variety of low-vision patients.
The heterogeneity of measurements is an important aspect. Other methods of assessing stereopsis are still being developed and validated, such as those shown by Wiegand et al. [97] and Han et al. [81] and conventional clinical tests may not adequately measure stereopsis in the dynamic or real-world situation. In the same way, Zhi et al. [98] demonstrated the effectiveness of the combination of various VF types to better comprehend a single parameter.
Finally, some of the supporting references were in a paediatric population, notably Choi, et al. [79] and Johansson, et al. [91] and do not necessarily apply to the population that they reviewed (adults). Likewise, contextual evidence for functional consequences of correcting visual impairment has been provided only by Gogate et al. [99] and evidence relating the visual impairment to more general health consequences in PD has

been provided by Hamedani et al. [100]. While these studies confirm the general functional theory, they don't offer a relationship specific to stereopsis.
Overall, evidence supports the idea that stereopsis in adults is not without importance for functional use of vision and apparent evidence exists for the potential strongest roles of stereopsis in visuomotor coordination, spatial function, mobility, and for vision-related QOL. However, its role is context dependent, and needs to be understood in a context of the whole multi dimensional puzzle of functional vision.

5. Conclusion

This systematic review emphasizes stereopsis plays a crucial role in visually impaired adult functional vision and may be correlated with diminished functioning in some functional areas. A reduction in stereopsis might relate to playing a role in depth perception, visio-motor coordination, fine motor function, spatial tracking, mobility, balance and vision related quality of life. But the relationship is complex and stereopsis can't be responsible on its own for the relationship.
The evidence reviewed also emphasizes the caveats to using only visual acuity and/or visual-field with respect to the characterization of functional vision. Information on higher order visual processes including binocular function, contrast sensitivity, ocular alignment, or fusion might provide clinically useful information that could be obtained on the functional level. Significantly, however, there is variability in how stereopsis and functional outcome are being evaluated, and many studies to date are cross sectional studies with small patient numbers and may therefore not be used to draw causal conclusions regarding stereopsis and functional outcome.
Future studies should thus use standard stereopsis measurements, in addition to performance measures of mobility, fine motor skills, activities of daily living and reading. Intervention and longitudinal studies are especially warranted to ascertain if interventions designed to improve stereopsis result in significant changes in real world function. Stereopsis is important to be seen in an assessment/rehabilitation from a multi-dimensional perspective.

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