Acta Ophthalmologica

ACTA OPHTHALMOLOGICA 2022

Review Article

Visual system and motor development in children: a systematic review

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ABSTRACT.

Purpose.
The aim of this study was to review the available scientific literature on the possible relationship between the visual system and motor development in children.
Methods.
This study was performed according to the Preferred Reporting Items for Systematic Reviews (PRISMA) statement recommendations. The review protocol is available in PROSPERO (CRD42021245341). Four different databases, namely Scopus, PubMed, CINAHL and Web of Science, were assessed from April 2005 to February 2021. To determine the quality of the articles, we used the Critical Appraisal Skills Programme (CASP) Quality Appraisal Scale, and a protocol was followed to define the levels of evidence on the basis of the Centre for Evidence-Based Medicine Levels of Evidence. The search strategy included terms describing motor development in children and adolescents with visual disorders.
Results.
Among the identified studies, 23 were included in the study. All selected articles examined the relationship between the visual system and development in children. The quality of most of the studies was moderate–high, and they were between evidence levels 2 and 4.
Conclusions.
Our systematic review revealed that all included studies established a relationship between the visual system and development in children. However, the methods for measuring the visual system and motor skills lacked uniformity.

Key words: amblyopia – child development – motor skills – ocular motility disorders – visual disorders

Acta Ophthalmol. 2022: 100: e1356–e1369

doi: 10.1111/aos.15111

Introduction

Infant motor development includes the acquisition of basic skills, such as moving the head and eyes to look around, moving the arms and hands to grasp objects and moving the body to sit or go somewhere. It also includes higher-order skills, such as wielding a hammer to hit a peg and stacking boxes to reach a high object. The opportunities for motor action depend on the current state of the body; therefore, the systems involved must remain in the correct state (Adolph & Hoch 2019). In all these cases, vision plays a fundamental role in the correct acquisition of skills.

Normal visual development begins at birth and continues throughout childhood. It involves changes in visual acuity, convergence and accommodation until adequate binocular vision and stereopsis are achieved (Zimmermann et al. 2019). Binocular vision provides the visual information required to accurately perceive depth (stereopsis). In this way, the child will be able to adequately execute the movements of the upper and lower extremities (Goodale 2011; Chapman et al. 2012).

When a child suffers from visual disturbance, an alteration in motor development normally occurs. Vagge et al. (2021) reported that the presence of binocular dysfunction may be one of the factors that contribute to alterations in the development of a child. Other authors reported that the surgical correction of strabismus in a group of children led to the partial recovery of binocular vision and improved hand–eye coordination skills (Caputo et al. 2007). Zipori et al. (2018) stated that the proper development of the visual system is crucial for the development of correct balance. They showed that postural instability was greater in a group of children with amblyopia and strabismus than in children with normal vision.

In addition, several studies show that children with amblyopia experience a deterioration of motor skills (Engel-Yeger 2008; Suttle et al. 2011; Webber et al. 2016; Birch et al. 2019a, 2019b). In general, these children have slower and less controlled movements than children with normal vision. Amblyopia is associated with longer saccades that decrease reading speed (Birch et al. 2019a, 2019b). Webber et al. (2016) reported that 5 weeks of treatment with visual therapy improved the fine motor skills of a group of children with amblyopia.

Other authors have established a relationship between the presence of refractive error and motor development. Atkinson et al. (2005) showed that the motor performance of hyperopic children aged between 3 and 6 years was significantly worse than that of emmetropic children of the same age. Children with hyperopia had deficits in manual dexterity, ball skills and balance.

The close relationship between visual and motor development is a topic of interest in the scientific community, although there is a lack of homogeneity, probably due to its multidisciplinary nature. Therefore, there is a need to conduct a systematic review to study the accumulated evidence.

The objective of this systematic review was to establish a relationship between visual and motor development in children. Additionally, we analysed the risk of bias assessment and publication certainty in all included studies.

Method

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al. 2009; Moher et al. 2009). The PRISMA statement has been designed for systematic reviews of studies that evaluate the effects of health interventions, irrespective of the design of the included studies. However, the checklist items are applicable to reports of systematic reviews evaluating other non-health-related interventions and many items are applicable to systematic reviews with objectives other than evaluating interventions (evaluating aetiology, prevalence, prognosis *etc*.). It includes a checklist to guide the reporting of systematic reviews (Page et al. 2021).

The revision was registered in PROSPERO (Registration No. CRD42021245341). For the interpretation of all results, $p \leq 0.05$ was considered statistically significant.

Search strategy

A systematic literature search was performed using the following databases: PubMed/MEDLINE (502 articles), Web of Science (27 articles), CINAHL (479 articles) and Scopus (27 articles).

The search strategy included terms describing a child's developmental stage (toddlers OR children OR Infant [Medical Subject Headings, MeSH]), terms describing motor development ("motor development" OR "motor function" OR "early motor development" OR "motor outcomes" OR "motor system" OR "motor coordination" OR "coordination skills" OR "motor skills") and terms describing visual development ("visual disorders" OR vision OR exophoria OR vergence OR exotropia OR esotropia OR heterophoria OR "ocular motility disorders" OR amblyopia OR stereoacuity OR "visual function" OR binocular OR accommodation OR accommodative OR "vertical deviation" OR "vertical disorder" OR "vertical anomalies" OR "vertical anomaly" OR "hyperdeviation" OR "strabismus" OR "eye movements" OR "visual complaints" OR "visual deterioration" OR phoria "visual development" OR stereovision OR "visual Skills" OR stereoacuity OR "Refractive errors" OR "visual acuity"). The search was updated from January to June 2021.

Inclusion criteria

Studies evaluating motor development in children with visual disorders were included. This evaluation had to be applied to children and adolescents with hyperopia, amblyopia and strabismus. The inclusion criteria were (1) studies with humans; (2) case reports; (3) case series, (4) cohort, cross-sectional and case–control studies and (5) randomized clinical trials.

Exclusion criteria

Articles were excluded if: (1) they did not report data on motor or visual development; (2) the patients included were adults; (3) the patients had undergone eye surgery; (4) the patients had any motor developmental disorder or were blind; (5) the article was a letter, conference abstract, study protocol or literary review; or (6) the article was not available in English or Spanish.

If full-text reading led to the conclusion that the article did not analyse motor and visual development in typically developing healthy children and adolescents, the article was excluded.

Quality of articles, levels of evidence and data extraction

Article grading and data extraction were independently performed by two authors: MCSG and EPP. To determine the quality of the articles, two reviewers with adequate reliability (EPP and MCSG) worked independently and blindly to create a summary table (Table 1) on the basis of the Critical Appraisal Skills Programme (CASP) Quality Appraisal Scale ('CASP CHECKLISTS – CASP – Critical Appraisal Skills Programme' n.d.). CASP is a tool that analyses the quality of the articles selected in a systematic review, and it also ensures sufficient representation of the items in case–control, cohort, randomized controlled trials, as well as in cross-sectional studies. Some of the elements analysed are as follows: theoretical basis for the study; appropriate methodological design; hiring information; description and representativeness of the participants; robustness of the research, including control or risk of bias; sufficiently appropriate and rigorous data analysis (including qualitative analysis, where appropriate); control of confounding factors; and clear discussion of the implications of the findings.

