Taylor & Francis
Taylor & Francis Group

Clinical and Experimental Optometry

ISSN: 0816-4622 (Print) 1444-0938 (Online) Journal homepage: www.tandfonline.com/journals/tceo20

Associations between vision anomalies and sensorimotor processes in children aged 7–16 years

Tina R. Johansen, Hilde R. Pedersen, Rigmor C. Baraas, Cecilie O. Bjørset, Rachel O. Coats, Lene A. Hagen, Gro Horgen, Ellen Svarverud, Hanne-Mari Schiøtz Thorud, Mark Mon-Williams & Trine Langaas

To cite this article: Tina R. Johansen, Hilde R. Pedersen, Rigmor C. Baraas, Cecilie O. Bjørset, Rachel O. Coats, Lene A. Hagen, Gro Horgen, Ellen Svarverud, Hanne-Mari Schiøtz Thorud, Mark Mon-Williams & Trine Langaas (08 Feb 2026): Associations between vision anomalies and sensorimotor processes in children aged 7–16 years, Clinical and Experimental Optometry, DOI: 10.1080/08164622.2026.2623993

To link to this article: https://doi.org/10.1080/08164622.2026.2623993

Published online: 08 Feb 2026.

CLINICAL AND EXPERIMENTAL OPTOMETRY
https://doi.org/10.1080/08164622.2026.2623993

Associations between vision anomalies and sensorimotor processes in children aged 7–16 years

Tina R. Johansen [a], Hilde R. Pedersen [a], Rigmor C. Baraas [a], Cecilie O. Bjørset [a], Rachel O. Coats [b], Lene A. Hagen [a], Gro Horgen [a], Ellen Svarverud [a], Hanne-Mari Schiøtz Thorud [a], Mark Mon-Williams [b] and Trine Langaas [a]

[a]National Centre for Optics, Vision and Eye Care, University of South-Eastern Norway, Kongsberg, Norway; [b]School of Psychology, University of Leeds, Leeds, UK

ABSTRACT

Clinical relevance: Vision plays an important role in the normal motor development of children. Increased understanding of this relationship is important for providing appropriate advice in a clinical setting.

Background: Growing evidence indicates that vision anomalies are associated with reduced motor performance in children. This study investigated whether feedback loop noise, induced by common vision anomalies, adversely affects sensorimotor processing in children aged 7 to 16.

Methods: Sensorimotor function was measured in 409 children aged 7–8, 10–11, and 15–16 years as part of an annual school vision programme. The vision programme included assessment of visual acuity, binocular vision and refraction. *Aiming* and *steering* sensorimotor performance were measured using a validated tool that utilised a stylus on a tablet computer. Analysis of covariance models tested whether visual function (binocular near visual acuity, amplitude of accommodation, near point of convergence) and refractive error, along with age, contributed to the variance in aiming and steering performance.

Results: Sensorimotor performance showed considerable variation within each age group. The simplest models that captured *aiming* variance included age and refractive error ($R^2 = 0.42$, $F[3, 402] = 99.04$, $p < 0.001$), whilst age and accommodative function contributed towards *steering* variance ($R^2 = 0.22$, $F[3, 400] = 38.72$, $p < 0.001$).

Conclusion: Hyperopic refractive errors and reduced accommodative function affect the ability to perform sensorimotor transformations, negatively impacting age-expected manual control skill levels. Longitudinal research is needed to test whether correcting hyperopia can: (i) improve the development of sensorimotor processing; (ii) produce beneficial changes in motor skill abilities.

ARTICLE HISTORY
Received 29 April 2025
Revised 18 November 2025
Accepted 25 January 2026

KEYWORDS
Accommodation; child; development; hyperopia; motor control

Introduction

Common vision anomalies, such as amblyopia, strabismus, or significant refractive error, can affect quality of life, education, mental health, and wellbeing[1,2] in children and these problems may extend into adulthood.[3] One plausible and probable causal mechanism that links visual status and childhood outcomes is sensorimotor function. There is a substantial body of evidence that shows sensorimotor function to be a major contributing factor to the long-term education and health outcomes of children, e.g., Barnett, et al.[4] and Grissmer, et al.[5]

Vision anomalies must logically create some degree of noise in the sensorimotor processes that underpin sensorimotor performance.[6] It therefore follows that vision anomalies will, at some level of severity, negatively impact on motor abilities in a child. In support of this, converging empirical evidence shows that vision anomalies such as amblyopia and strabismus are associated with impaired motor development in children, specifically affecting fine motor skills and balance.[7] Moreover, impaired motor performance is evident in preschool children with significant hyperopia (≥ +3.00D) even after controlling for amblyopia and strabismus.[8–10]

CONTACT Trine R. Langaas trine.langaas@usn.no National Centre for Optics, Vision and Eye Care, University of South-Eastern Norway, Kongsberg, Norway