If the quality of the included articles was considered sufficient, a protocol was followed to define the levels of evidence on the basis of the Centre for Evidence-Based Medicine (CEBM) Levels of Evidence ('OCEBM Levels

Table 1. Quality appraisal of articles.

Author and date	Yes/total
Engel-Yeger (2008)	7/11
Webber et al. (2008)	8/11
Suttle et al. (2011)	7/11
Niechwiej-Szwedo et al. (2017)	6/11
Kelly et al. (2020)	7/11
Atkinson et al. (2005)	9/12
O'Connor et al. (2010)	8/12
Wilson and Welch (2013)	5/12
Alramis et al. (2016)	5/12
Chakraborty et al. (2017)	10/12
Fang et al. (2017)	7/12
Thompson et al. (2017)	9/12
Zipori et al. (2018)	6/12
Birch et al. (2019a)	9/12
Birch et al. (2019b)	9/12
Birch et al. (2020)	5/12
Hemptinne et al. (2020)	8/12
Niechwiej-Szwedo et al. (2020a)	9/12
Niechwiej-Szwedo et al. (2020b)	9/12
Pinero-Pinto et al. (2020)	8/12
Sá et al. (2021)	6/12
Vagge et al. (2021)	7/12
Webber et al. (2016)	7/11

Critical Appraisal Skills Programme (CASP) Quality Appraisal Scale.

of Evidence – Centre for Evidence-Based Medicine (CEBM), University of Oxford' n.d.). The CEBM levels of evidence were produced to enable the process of finding appropriate evidence and making its results explicit.

Any disagreements between the two reviewers were solved by a third unblinded reviewer (RPC). This analysis did not discard any articles. The main summary measures used in this systematic review were measures of visual development and assessment of motor development in all the included studies.

The quality of the included articles was classified into 3 outcome levels of equal measure: low (yes = 0–3), moderate (yes = 4–7) and high (yes = 8–12) for observational cohorts and cross-sectional studies, and low (yes = 0–3), moderate (yes = 4–7) and high (yes = 8–11) for case–control studies and controlled intervention studies. On the basis of this classification, we found that all case–control studies (Engel-Yeger 2008; Webber et al. 2008; Suttle et al. 2011; Niechwiej-Szwedo et al. 2017; Kelly et al. 2020) were of moderate–high quality and that the single controlled intervention study (Webber et al. 2016) was of moderate quality. Regarding the cohort and cross-sectional studies, we found seven studies (Wilson & Welch 2013; Alramis et al. 2016; Fang et al. 2017; Zipori et al. 2018; Birch et al. 2020; Sá et al. 2021; Vagge et al. 2021) with high quality, and the remaining 10 (Atkinson et al. 2005; O'Connor et al. 2010; Chakraborty et al. 2017; Thompson et al. 2017; Birch et al. 2019a, 2019b; Hemptinne et al. 2020; Niechwiej-Szwedo et al. 2020a, 2020b; Pinero-Pinto et al. 2020) had moderate quality.

On the basis of the classification of the Oxford CEBM Levels of Evidence ('OCEBM Levels of Evidence – Centre for Evidence-Based Medicine (CEBM), University of Oxford' n.d.), we obtained 12 articles (O'Connor et al. 2010; Alramis et al. 2016; Webber et al. 2016; Chakraborty et al. 2017; Fang et al. 2017; Zipori et al. 2018; Birch et al. 2019a, 2019b; Birch et al. 2020; Pinero-Pinto et al. 2020; Sá et al. 2021; Vagge et al. 2021) from level 2, six articles (Atkinson et al. 2005; Wilson & Welch 2013; Thompson et al. 2017; Hemptinne et al. 2020; Niechwiej-Szwedo et al. 2020a, 2020b) from level 3 and five articles (Engel-Yeger 2008; Webber et al. 2008; Suttle et al. 2011; Niechwiej-Szwedo et al. 2017; Kelly et al. 2020) from level 4.

Table 1 shows the representation of the agreed-upon ratings for the CASP Quality Appraisal Scale.

Results

A total of 1035 articles were identified. After removing duplicates, 865 articles were subjected to title and abstract reading by two authors, excluding 745 articles. If there was a conflict with the selection of an article, the third author decided the outcome. The full texts of the 120 articles were read, and 97 were excluded based on the exclusion criteria. A total of 23 articles were finally included in the review.

Figure S1 shows the Preferred Reporting Items for the Systematic Reviews and Meta-Analysis Flow Chart.

Characteristics of the studies

A total of 3980 children aged 2–18 years were evaluated for visual and motor development.

The systematic review suggests that there is a relationship between the visual system and motor development. Among all the reviewed articles, 9 articles established a relationship between amblyopia and fine and gross motor skills (Engel-Yeger 2008; Webber et al. 2008; Suttle et al. 2011; Wilson & Welch 2013; Birch et al. 2019a, 2019b; Birch et al. 2020; Kelly et al. 2020; Sá et al. 2021), 10 articles associated binocular vision and motor development (O'Connor et al. 2010; Alramis et al. 2016; Chakraborty et al. 2017; Niechwiej-Szwedo et al. 2017; Thompson et al. 2017; Zipori et al. 2018; Hemptinne et al. 2020; Niechwiej-Szwedo et al. 2020a, 2020b; Pinero-Pinto et al. 2020; Vagge et al. 2021), 1 article associated the presence of hyperopia and the impairment of manual dexterity and balance (Atkinson et al. 2005), 1 article described how visual perception and motor coordination change in preschool children (Fang et al. 2017), and 1 article studied the state of binocular vision and the accommodative system in children with typical motor development (Niechwiej-Szwedo et al. 2020a, 2020b).

The only intervention study included in the review, Webber et al. (2016), describes the efficacy of a visual therapy treatment for 5 weeks in a group of children with amblyopia. In this research, they trained binocular vision skills by using an iPod game. Fine motor skills improved in all children, and the results were maintained over time.

Regarding the motor development assessment tests, five studies (Atkinson et al. 2005; Engel-Yeger 2008; Chakraborty et al. 2017; Kelly et al. 2020; Sá et al. 2021) used the Movement Assessment Battery for Children (MABC), and three studies (Webber et al. 2008; Webber et al. 2016; Zipori et al. 2018) used the Bruininks–Oseretsky Test of Motor Proficiency. Three studies (O'Connor et al. 2010; Suttle et al. 2011; Niechwiej-Szwedo et al. 2020a, 2020b) used tests that were specifically designed for the study, and seven studies (Wilson & Welch 2013; Alramis et al. 2016; Niechwiej-Szwedo et al. 2017; Birch et al. 2019a, 2019b; Birch et al. 2020; Hemptinne et al. 2020; Niechwiej-Szwedo et al. 2020a, 2020b) did not report the test they used or did not provide data. Regarding the remaining four studies (Fang et al. 2017; Thompson et al. 2017; Pinero-Pinto et al. 2020; Vagge et al. 2021), each study used a different test that has not been used in any other study.

Among all the articles, four articles reported data on gross motor development (Atkinson et al. 2005; Engel-Yeger 2008; Webber et al. 2008; Zipori et al. 2018), another four reported on fine motor development (O'Connor et al. 2010; Suttle et al. 2011; Webber et al. 2016; Fang et al. 2017), seven articles analysed fine and coarse motor development (Chakraborty et al. 2017; Thompson et al. 2017; Kelly et al. 2020; Niechwiej-Szwedo et al. 2020a, 2020b; Pinero-Pinto et al. 2020; Sá et al. 2021; Vagge et al. 2021), and eight did not report data on motor development (Wilson & Welch 2013; Alramis et al. 2016; Niechwiej-Szwedo et al. 2017; Birch et al. 2019a, 2019b; Birch et al. 2020; Hemptinne et al. 2020; Niechwiej-Szwedo et al. 2020a, 2020b).

Table 2 provides the study characteristics of all included articles.

The results of each study were classified by vision outcomes (Table 3) and motor outcomes (Table 4).

Discussion

The prevalence of visual dysfunction in the paediatric population has increased significantly in recent years (Cacho-Martínez et al. 2010; Jang & Park 2015; Hussaindeen et al. 2017). An early diagnosis of visual abilities in children is necessary to prevent the appearance of possible non-strabismic binocular and accommodative alterations that could affect motor development and quality of life. There are several symptoms and

Table 2. Studies characteristics.

Autor (date)	Design	Conflict of interest	Follow-up (months)	*n* (subjects)	Sex (F/M)	Age
Atkinson et al. (2005)	OC	NR	24	HG 1st: 110; 2nd: 99 CG 1st: 131; 2nd:113	HG 1st: 63/47; 2nd:56/43 CG 1st: 70/61; 2nd: 62/51	1st: 3 years, 7 ± 1.6MM 2nd: 5 years, 6 ± 1.7MM
Engel-Yeger (2008)	CC	NR	No	AG: 22 CG: 25	AG: 11/11 CG: 13/12	AG: 5.65 ± 0.91 years CG: 5.53 ± 0.71 years
Webber et al. (2008)	CC	NR	No	AG: 82 CG: 37	AG: 45/37 CG: 18/19	AG: 8.2 ± 1.7 years CG: 8.3 ± 1.3 years
O'Connor et al. (2010)	CS	NR	No	SG: 121	SG: 91/30	18.8 years (12–28)
Suttle et al. (2011)	CC	NR	No	AG: 21 CG: 47	Not described	AG: 4–8 years CG: 4–8 years; 20–42 years
Wilson and Welch (2013)	OC	No	No	AG: 1032	AG: 493/539	3–32 years
Alramis et al. (2016)	CS	NR	No	52 Children 19 Adults	Children: 30/22 Adults: 10/9	Children: 5–13 years Adults: 18–38 years
Webber et al. (2016)	CI	NR	5 weeks 17 weeks	AG: 20 CG: 10	AG: 11/9 CG: 4/6	AG: 8.5 ± 1.3 years CG: 9.63 ± 1.6 years
Chakraborty et al. (2017)	CS	NR	No	606	287/319	4.5 years
Fang et al. (2017)	CS	No	No	151	70/81	4–6 years
Niechwiej-Szwedo et al. (2017)	CC	NR	No	SG: 19 CG: 19	SG: 10/10 CG: 10/100	SG: 8.68 ± 1.89 years CG: 8.68 ± 1.89 years
Thompson et al. (2017)	OC	No	24	375	177/198	24 months (23–25)
Zipori et al. (2018)	CS	No	No	AG: 18 SG: 16 CG: 22	AG: 10/8 SG: 6/10 CG: 12/10	AG: 8.5 ± 2.0 years SG: 10.9 ± 3.6 years CG: 10.6 ± 3.2
Birch et al. (2019a)	CS	NR	17	AG: 50 NAG: 13 CG: 18	AG: 31/19 NAG: 7/6 CG: 10/8	AG: 10.6 ± 1.3 years NAG: 10.7 ± 1.2 years CG: 10.6 ± 1.4 years
Birch et al. (2019b)	CS	Yes	28	AG: 60 NAG: 30 CG: 20	AG: 28/32 NAG: 16/14 CG: 11/9	AG: 6.3 ± 1.3 years NAG: 5.9 ± 1.3 years CG: 6.1 ± 1.1 years
Birch et al. (2020)	CS	NR	No	AG: 15 CG: 20	AG: 5/10 CG: 8/12	AG: 4.6 ± 1.0 years CG: 5.0 ± 1.0 years
Hemptinne et al. (2020)	OC	NR	No	SG: 40 CG: 18	SG: 19/21 CG: 6/12	SG: 7.25 ± 3.83 years CG: 8.33 ± 5.42 years
Kelly et al. (2020)	CC	No	No	AG: 96 NAG: 47 CG: 35	AG: 43/53 NAG: 22/25 CG: 18/17	AG: 8.2 ± 2.5 years NAG: 7.0 ± 2.6 years CG: 8.3 ± 2.8 years
Niechwiej-Szwedo et al. (2020a)	OC	No	No	57	31/26	F: 10.63 ± 1.93 years M: 10.74 ± 2.03 years
Niechwiej-Szwedo et al. (2020b)	OC	NR	No	226	110/116	F: 9.21 ± 2.58 years M: 9.70 ± 2.56 years
Pinero-Pinto et al. (2020)	CS	No	No	116	63/53	29.57 ± 3.45 months
Sá et al. (2021)	CS	No	No	NAG: 97 CAG: 37 NCAG: 31	NAG: 46/51 CAG: 22/15 NCAG: 20/11	NAG: 7.6 ± 1.2 years CAG: 7.6 ± 1.2 years NCAG: 6.9 ± 1.0 years
Vagge et al. (2021)	CS	No	No	SG: 23 CG: 24	SG: 9/14 CG: 10/14	SG: 7.5 ± 2.0 years CG: 7.2 ± 1.7 years

AG = amblyopic group, CAG = corrected-amblyopic group, CC = case–control study, CG = control group, CI = controlled Intervention study, CS = cross-sectional study, F/M = female/male, HG = hyperopic group, NAG = non-amblyopia group, NCAG = non-corrected-amblyopic group, NR = not reported, OC = observational cohort study, SG = strabismus group.

Table 3. Vision outcomes.