Stereoacuity and vergence facility have been found to be associated with grasping performance in a bead threading task in healthy 8–14-year-old children with otherwise normal binocular vision.[11] Reduced accommodative function has been shown to be negatively associated with motor performance in children with reading difficulties[12] and developmental coordination disorder.[13]

In summary, numerous studies have shown that vision anomalies affect sensorimotor function in children. This raises a more intriguing question: at what threshold does a vision anomaly begin to impact performance? An additional question arises from the dynamic nature of sensorimotor learning during childhood: May common vision anomalies, that do not prevent task performance (such as reduced visual acuity[14] and unilateral vision loss[15]), nevertheless hinder optimal sensorimotor development by introducing noise in the feedback loops that underpin sensorimotor learning (Figure 1)?[6] This is an important question in childhood development, where reduced visual input may hinder sensorimotor learning and control, much like how uncorrected refractive error can prevent the optimal development of spatial resolution in vision, e.g., Cotter et al.[16]

To address this question, the Clinical Kinematic Assessment Tool (CKAT)[17,18] was used. CKAT measures performance on three visuomotor transformations that capture the three fundamental sensorimotor processes of aiming, steering (also known as tracing[19]), and tracking. The tool effectively captures changes in sensorimotor processing as children age from 4 to 11 years.[18,19] The tracking task is minimally affected by monocular viewing,[15] and relies more on predicting target movement than visual feedback.[20] In contrast, aiming and steering rely on online visual feedback,[21] with performance improving under binocular viewing.[15] Online visual feedback provides real-time visual information on hand position and speed relative to an object.[22]

The hypothesis was that mild vision anomalies, such as hyperopic refractive error and reduced accommodation, though not severe enough to prevent a child from performing the visuomotor transformations required for CKAT tasks, would still impair performance by introducing noise into the feedback loops underlying sensorimotor learning.[6] This was informed by observations of negative impacts on sensorimotor function in adults with simulated monocular vision[15] and reduced visual acuity.[14] It seemed reasonable, therefore, to hypothesise that low-to-moderate hyperopic refractive errors could impair sensorimotor function. The hypothesis was tested using CKAT in 7–16-year-old children participating in a school vision programme.

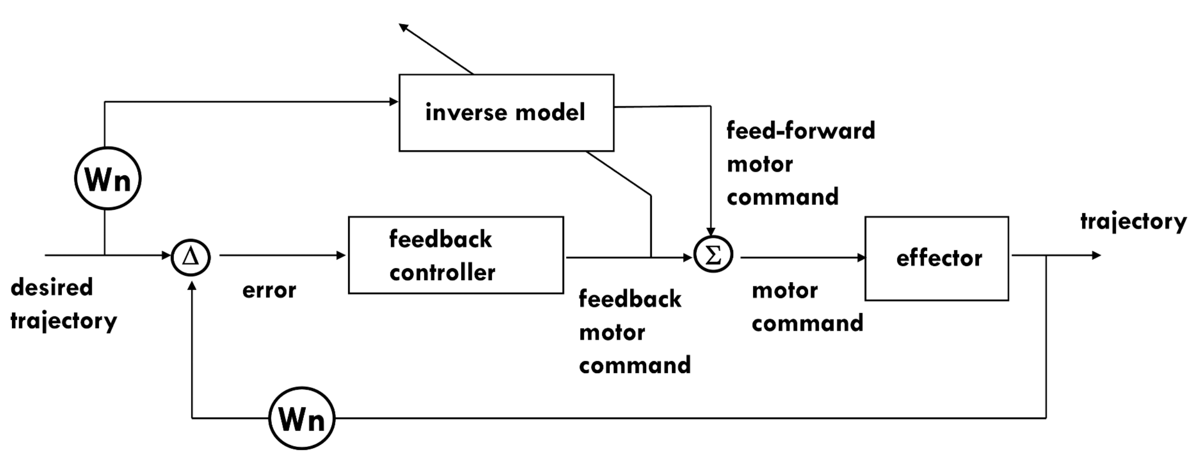

Figure 1. Schematic showing the key components of learning and sensorimotor control processes. Feedback signals (such as visual and other sensory inputs) are essential for effective learning (enabling fine tuning of 'internal models') and online control. These signals are subject to noise (Wn). It follows that decreasing the quality of the visual signal (i.e., increasing noise) will impair learning and control. Physiological constraints place an upper bound on the quality of the visual signal, but it follows that visual deficiencies (e.g., blurred visual feedback caused by uncorrected hyperopia or impaired accommodative function) above this physiological threshold will increase noise and decrease performance on sensorimotor tasks.

Methods

Participants

This cross-sectional study included school children aged 7–8, 10–11, and 15–16 years (attending 2nd, 5th and 10th grade, respectively). The children were recruited as part of an annual, free of charge school vision testing program offered to all children in four community schools of Kongsberg municipality, Norway, within the period 2016–2022. The majority of Kongsberg population is ethnic Norwegians (Caucasian) (83% in 2020–2022[23]), and the socio-demographic status of the municipality is representative of Norway.[24] There were no further inclusion or exclusion criteria.