Author et al. (year)	Vision measures			
Atkinson et al. (2005)	**Refraction greatest axis D, mean (SD)**		**Hyperopic group**	3 years, 7 months: +5.33 (1.48) 5 years, 6 months: +5.30 (1.49)
Engel-Yeger (2008)	Not described			
Webber et al. (2008)	**Vision assessment**		**Amblyopia group (n = 82)**	
	Stereopsis sec arc	Nil	50 (61)	
		800–60	27 (33)	
		≤40	5 (6)	
	Interocular difference VA (logMAR)		0.31 (0.06)	
	VA better eye (logMAR)		0.10 (0.01)	
	VA worse eye (logMAR)		0.38 (0.05)	
	Refractive error (D)		2.30 (0.25)	
O'Connor et al. (2010)	**Vision assessment**		**Strabismus group**	
	VA		of the poorer seeing eye ranged from 0.2 to 1.6 logMAR of the fellow eyes from 0.24 to 0.30 logMAR	
	Worth 4 dot test		Fusion (n = 99) (a response of four lights) Suppression (n = 16) (a response of two or three lights)	
	4 (D) base-out test		Bifoveal (n = 94) (Vergence movement of eye not under prism following conjugate version movements by both eyes) Central suppression (n = 6) (no vergence movement)	
	Motor fusion		Prism bar Normal (n = 101) Reduced (n = 7) Nil (n = 13)	Risley prism Normal (n = 84) Reduced (n = 17) Nil (n = 14)
	Positive vergence (convergence)		Normal (n = 97) Reduced (n = 9) Nil (n = 15)	Normal (n = 61) Reduced (n = 41) Nil (n = 14)
Suttle et al. (2011)	**Vision assessment**		**Group normal child**	**Amblyopic children**
	VA, binocular (logMar) Mean (SD)		Early = 0.01 (0.05) Middle = – 0.02 (0.07) Late = – 0.06 (0.06)	–
	VA, dom eye (logMar) Mean (SD)		Early = 0.06 (0.07) Middle = 0.04 (0.08) Late = 0.01 (0.08)	–
	VA, non-dom eye (logMar) Mean (SD)		Early = 0.08 (0.06) Middle = 0.02 (0.07) Late = 0.03 (0.08)	–
	Interocular difference (IOD) Mean (SD)		Early = 0.05 (0.04) Middle = 0.04 (0.04) Late = 0.04 (0.03)	Mild amblyopia (IOD = 0.11–0.3) Moderate-to-severe amblyopia (IOD ≥0.31)
	Stereo acuity crossed (arc sec) Mean (SD)		Early = 45 (13) Middle = 44 (24) Late = 51 (15)	–
	Stereo acuity uncrossed (arc sec) Mean (SD)		Early = 57 (21) Middle = 63 (28) Late = 50 (19)	–
	Stereo acuity (arc sec) Mean (SD)		–	Mild amblyopia and Moderate-to-severe amblyopia Coarse and negative

Wilson and Welch (2013)	**TNO best score (arc sec)**	**Amblyopia**	**Possible amblyopia**	**Recovered amblyopia**	**No amblyopia**
	Absent	6 (24%)	5 (20%)	1 (4%)	13 (52%)
	480	0 (0%)	3 (27%)	1 (9%)	7 (64%)
	240	2 (14%)	3 (22%)	0 (0%)	9 (64%)
	120	1 (4%)	6 (24%)	1 (4%)	17 (68%)
	60	5 (1%)	27 (6%)	6 (2%)	394 (91%)
	30	1 (<1%)	19 (6%)	2 (1%)	313 (93%)
	15	0 (0%)	0 (0%)	0 (0%)	33 (100%)
	Mean (SD)	2.1(0.05)	3.7(0.19)	3.5(0.47)	4.3(0.03)
Alramis et al. (2016)	**Vision assessment**	**Group child**			
	VA	Monocular RE ≥0.1 log MAR Monocular LE ≥0.1 log MAR Binocular ≥0.1 log MAR			
	Stereoacuity range (arc sec)	Young = 20–70 Middle = 20–70 Older = 20–30			
Webber et al. (2016)	**Vision assessment**	**Treated amblyopes**			
	VA worst eye (logMAR) Mean (±SD)	Baseline = 0.46 (0.16) 5 weeks (post-treatment) = 0.37 (0.16) 17 weeks (12 weeks after treatment ceased) = 0.36 (0.18)			
	VA both eyes (logMAR) Mean (±SD)	Baseline = −0.03 (0.09) 5 weeks (post-treatment) = −0.06 (0.09) 17 weeks (12 weeks After Treatment Ceased) = −0.03 (0.06)			
	BF score (log stereoacuity) Mean (±SD)	Baseline = 3.44 (1.27) 5 weeks (Post-treatment) = 2.88 (1.05) 17 weeks (12 weeks After Treatment Ceased) = 2.74 (1.06)			
Chakraborty et al. (2017)	**Vision assessment**	**Group child**			
	VA; *N* (%)	≤0.3 logMAR = 578 (95.37) >0.3 logMAR = 28 (4.62)			
	Stereoacuity; *N* (%) (arc sec)	<100 = 476 (78.54) >100–800 = 84 (13.86) >800 = 46 (7.59)			
Fang et al. (2017)	**Vision assessment**	**Group child**			
	Visual motor integration Mean (±SD)	4 years = 107.58 (10.98); Range = 83–141 5 years = 112.38 (10.99); Range = 95–138 6 years = 105.80 (10.46); Range = 90–138			
	Visual perception Mean (±SD)	4 years = 111.53 (16.10); Range = 67–144 5 years = 117.70 (11.45); Range = 92–146 6 years = 115.07 (8.94); Range = 92–146			
Niechwiej-Szwedo et al. (2017)	**Vision assessment**	**Group child**			
	VA (logMAR) distance/near (n = 19) (Mean ± SD)	−0.01 ± 0.02 (−0.10 to 0.00)/0.01 ± 0.02 (0.00–0.10) Snellen range: 20/15–20/25			
	Stereopsis (sec of arc) (n = 19) (Mean ± SD) [range]	28 ± 10 (20–50)			
	Positive fusional vergence (BO) Near – break/recovery (n = 17) (Mean ± SD) [range]	27 ± 12 (12–45)/17 ± 8 (8–30)			
	Negative fusional vergence (BI) Near – break/recovery (n = 17) (Mean ± SD) [range]	12 ± 5 (6–20)/9 ± 5 (2–20)			
	Binocular accommodation facility (cpm) (n = 15) (Mean ± SD) [range]	8 ± 3 (3–11.5)			
	Monocular accommodation facility	8 ± 3 (3–13)/8 ± 3 (3–13)			

	RE and LE (cpm) (*n* = 16) (Mean ± SD) [range]			
	Amplitude of accommodation RE and LE (D) (*n* = 18) (Mean ± SD) [range]			12 ± 2 (8–16)/ 12 ± 2 (8–16)
Thompson et al. (2017)	**Vision assessment**	**Group child**		
	Binocular visual acuity (LogMAR) mean (SD) [range]	0.06 (0.15) [−0.20, 1.00]		
	Stereoacuity (sec of arc) mean (SD) [range]	366 (196) [200, 1200]		
	Vision impairment score, *n* (%)	*n* = 290 (77%) (normal) *n* = 69 (18%) (internal or external ocular health problem or strabismus or abnormal motility or absence of stereopsis or binocular visual acuity worse than 0.5 logMAR) *n* = 16 (4%) (two or more visual dysfunctions)		
	Refractive error score, *n* (%)	*n* = 177 (90.5%) (normal) *n* = 17 (9%) (Hyperopia (mean sphere [M] ≥ +4.00 diopter [D])) or myopia (M ≤ −1.00 D) or astigmatism (cylinder [C] ≤ −1.50 D in any meridian) or anisometropia (difference in M between eyes of ≥3.00 D in either the most positive or negative meridian) *n* = 1 (0.5%) (two or more refractive errors)		
Zipori et al. (2018)	**Vision assessment**	**Unilateral amblyopia**	**Strabismus without amblyopia**	
	VA (logMAR)	BCVA between (0.3 logMAR) and (1.3 logMAR) in the amblyopic eye VA of (0.1 logMAR) or better in the non-amblyopic eye	Normal VA in both eyes	
	Strabismus	–	Esotropia (*n* = 9) Exotropia (*n* = 7)	
	Stereoacuity (arcsecond)	3000 (*n* = 2) 140 (*n* = 1)	3000 (*n* = 10) 20–60 (*n* = 8)	
Birch et al. (2019a)	**Vision assessment**	**Group child**		
	VA (logMAR)	**With amblyopia**	**Without amblyopia**	
	≤0.1	0 (0%)	0 (0%)	
	0.2–0.3	30 (60%)	0 (0%)	
	0.4–0.5	12 (24%)	0 (0%)	
	0.6–0.7	4 (8%)	0 (0%)	
	>0.7	4 (8%)	0 (0%)	
	Mean (SD); (range)	0.41 (0.33); (0.2–1.9)	−0.01 (0.03); (−0.1 to 0.1)	
	Fellow eye visual acuity (logMAR)	**With amblyopia**	**Without amblyopia**	
	−0.1	34 (68%)	7 (50%)	
	0.0	13 (26%)	5 (43%)	
	0.1	3 (6%)	1 (7%)	
	Mean (SD); (range)	−0.06 (0.06); (−0.1 to 0.1)	0.00 (0.02); (−0.1 to 0.1)	
	Stereoacuity (log arcsec). Median (range) (Nil stereoacuity was assigned a value of 4.0 log arc per second)	**With amblyopia** 4.00 (1.6-nil)	**Without amblyopia** 2.30 (1.6-nil)	
	Vision assessment	**Group child**		

Birch et al. (2019b)	**VA (logMAR)**	**With Amblyopia**	**Without Amblyopia**
	≤0.1	0 (0%)	30 (100%)
	0.2–0.3	22 (37%)	0 (0%)
	0.4–0.5	21 (35%)	0 (0%)
	0.6–0.7	5 (8%)	0 (0%)
	>0.7	12 (20%)	0 (0%)
	Mean (SD); (Range)	0.49 (0.27; [0.2–1.4]	0.04 (0.07); [−0.1 to 0.2]
	Fellow eye visual acuity (logMAR)	**With amblyopia**	**Without amblyopia**
	−0.1 (20/16)	12 (20%)	5 (17%)
	0.0 (20/20)	27 (45%)	18 (60%)
	0.1 (20/25)	21 (35%)	7 (23%)
	Mean (SD) [range]	0.01 (0.07); [−0.1 to 0.1]	0.01 (0.06); [−0.1 to 0.1
	Snellen equivalent	20/20; [20/16–20/25]	20/20; [20/16–20/25]
	Stereoacuity (log arcsec). Median (range) (Nil stereoacuity was assigned a value of 4.0 log arc per second)	3.75 (0.58); [1.8 to nil]	3.33 (0.83); [1.8 to nil]
Birch et al. (2020)	**Vision assessment**	**Amblyopia group**	
	VA (logMAR)		
	Amblyopic eye BCVA	0.4–2.0; (20/50–2000)	
	Mean (SD) [range]		
	Fellow eye visual acuity	−0.1 to 0.2; (20/15–30)	
	Mean (SD) [range]		
	VA in each eye	–	
	Stereoacuity (arcsecond)	Nil	
Hemptinne et al. (2020)	**Vision assessment**	**Strabismus group**	
	Strabismus type	Infantile esotropia (n = 13), secondary esotropia (n = 6), acquired esotropia (n = 21)	
	Binocularity degree	Absent (n = 21), partial (n = 13), normal (n = 6)	
	Deviation angle, corrected	0Δ–12Δ (n = 29), 12Δ–20Δ (n = 5), ≥20Δ (n = 6)	
	Distance VA (logMAR)	RE	LE
		Nihil (n = 2)	Nihil (n = 1)
		Hand motions (n = 1)	Hand motions (n = 1)
		0.0 (n = 22)	0.0 (n = 25)
		0.1 (n = 7)	0.1(n = 1)
		0.2 (n = 4)	0.2 (n = 6)
		0.3 (n = 3)	0.3 (n = 1)
		0.4 (n = 0)	0.4 (n = 3)
		0.5 (n = 1)	0.5 (n = 2)
Kelly et al. (2020)	**Visión assessment**	**Amblyopic**	**Non-amblyopic**
	BCVA (logMAR) (amblyopic eye)	0.4 ± 0.3	0.1 ± 0.1
		0.1–1.9	−0.1 to 0.3
	Mean ± SD; range		
	BCVA (logMAR)	0.0 ± 0.1	0.1 ± 0.1
	(fellow eye)	−0.1 to 0.2	−0.1 to 0.3
	Mean ± SD; range		
	Stereoacuity (arcsecond)	3.4 ± 0.8	3.1 ± 1.0
	Mean ± SD; range	(1.8–4)	(1.6–4)
	Extent of suppression (log deg)	0.4 ± 0.4	0.3 ± 0.6
	Mean ± SD; range	(−0.2 to 1.2)	(−0.2 to 1.2)
	Depth of suppression (CBI)	4.8 ± 3.6	3.0 ± 2.9
	Mean ± SD; range	(0.2–11.0)	(0.2–11.0)
Niechwiej-Szwedo et al. (2020a)	**Vision assessment**	**Typically developing children. Mean ± SD (range)**	
	Visual acuity (logMAR) distance/near	−0.02 ± 0.07 (−0.10–0.18)/ 0.01 ± 0.03 (0.00–0.18)	
		Snellen range: 20/15–20/25	
	Stereopsis (secof arc)	24 ± 7 (20–50)	
	Phoria (PD) distance/near	24 ± 10 (8–45)/18 ± 11 (2–45)	
	Negative fusional vergence (BI, divergence) near – break/ recovery (PD)	14 ± 4 (4–25)/11 ± 4 (4–20)	
	Vergence facility (cpm)	14 ± 4 (5–24)	