The study followed the Declaration of Helsinki and was approved by the Regional Committees for Medical and Health Research Ethics in South-Eastern Norway and Norwegian Agency for Shared Services in Education and Research. Informed written consent was obtained from both parents/guardians, in addition to verbal consent from the children (themselves) before starting any procedure. Adolescents who had turned 16, consented on their own behalf.

Procedure

Vision assessment

The vision assessment was performed at school by authorised optometrists and optometry students under supervision. The examinations consisted of an age-appropriate symptoms questionnaire including queries about vision-related symptoms for distance, for near (adapted from the Convergence Insufficiency Symptom Survey (CISS)[25]) and for ocular health. Non-cycloplegic refraction using retinoscopy (conducted by an experienced optometrist) and monocular (6 m) and binocular (40 cm) visual acuity (logarithm of the Minimum Angle of Resolution [logMAR]) measured with Bailey-Lovie ETDRS test charts (Precision Vision, Woodstock, IL, USA) were included.

Binocular vision tests consisted of cover test [prism dioptres] at near (40 cm) and distance (6 m), monocular amplitude of accommodation (push in and pull out values in dioptres [D]) and near point of convergence (cm) using the Royal Air Force (RAF) ruler.[26] The TNO stereo test (Laméris Ootech, Ede, Netherlands) was used to measure stereoacuity [seconds of arc (″)] at near (40 cm). The measurements were obtained with habitual correction, if previously prescribed.

Assessment of sensorimotor function

All children completed the standardised sensorimotor tasks included in the CKAT.[17,18] The CKAT has been used in the Born in Bradford study, United Kingdom, with over 15,000 children.[19,27] The tasks were presented on a tablet computer with two-dimensional (2D) visual stimuli (refresh rate 60 Hz), using a pen-shaped stylus as the input device (movement recorded at 120 Hz). The tablet was laid flat on the school desk in front of the child, who was seated on a chair. Instructions were given both orally and in writing on the tablet before each task. The children used their preferred hand to perform tracking, aiming and steering tasks. Time to complete the sensorimotor tasks was 12–15 minutes, and all tasks were completed either on the same day or within a few weeks as the vision assessment.

Previous studies have shown that the aiming and steering tasks depend on online visual feedback.[15,21] This is unlike the tracking task, that depends more on predictions of a moving target.[20] Therefore, only aiming and steering tasks will be presented in this study.

A detailed description of aiming and steering tasks can be found in a previously published study.[18] The aiming task (Figure 2) challenges the child to aim as quickly and accurately as possible to an appearing dot, that relocates once the dot is reached (in an invisible star-like pattern). Movement time (MT) was recorded for each move, from one dot to the next. The mean MT for the 50 distinct moves were calculated (known as *Baseline*[18]). The steering task (Figure 3) challenges the child to trace two abstract shapes (shape A and B, where B was mirrored vertically to A) as accurately as possible within a 4 mm wide path, while staying inside a ‘pacing box’ to control the speed.

In contrast to Flatters et al.[18] who presented shape A and B three times each, the test battery used in current study tested both shapes only once (starting with shape A), to reduce the total testing time, similar to Hill et al.[19] The outcome measure for the steering tasks was penalised path accuracy (pPA). Both path

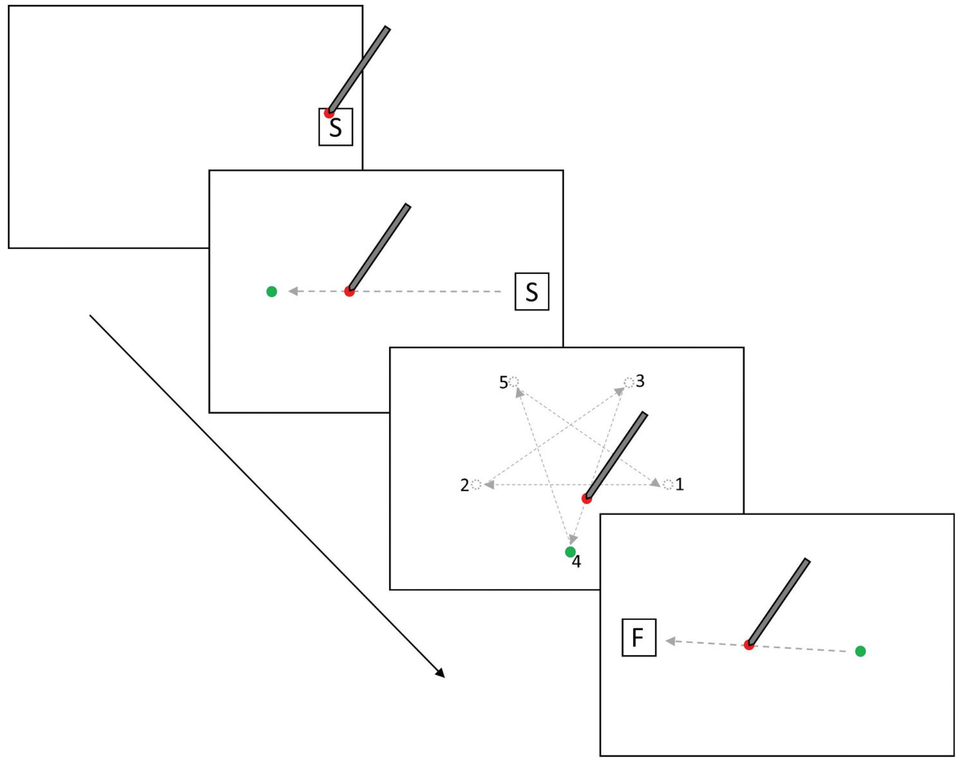

Figure 2. Aiming task. The participant began the task in the start position ('S') (top image). A green dot appeared on the screen, and the participant was instructed to move the stylus (the grey shape with a red dot. The red dot showed up on the screen when the stylus touched the screen) as fast and accurate as possible to the green dot (second image). The green dot disappeared once the participant 'hit' the dot, and the dot continued to move in an invisible star-like-pattern, with a total of 50 distinct moves, known as Baseline[18] (third image). The task ended once the participant arrived at the finish box ('F') (bottom image). The grey arrows and numbers were not visible but were added here to show the direction of movement. (The figure is modified from Flatters et al.[18] and Hill et al.[19]).

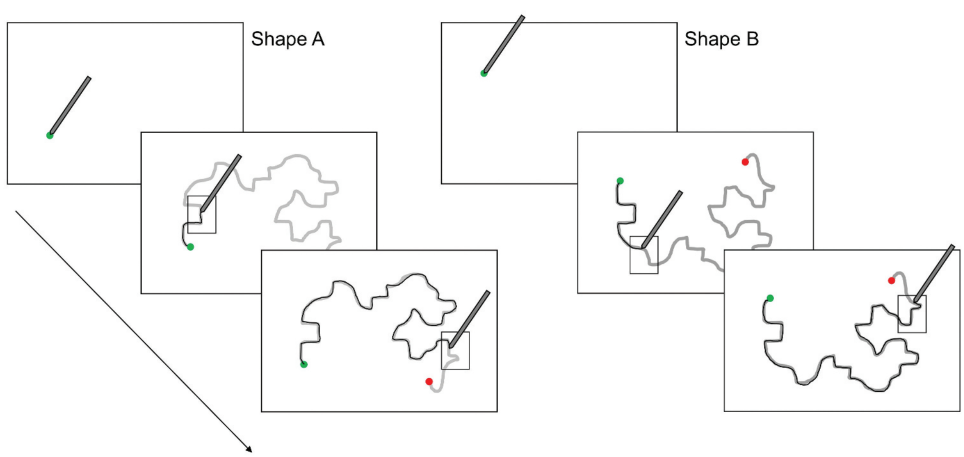

Figure 3. Steering task, shape A (left) and B (right). The participant started with shape a (top left image) and were instructed to follow the appearing path (grey colour) as accurately as possible within a 'pacing box' (middle image), leaving a black 'ink trail' all the way from start (green dot) to finish (red dot, bottom image). The same procedure was repeated for shape B. (The figure is modified from Flatters et al.[18] and Hill et al.[19]).

accuracy (defined as the arithmetic mean of the distance between the drawn line and the actual pathway of the shape, measured in mm) and the time used (ideally 36 seconds if the child kept inside the 'pacing box') were calculated,[15,18] as follows:

$$pPA = path\ accuracy(mm) * \left(1 + \left(\frac{movement\ time(s) - 36}{36}\right)\right)$$

Data analyses

All statistical analyses were conducted using R 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).[28] The significance level was set at $\alpha = 0.05$.

The sensorimotor outcomes, aiming (mean MT(s)) and steering (pPA, mean of shape A and B), were inspected for normality using histograms and Q-Q plots. As the assumption of normality was violated, the outcomes were transformed into reciprocal values to normalise the distribution.

A one-way analysis of covariance (ANCOVA) was used to compare the reciprocal mean MT (rec-MT) and reciprocal mean pPA (rec-pPA), in the three age groups, whilst controlling for the following covariates reported to be associated with motor performance: spherical equivalent refraction[8–10] (SER = sphere + ½ cylinder, estimated from dry retinoscopy), binocular near visual acuity (NVA),[14] push in value of amplitude of accommodation (AC)[12,13] and near point of convergence (NPC).[29] The following normal values or thresholds for SER, NVA, AC and NPC were considered: +1.50D,[30] 0.00 logMAR,[31] 7–8 years: ~13.00D, 10–11: ~12.40D and 15–16: ~11.00D (minimum)[32] and 4.5 cm,[33] respectively. Right eye was used for SER and AC due to high correlation between the two eyes ($R = 0.90$, $p < 0.001$ and $R = 0.82$, $p < 0.001$, respectively).