	Binocular accommodative facility (cpm)	8 ± 3 (0.5–14.5)	
	Amplitude of accommodation–RE and LE (D)	11 ± 2 (7–16)/11 ± 2 (6–16)	
	Accuracy of accommodation (MEM)–RE and LE (D)	1.06 ± 0.40 (0.25–2.00)/ 21.06 ± 0.40 (0.25–2.00)	
Niechwiej-Szwedo et al. (2020b)	**Vision assessment**	**Typically developing children. Mean ± SD (range)**	
	Binocular visual acuity (logMAR) distance	0.00 ± 0.11 (−0.2 to 0)	
	Monocular visual acuity (logMAR) distance	0.04 ± 0.12 (−0.1 to 0)	
	Interocular visual acuity difference (logMAR)	0.06 ± (0.10) (0.0–0.6)	
	stereoacuity (sec of arc)	45 ± 27 (20–200)	
Pinero-Pinto et al. (2020)	**Visual development parameter**	**Gross motor quotient < 100**	**Gross motor quotient > 100**
	Visual acuity (CardiffTest—LogMAR) (RE)/(LE)	0.18 ± 0.10/0.18 ± 0.10	0.18 ± 0.10/0.18 ± 0.09
	Visual acuity (Broken Wheels—LogMAR) (RE)/(LE)	0.36 ± 0.05/0.36 ± 0.04	0.37 ± 0.04/0.37 ± 0.04
	Retinoscopy refraction (Diopters D) (RE)/(LE)	+1.27 ± 0.91/+1.35 ± 0.92	+1.35 ± 0.73/+1.49 ± 0.74
	Spherical equivalent refraction		
	Kappa angle (negative/0/positive) (RE)	4 (10%)/7 (17.5%)/29 (72.5%)	1 (1.3%)/28 (36.8%)/47 (61.8%)
	Kappa angle (negative/0/positive) (LE)	4 (10%)/8 (20%)/28 (70%)	2 (2.26%)/26 (34.3%)/48 (63.2%)
	Hirshberg reflex (temporal/centred/nasal) (RE)	3 (7.7%)/7 (17.95)/29 (74.4%)	1 (1.3%)/30 (39.5%)/45 (59.2%)
	Hirshberg reflex (temporal/centred/nasal) (LE)	3 (7.9%)/8 (21.1%)/27 (71.1%)	2 (2.6%)/30 (39.5%)/44 (57.9%)
	Krismky test (normal/deviated)	70 (87.5%)/10 (12.5%)	36 (100%)/0 (0%)
	Near point of convergence (centimetre, cm)	2.46 ± 4.07	1.00 ± 2.02
	Base-out 6ΔPrism Test (prism diopters, Δ) (negative/positive)	27 (33.8%)/53 (66.3%)	16 (44.4%)/20 (55.6%)
	Base-In 6ΔPrism Test (prism, diopters, Δ (negative/positive)	60 (75%)/20 (25%)	26 (72.2%)/10 (27.8%)
	Stereopsis lang test (second arc) (200″, 400″ y 600″)	303.89 ± 143.67	282.35 ± 131.35
	Bruckner test (normal/deviated)	71 (88.8%)/9 (11.3%)	36 (100%)/0 (0%)
	Fixation test (passed/not passed)	64 (80%)/16 (20%)	26 (72.2%)/10 (27.8%)
	Reflection and head (saccades movements)	46 (57.5%)/34 (42.5%)	21 (58.3%)/15 (41.0%)
	Head (saccades movements) (motionless/slight/ medium/strong)	12(15%)/33(41.3%) 24(30%)/11(13.85)	3(8.3%)/21(58.3%) 6(16.7%)/6(16.7)
Sá et al. (2021)	**Amblyopic group**		
	Visual acuity values <0.7 on the Snellen scale in one or both eyes or difference in vision between the eyes greater than two lines on that scale.		
Vagge et al. (2021)	**Vision assessment**	**Strabismus group**	
	Stereopsis	Normal (n = 11); absent (n = 12)	
	Amblyopia	n = 9	
	Non-amblyopia	n = 14	

BCVA = best-corrected visual acuity, BCVA = monocular best-corrected visual acuity, BF = binocular function, BI = base-in, BO = base-out, CBI = Contrast Balance Index, CPM = cycles per minute, D = diopters, Dom Eye = dominant eye, LE = left eye, Log deg = log degrees (Extent of suppression scotoma), MEM = monocular estimate method, Non-dom eye = nondominant eye, PD = prism diopter; Positive fusional vergence (BO, convergence) near – break/recovery (PD), RE = right eye, SD = standard deviation, Δ = prism diopter.

Table 4. Motor outcomes.

Author et al. (year)	Motor measures				
Atkinson et al. (2005)	Movement Assessment Battery for Children (MABC-2) Mean (SD)		**Hyperopic group**		
		Parameters	**Age 3 1/2 years**		**Age 5 1/2 years**
		Catch bean bag (bags caught)	6 (5.9)		8 (8.2)
		Roll ball (balls rolled into goal)	4 (3.9)		6 (6.4)
		Walk (steps walked)	5 (6.4)		13 (12.1)
		Jump score	0 (1.5)		0 (0.6)
		Balance (PL) (seconds balanced)	4 (4.3)		11 (9.5)
		Balance (NPL) (seconds balanced)	3 (4.5)		7 (7.9)
		Coin (PH) (seconds taken)	26 (26.3)		19 (19.8)
		Coin (NPH) (seconds taken)	28 (30.5)		22 (22.3)
		Beads: (6 beads) (seconds taken)	46 (49.2)		59 (63.0)
		Bicycle trail (errors made)	6 (7.0)		0 (0.6)
Engel-Yeger (2008)	Balance and ball skills sub-tests from the Movement Assessment Battery for Children (MABC-2) Mean ± SD				**Amblyopic group**
		Static balance	Standing on one leg		1.9 ± 1.99
		Dynamic balance	Jumping over cord		0.85 ± 1.76
			Walking heels raised		1.45 ± 1.81
		Mean dynamic balance score			1.15 ± 1.09
		Total mean balance score			1.4 ± 1.05
		Ball skills	Catch		1.9 ± 1.86
			Roll		1.04 ± 1.43
		Total mean ball skills score			1.47 ± 1.17
Webber et al. (2008)	**Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)**	**Amblyopic group**			
		Visual motor control		**Upper limb speed and dexterity**	
		Cutting circle	4 (0–4)	Pennies in box	4 (1–6)
		Drawing crooked path	4 (0–4)	Penny cards	9 (1–10)
		Drawing straight path	4 (0–4)	Sorting cards	3 (1–7)
		Drawing curved path	3 (0–4)	Stringing beads	2 (1–4)
		Copying circle	2 (0–2)	Displacing pegs	4 (2–7)
		Copying triangle	2 (0–2)	Drawing vertical lines	5 (0–8)
		Copying diamond	1 (0–2)	Dots in circles	4 (1–8)
		Copying pencils	2 (0–2)	Making dots	5 (1–9)
		Sum item 7	21 (6–24)	Sum item 8	37 (11–50)

O'Connor et al. (2010)	**Vision assessment**			**Pegboard**	**Bead task time (s)**		**Water task**	
				Mean ± SD	Mean ± SD		Mean ± SD	
					Large	Small	Error (ml)	Time (s)
	Worth 4 dot response	Worth 4 dot	Fusion	16.8 ± 1.6	49.2 ± 5.2	57.2 ± 7.9	1.1 ± 1.0	43.4 ± 10.7
			Suppression	15.2 ± 1.3	58.4 ± 7.0	72.3 ± 9.9	1.56 ± 1.09	46.1 ± 11.7
		4 D	Bifoveal	16.8 ± 1.5	48.9 ± 5.2	56.5 ± 7.4	1.1 ± 0.9	43.5 ± 10.7
			CS	15.3 ± 2.0	52.5 ± 3.8	66.7 ± 7.1	1.0 ± 0.6	48.0 ± 11.0
	Prism fusion range total amplitude	Prism bar	Normal	16.7 ± 1.6	49.4 ± 5.3	57.1 ± 7.6	1.1 ± 1.0	43.2 ± 10.6
			Reduced	17.0 ± 1.3	51.7 ± 9.9	66.4 ± 11.0	1.4 ± 0.5	44.1 ± 11.6
			Nil	15.0 ± 1.4	58.5 ± 5.7	72.2 ± 11.0	1.5 ± 1.2	47.2 ± 12.1
		Risley	Normal	16.6 ± 1.6	49.3 ± 5.4	58.1 ± 7.7	1.2 ± 0.9	42.3 ± 9.3
			Reduced	17.2 ± 1.6	49.8 ± 7.0	55.6 ± 9.8	0.9 ± 1.0	45.6 ± 14.5
			Nil	15.1 ± 1.4	58.1 ± 5.7	72.2 ± 10.5	1.5 ± 1.2	45.8 ± 12.8
	Prism fusion-adjusted positive vergence measure	Prism bar	Normal	16.7 ± 1.6	49.2 ± 5.2	57.0 ± 7.6	1.1 ± 1.0	42.7 ± 10.2
			Reduced	17.3 ± 1.5	49.8 ± 59.1	62.1 ± 10.6	1.0 ± 0.7	51.7 ± 11.4
			Nil	15.1 ± 1.4	59.1 ± 6.7	72.0 ± 10.2	1.5 ± 1.1	45.3 ± 12.5
		Risley	Normal	16.7 ± 1.6	49.3 ± 5.7	58.3 ± 8.4	1.4 ± 1.0	41.0 ± 9.4
			Reduced	16.7 ± 1.6	49.5 ± 5.8	56.8 ± 7.6	0.8 ± 0.7	45.8 ± 11.2
			Nil	15.1 ± 1.4	58.1 ± 5.7	72.2 ± 10.5	1.5 ± 1.2	45.8 ± 12.8