The model specification for aiming was: rec-MT ~ Age group × SER × NVA × AC × NPC and was similar to steering, only changing the outcome variable to rec-pPA. The stepAIC() function from the MASS package was used to perform stepwise model selection by minimising the Akaike Information Criterion (AIC), which balances model goodness-of-fit and simplicity.[34] The impact of each main effect and interaction terms was evaluated using the likelihood-ratio test.

Where consensus-based clinical thresholds for treatment exist, additional analyses were conducted to determine if significant covariates would yield a differential effect on the type of sensorimotor outcome.

Previous research has linked impaired stereoacuity to reduced motor skills, though its impact is task dependent. Alramis et al.[35] found stereoacuity crucial for a bead-threading task but not for a peg-board task, likely due to differences in 3D vs. 2D localisation demands. In this study, no significant differences were found between children with impaired (>120 ″) and normal (≤120 ″) stereoacuity, aligning with Sheppard et al.,[15] who noted the CKAT does not rely on binocular cues.

Additionally, normal stereoacuity of ≤120 ″[36] was observed in most cases ($n = 376$), while impaired stereoacuity was observed in a smaller subset ($n = 26$). The relatively small size of the latter subset was insufficient for yielding statistically significant comparisons between the two groups. Consequently, the analyses conducted in this study encompass data from both groups collectively.

Results

Four hundred and nine children (210 females, 51%) aged 7–8, 10–11, and 15–16 years, participated in the study. Data were missing for seven participants, leaving $n = 402$. Table 1 shows the participant demographics per age group and measures of visual function and refractive error.

Age, refractive error, and binocular visual function

Aiming (movement time)

A one-way ANCOVA was conducted to compare the rec-MT in the three age groups, whilst controlling for the covariates SER, NVA, AC and NPC. Interactions between the predictor variables did not improve the fit of the model (χ^2 [41] = 0.92, $p = 0.609$). The analysis showed that age group and refractive error (SER) collectively accounted for 42% of the variance in aiming performance (rec-MT) ($R^2 = 0.42$, $F[3, 402] = 99.04$, $p < 0.001$). There was a significant difference in rec-MT between the three age groups ($F[2, 402] = 143.32$, $p < 0.001$, $\eta_p^2 = 0.416$), whilst adjusting for SER ($F[1, 402] = 10.48$, $p = 0.001$, $\eta_p^2 = 0.025$).

Table 1. Participant demographics per age group including sex and age, followed by median (range) values for DVA and NVA, SER and AC in RE and LE and NPC.

	All	7–8 yrs.	10–11 yrs.	15–16 yrs.
n	409	121	130	158
Sex				
Male	199	57	56	86
Female	210	64	74	72
Age (years)	10.7 (6.9–16.4)	7.6 (6.9–8.3)	10.5 (10.0–11.9)	15.7 (15.0–16.4)
DVA (logMAR)†				
RE	0.00 (−0.30–0.70)	0.06 (−0.20–0.50)	0.00 (−0.20–0.70)	0.00 (−0.30–0.70)
LE	0.00 (−0.30–0.90)	0.06 (−0.14–0.50)	0.00 (−0.20–0.60)	−0.02 (−0.30–0.90)
NVA (logMAR)	−0.02 (−0.30–0.75)	0.00 (−0.30–0.60)	0.00 (−0.30–0.75)	−0.08 (−0.24–0.40)
SER (D)‡				
RE	0.50 (−2.75–8.25)	0.75 (−0.25–6.13)	0.75 (−1.25–8.25)	0.31 (−2.75–6.75)
LE	0.50 (−3.13–8.63)	0.75 (−0.25–5.50)	0.75 (−1.88–8.63)	0.38 (−3.13–6.63)
AC (D)				
RE§	12 (2.0–20)	13.50 (3.0–20)	13.00 (3.5–20)	12.00 (2.0–20)
LE¶	12 (2.75–20)	14.00 (3.0–20)	13.00 (4.0–20)	12.00 (2.75–20)
NPC (cm)††	5.0 (4.50–46)	5.0 (4.5–46)	5.0 (4.5–26)	5.0 (4.5–28)

Note: DVA = monocular distance visual acuity, logMAR = the logarithm of the Minimum Angle of Resolution, RE = right eye, LE = left eye, NVA = binocular near visual acuity, SER = spherical equivalent refractive error, D = dioptres, AC = accommodative amplitude (push in value), NPC = near point of convergence, cm = centimetres. †Data for both eyes were missing for one participant 15–16-year-old. ‡Data for both eyes were missing for two participants, both 15–16-year-olds. §Data were missing for four participants, one 10–11-year-old and three 7–8-year-olds. ¶Data were missing for four participants, one 7–8-year-old, one 10–11-year-old and two 15–16-year-olds. ††Data were missing for one participant 10–11-year-old.

The estimate of SER showed a negative value (β = −0.01, SE = 0.004), which means that slower movement time was associated with increased hyperopic refractive error (Figure 4). Tukey post hoc test showed a significant difference in rec-MT between all three age groups (all, $P_{adj} < 0.001$), where fastest rec-MT were seen in the oldest age group (estimated marginal means [EMM] = 0.87 s^{-1}, 95% confidence interval [CI] [0.85–0.89]) compared to middle (EMM = 0.76 s^{-1}, 95% CI [0.75–0.78]) and youngest (EMM = 0.67 s^{-1}, 95% CI [0.65–0.69]) age groups.

According to Leat[30] 'a full or near full correction' may be prescribed for hyperopia of SER ≥ +1.50D even if the child has no symptoms. It was therefore of interest to conduct an additive two-way ANOVA to examine the effects of such a threshold of hyperopia on rec-MT (including age groups). The analysis revealed that children with SER ≥ +1.50D (*n* = 50) had significantly slower movement time (lower rec-MT) (β = −0.04, SE = 0.015) than children with SER < +1.50D (*n* = 357) in all age groups (F[1, 402] = 7.99, *p* = 0.005, η_p^2 = 0.019).

Steering (penalised path accuracy)

Like aiming, interactions between the predictor variables did not improve the fit of the model (χ^2 [41] = 1.12, *p* = 0.296). The analysis showed that age group and AC collectively accounted for 22% of the variance in steering performance (rec-pPA) ($R^2 = 0.22$, *F*[3, 400] = 38.72, $p < 0.001$). There was a significant difference in rec-pPA between the three age groups (*F*[2, 400] = 56.15, $p < 0.001$, $\eta_p^2 = 0.291$), whilst adjusting for AC (*F*[1, 400] = 3.87, *p* = 0.050 $\eta_p^2 = 0.010$). The estimate of AC showed a positive value (β = 0.004, SE = 0.002), which means that better steering accuracy is associated with higher AC (Figure 5).

Tukey post hoc test showed a significant difference in rec-pPA between all three age groups (all, $P_{adj} < 0.001$), where highest accuracy of rec-pPA was seen in the oldest age group (EMM = 0.90, 95% CI [0.88–0.93]) compared to middle (EMM = 0.78, 95% CI [0.75–0.81]) and youngest (EMM = 0.70, 95% CI [0.67–0.73]) age groups.

According to Hofstetter's (minimum) formula[32]: 15 - (0.25 * age), 7–8 (median 7.6), 10–11 (median 10.5) and 15–16 (median 15.7) year olds in the current study should have a minimum expected AC of 13.10 D, 12.38D and 11.08D, respectively. It was therefore of interest to conduct an additive two-way ANOVA to examine the effects of such a threshold of AC on rec-pPA (including age groups). The analysis revealed that there was no difference in steering accuracy between children with above (*n* = 217) or below (*n* = 188, β = −0.01, SE = 0.002) expected AC according to their respective age (F[1, 400] = 0.41, *p* = 0.521, $\eta_p^2 = 0.001$).

Discussion

This study investigated whether sensorimotor processing was negatively impacted in 7–16-year-old children by vision anomalies severe enough to cause noise in sensorimotor feedback loops, but not so