Suttle et al. (2011)	**Parameter**	**Amblyopic group**		
	Mean ± SD	Binocular	Dom eye	Non-don eye
	Movement time (ms)	1056 ± 66	1122 ± 45	1118 ± 52
	Reaching			
	Peak velocity, mm/s	579 ± 25	549 ± 28	537 ± 25
	Reach duration, ms	844 ± 52	877 ± 43	889 ± 46
	Time to peak dec, ms	511 ± 21	512 ± 26	512 ± 22
	Low velocity phase, ms	326 ± 47	355 ± 38	364 ± 42
	Grasping			
	Peak grip aperture, ms	73 ± 2	75 ± 2	75 ± 2
	Grip size contact, mm	51 ± 1	54 ± 1	57 ± 2

	Time to peak grip, ms	588 ± 38	603 ± 26	654 ± 34
	Grip closure time, ms	237 ± 20	251 ± 21	244 ± 28
	Grip application time, ms	174 ± 16	174 ± 16	185 ± 23
	Reach-grasp coupling			
	Peak dec-to-peak grip, ms	66 ± 25	88 ± 19	95 ± 21
	At object contact, ms	70 ± 8	75 ± 5	85 ± 9
Wilson and Welch (2013)	NR			
Alramis et al. (2016)	ND			
Webber et al. (2016)	Bruininks-oseretsky test of motor proficiency	**FMS**	**Amblyopic group**	
		Fine motor skills (FMS)	35.80 (4.53)	
	Mean (SD)	FMS age-standardized scaled score	14.10 (3.37)	
Chakraborty et al. (2017)	Movement Assessment Battery for Children (MABC-2)	Fine motor control percentile (n = 594)	36.3 (27.78)	
		Gross motor control percentile (n = 587)	43.8 (22.12)	
	Mean (SD)	Total motor control percentile (n = 594)	37.8 (26.89)	

Fang et al. (2017)	Beery developmental test package (motor coordination task-MC task)	Motor coordination predicting the VMI skills of 4–6-year-old children B = 0.27 (p < 0.001)	Motor coordination predicting the VMI skills of 4-year-old children B = 0.40 (p < 0.001)	Motor coordination associated with the VMI skills of 5-year-old children B = 0.20 (p < 0.1)
Niechwiej-Szwedo et al. (2017)	ND			
Thompson et al. (2017)	Bayley Scales of Infant Development (Bayley III)	**Subtest**	**Association with stereoacuity**	**Association with visual accuity**
		Composite motor	−0.04 (−0.06, −0.02)	−0.65 (−1.08, −0.21)
		Fine motor subtest	−0.05 (−0.07, −0.03)	−0.94 (−1.41, −0.47)
	Mean ± SD	Gross motor subtest	−0.02 (−0.04, 0.00)	−0.12 (−0.54, 0.30)
Zipori et al. (2018)	The Bruininks-Oseretsky Test of Motor Proficiency (Balance subtest)	**Amblyopia group**	**Strabismus with amblyopia group**	
		9.0 ± 3.1	8.6 ± 2.4	
			Esotropia	Exotropia
	Mean ± SD		8.0 ± 1.7	9.9 ± 3.1
Birch et al. (2019a)	NR			
Birch et al. (2019b)	NR			
Birch et al. (2020)	NR			
Hemptinne et al. (2020)	NR			

Kelly et al. (2020)	Movement Assessment Battery for Children, Second Edition		**Amblyopic**	**Non-amblyopic**
		Total motor	7.4 ± 2.7	8.2 ± 2.9
	Mean ± SD	Manual dexterity	7.6 ± 2.7	8.5 ± 3.0
		Aiming & catching	8.8 ± 3.4	9.3 ± 3.2
		Balance	7.8 ± 3.1	8.3 ± 3.1
Niechwiej-Szwedo et al. (2020a)	Bead threading measures	Total movement time (ms)		1551 ± 302
	Mean ± SD	Peak velocity (m/s)		0.886 ± 0.137
		Reach duration (ms)		411 ± 48
		Grasp duration (ms)		173 ± 78
		Placement duration (ms)		559 ± 190
		Reach-to-bead acceleration interval duration (ms)		182 ± 32
		Reach-to-bead deceleration interval duration (ms)		236 ± 34
		Reach-to-needle acceleration interval duration (ms)		212 ± 32
		Reach-to-needle deceleration interval duration (ms)		193 ± 28
Niechwiej-Szwedo et al. (2020b)	NR			
Pinero-Pinto et al. (2020)	Peabody Developmental Motor Scale-Second Version (PDMS-II)	Static percentile		72.04 ± 19.90 (9.00–99.00)
	Mean ± SD (range)	Locomotion percentile		15.87 ± 11.08 (2.00–50.00)
		Handling percentile		43.43 ± 21.20 (5.00–95.00)
		Grasp percentile		73.53 ± 24.16 (5.00–99.00)
		Coordination percentile		37.79 ± 18.76 (2.00–84.00)
		Gross motor percentile		42.40 ± 21.00 (8.00–95.00)
		Fine motor percentile		56.68 ± 24.33 (12.00–99.00)
		Overall motor percentile		49.71 ± 22.32 (4.00–96.00)
		Gross motor quotient		96.81 ± 9.15 (79.00–124.00)
		Fine motor quotient		104.52 ± 14.90 (14.00–151.00)
		Overall motor quotient		98.66 ± 14.55 (0.00–126.00)