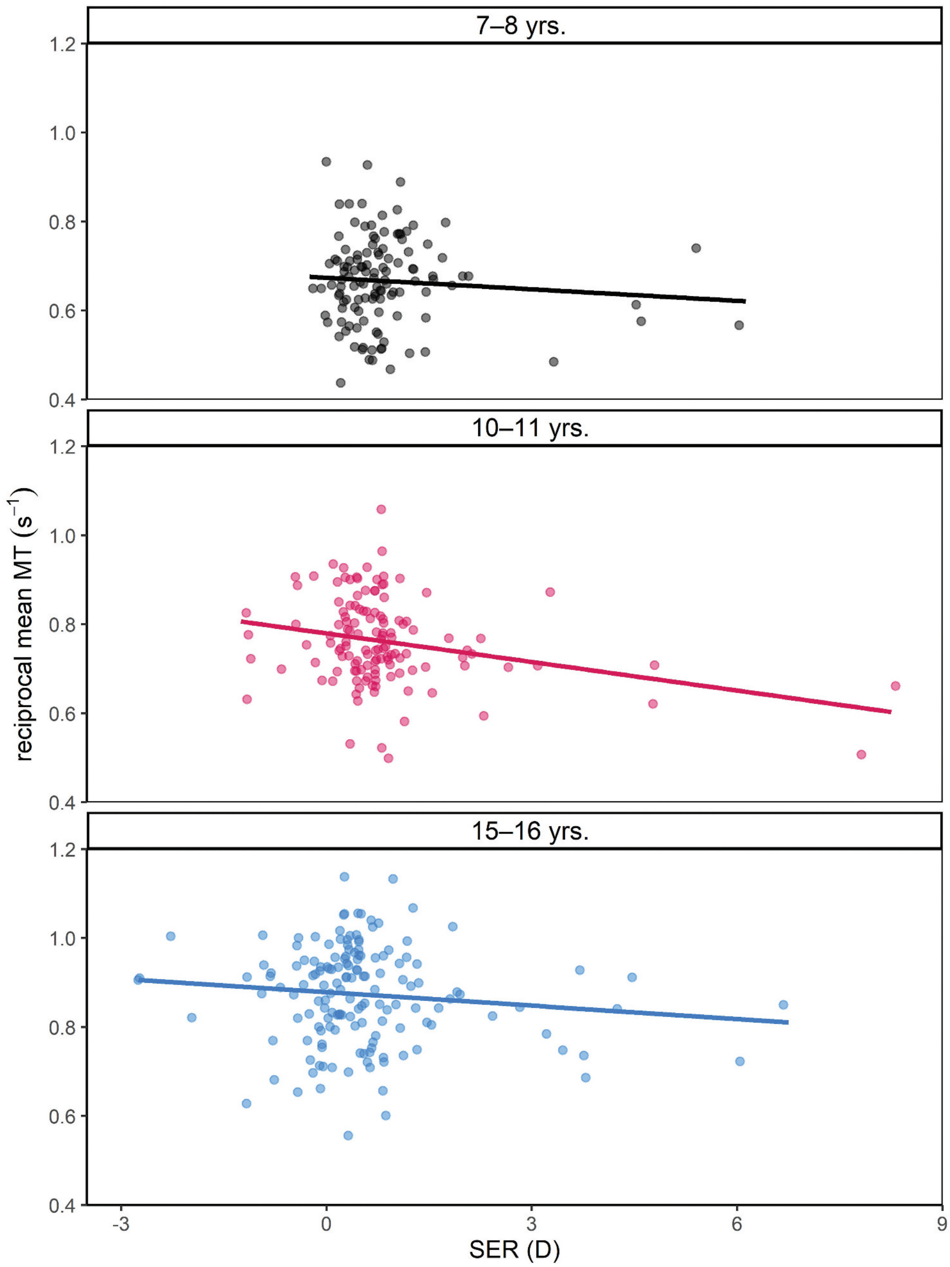

Figure 4. Scatterplot and linear regressions of all participants ($n = 406$) from the aiming task, reciprocal mean movement time (MT), as a function of spherical equivalent refractive error (SER) in dioptres (D) for the right eye. A higher reciprocal mean MT means better (faster) aiming performance. The simplest one-way ANCOVA included SER and was significant at $p < 0.001$. The figure shows that children with greater hyperopia demonstrated slower aiming performance.

severe as to prevent a child undertaking the task. The results demonstrated the expected developmental improvements in sensorimotor control that occur over childhood and confirmed that all the children were able to perform the task.[18,19,37]

There was a significant effect of increasing hyperopia on sensorimotor performance in the aiming task (Figure 4), confirming the study hypothesis. This is consistent with the body of evidence showing an association between motor development in children and vision anomalies such as hyperopia[8–10] and accommodative function.[11–13] Several studies[8–10] have shown that being hyperopic (≥+3.00D) during preschool years has a negative effect on motor development compared to controls, even when controlling for amblyopia and strabismus. A non-cycloplegic refraction is likely to underestimate hypermetropia in children.[38] Support is therefore given to Leat[30] that prescribing correction for children with hyperopia