Sá et al. (2021)	Motor competence assessment (MAC)			**Non-amblyopia group**	**Corrected amblyopia**	**Non-Corrected amblyopia**
	Mean (SD)	Shifting platforms		82.18 (22.33)	69.32 ± 31.94	67.29 ± 25.63
		Jumping laterally		50.31 (24.96)	42.70 ± 24.75	36.13 ± 27.68
		Standing long jump (cm)		68.46 (23.13)	57.92 ± 27.61	61.97 ± 23.57
		Shuttle run (s)		50.54 (24.21)	39.59 ± 27.29	31.26 ± 23.31
		Ball throwing velocity (km/h)		64.73 (26.77)	56.51 ± 30.02	50.71 ± 28.90
		Ball kicking velocity (km/h)		51.94 (29.67)	51.19 (26.91)	46.26 (31.64)
		MC components stability		66.24 (19.36)	56.01 (23.5)	51.71 (23.20)
		Locomotor		59.50 (20.18)	48.75 (24.40)	46.61 (20.01)
		Manipulative		58.33 (22.47)	53.85 (21.40)	48.48 (25.19)
		MCA total		66.24 (19.36)	56.01 (23.57)	51.71 (23.20)
	Physical activity questionnaire (PAQ-C) Mean (SD)			2.5 (0.3)	2.5 (0.3)	2.4 (0.3)
Vagge et al. (2021)	Developmental Coordination Disorder Questionnaire (DCDQ) 2007	**Strabismus group (*n* = 23)**	**Normal stereopsis group (*n* = 11)**	**Absent stereopsis (*n* = 12)**	**Amblyopia (*n* = 9)**	**No amblyopia (*n* = 14)**
		Total DCDQ score 58.7 ± 11.3	Total DCDQ score 67.3 ± 4.8	Total DCDQ score 50.8 ± 9.5	Total DCDQ score 55.4 ± 5.9	Total DCDQ score 60.7 ± 13.5
	Mean ± SD	Control during movement 24.2 ± 6.5	Control during movement 28.8 ± 1.8	Control during movement 19.9 ± 6.3	Control during movement 22.9 ± 3.3	Control during movement 25.0 ± 7.9
		Fine motor 13.3 ± 4.4	Fine motor 14.3 ± 4.2	Fine motor 12.3 ± 4.6	Fine motor 11.3 ± 3.8	Fine motor 14.5 ± 4.9
		General coordination 22.3 ± 3.4	General coordination 24.2 ± 2.2	General coordination 20.7 ± 3.6	General coordination 21.2 ± 2.8	General coordination 23.1 ± 3.8

CS = central suppression, NR = not reported, VMI = visual motor integration.

signs that define the visual state of a subject (Cacho-Martínez et al. 2014; Cacho-Martínez et al. 2015). However, in the paediatric population, there is a lack of consensus on the diagnostic criteria, mainly in preschool-age children, in whom visual and cognitive abilities are still developing.

The presence of visual disturbances negatively affects the development of motor skills. Children follow a developmental pattern that is highly dependent on the subject's ability to focus, as well as on eye movements and refraction. The studies included in this review established a relationship between amblyopia, binocular vision, accommodative alterations and refractive status with gross and fine motor development in children.

Amblyopia and development

Amblyopia is a decrease in visual acuity without any organic lesion to justify it. The involvement is generally unilateral and occurs as a consequence of a lack of adequate visual stimulation during the critical period of visual development. Amblyopia may affect both eyes, if both have suffered a long period of visual deprivation (DeSantis 2014), and it is related to the presence of an asymmetric refractive error that has not been detected or treated during childhood.

There is a close relationship between visual acuity deficit and motor delay. Several studies revealed the importance of vision in relation to balance and coordination (Atkinson et al 2005; Chakraborty et al. 2017; Fang et al. 2017; Thompson et al. 2017; Zipori et al. 2018; Hemptinne et al. 2020; Sá et al. 2021), although no study found significant results in this association (Wilson & Welch 2013).

Most of the studies indicated that fine motor skills may be affected if there is any alteration of vision, particularly in the case of amblyopia and strabismus, and can be improved in cases of correct binocular vision (O'Connor et al. 2010; Suttle et al. 2011; Alramis et al. 2016; Webber et al. 2016; Niechwiej-Szwedo et al. 2017; Webber 2018; Kelly et al. 2019; Niechwiej-Szwedo et al. 2020a, 2020b; Vagge et al. 2021). Gross and fine motor skills have been shown to be reduced in children with amblyopia (Engel-Yeger 2008; Webber et al. 2008). Manual dexterity tasks require more time for execution and planning. Reading speed and hand–eye coordination are also affected (Suttle et al. 2011; Birch et al. 2019a, 2019b; Birch et al. 2020).

The deficiencies in motor performance were greater in manual dexterity tasks, which require speed and precision. Children with amblyopia are slower in planning and executing reaching movements and have a less precise grip than children without amblyopia.

In addition, children with amblyopia present postural instability, which is a consequence of poor static balance (Kelly et al. 2020; Sá et al. 2021). Children with amblyopia are more cautious when walking, take shorter steps and slow down as a result of poor visual processing (Buckley et al. 2010).

Several studies have identified that lower self-perception of peer acceptance and physical competence identity is associated with worse motor skills, which may be related to the wide-ranging effects of impaired visual development in children with amblyopia in their daily lives (Birch et al. 2019a, 2019b; Birch et al. 2020). One study also revealed that amblyopia can negatively affect children's motor skills, as expressed by objective measures in daily life, whereas self-perception is less affected (Engel-Yeger 2008).

Binocular vision and development

Binocular vision is the ability to integrate two images into one. This requires both eyes to be perfectly aligned on the fixation point. Normal binocular vision positively influences the optimal development of fine motor skills and tasks related to reading. Niechwiej-Szwedo et al. (2017) assessed motor performance in a group of children with reading difficulties by using two tasks: threading beads and pegboard. Children with reading problems had difficulty in the task of threading beads but not with the pegboard. This group performed poorly on a single task that relied heavily on binocular information.

Chakraborty et al. (2017) and Thompson et al. (2017) evaluated binocular vision (visual acuity, stereopsis, alignment of visual axes, ocular motility and self-refraction) and showed that it is strongly related to motor function by using the MABC-2 scales, Peabody Developmental Motor Scale-2nd Version and Bayley Scales of Infant Development, all of which are valid and reliable for measuring infant motor development. In addition, Pinero-Pinto et al. (2020) performed a comprehensive study of binocular vision in a group of typically developing children. They confirmed that children with slower motor development had greater exophoria and a closer convergence point further away, which hindered fusion and binocular vision. In addition, other authors have highlighted the influence of age and affirm that the role of vision in the performance of fine motor skills depends on both the task and age (Alramis et al. 2016; Niechwiej-Szwedo et al. 2020a, 2020b).

Strabismus is an anomaly of binocular vision consisting of the loss of parallelism of both eyes. The lack of binocularity and stereopsis in children with strabismus is associated with the significant impairment of motor skills, particularly for static balance and capture tasks (Hemptinne et al. 2020; Vagge et al. 2021). Furthermore, when normal binocular vision is interrupted in childhood due to strabismus and/or amblyopia, vision and posture are affected, and balance is reduced (Zipori et al. 2018).

Hyperopia and development

Toddlers typically have uncorrected hyperopes (Mayer et al. 2001). Uncorrected hyperopia presents a greater accommodative demand that causes a closure of the visual axes (endophoria) (Leone et al. 2010). A total of 20% of children with high hyperopia (>3.5 D) develop convergent strabismus (Anker et al. 2004; Babinsky and Candy 2013). Atkinson et al. (2005) compared motor skills in hyperopic and emmetropic children by using the MABC-2 as a motor development measurement tool. Hyperopic children performed worse on at least one test in each category (manual dexterity, balance and ball skills). This implies an impairment in fine motor skills in hyperopic children.

This review has several limitations, particularly with regard to the difficulty of extracting data *via* varied methodologies and different visual systems and motor development assessment tools. Furthermore, there could be some inherent bias due to the professional interests of the authors that are unknown to us. To the best of our knowledge, this is the first review to analyse the relationship between motor development and the visual system. Therefore, this review provides valuable information for the evaluation and treatment of children by professionals from different disciplines in relation to paediatrics.

Conclusions

All included studies confirmed a relationship between the visual system and development in children, although they also demonstrated a lack of uniformity in the methods of visual system measurement and developmental assessment.

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Received on August 8th, 2021.
Accepted on January 20th, 2022.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Flow chart.