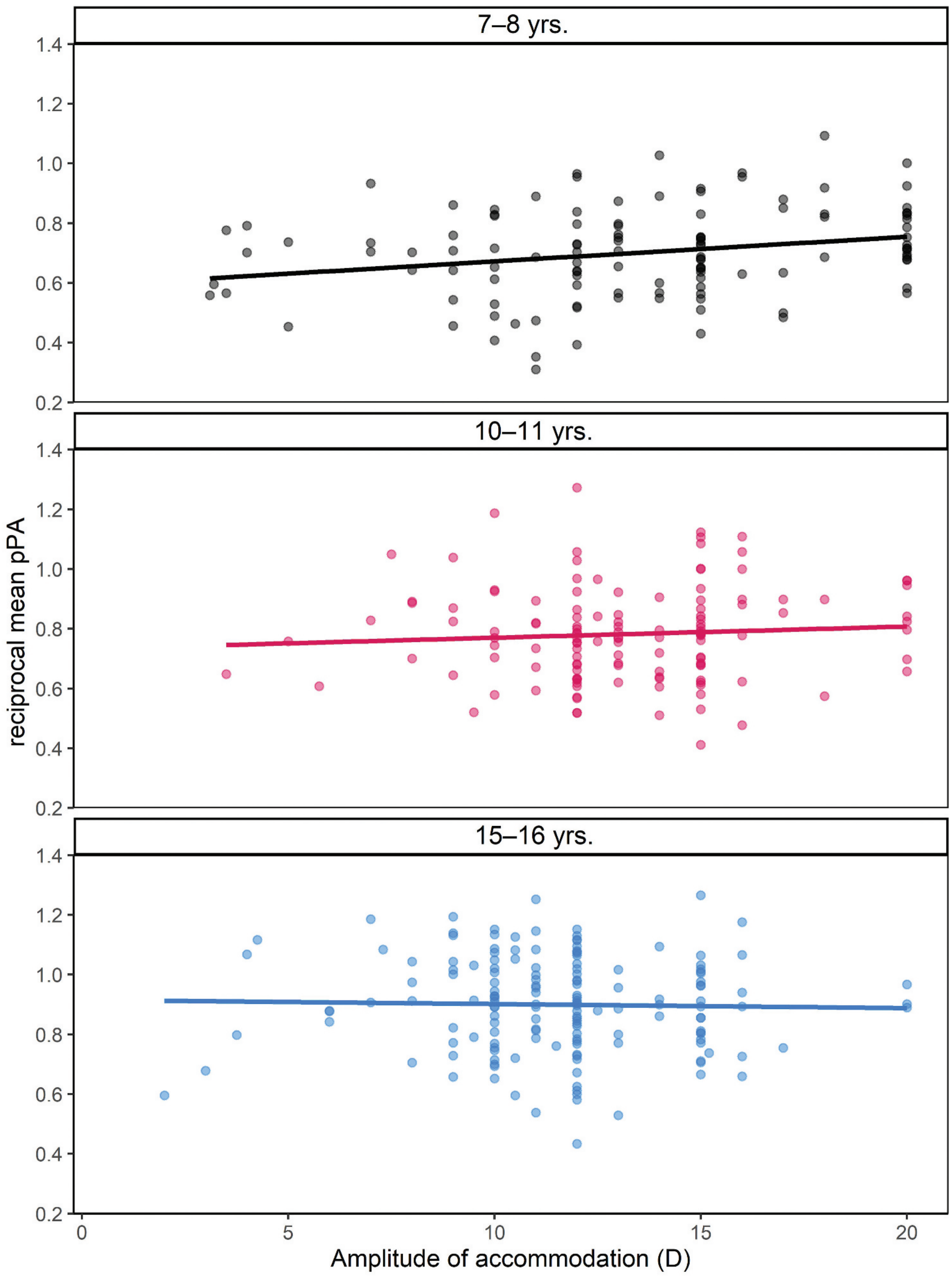

Figure 5. Scatterplot and linear regressions of all participants ($n = 404$) from the steering task, reciprocal mean penalised path accuracy (pPA), adjusted for amplitude of accommodation (AC) in dioptres (D) for the right eye. A higher reciprocal mean pPA means better (more accurate) steering performance. The simplest one-way ANCOVA included AC and was significant at $p < 0.001$. The figure shows that children with greater AC demonstrated more accurate steering performance.

≥ + 1.50D might be beneficial, irrespective of visual symptoms. It is emphasised that non-cycloplegic refraction was used in the current study.

As proposed in the introduction (Figure 1), blurred visual feedback may introduce noise in the sensorimotor processes. It is plausible that uncorrected hyperopes benefit from optical correction, as it improves the quality of visual feedback fed into the central nervous system, thereby enhancing motor actions. Two studies have investigated the effects of optical correction on motor function in children with uncorrected hyperopia (and/or astigmatism) in the absence of amblyopia and/or strabismus, however with different conclusions.

Roch-Levecq et al.[9] observed improved performance using Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI) after six weeks of spectacle wear in preschool children with uncorrected refractive errors. In contrast, Atkinson, et al.[8] found no difference on the Movement Assessment Battery for Children (M-ABC) scores between hyperopic children who were prescribed spectacles and those who were not. Several factors may account for these differences. The study by Roch-Levecq et al. focused on short-term outcome of spectacle wear (intervention) in children 3 to 5 years, whereas Atkinson, et al. investigated the long-term developmental outcomes of children with hyperopia from infancy to 5.5 years.

As noted by Roch-Levecq et al., Atkinson et al. conducted post hoc comparison between children wearing spectacles and those with uncorrected refractive errors. The tasks used in these studies also differ; the M-ABC assesses a broader range of motor skills and may be less sensitive to changes compared with the VMI. Additionally, there were differences in the study populations. Atkinson et al. investigated children from a general population, while Roch-Levecq et al. focused on preschool children with refractive errors from low-income families. These differences, along with differences in study design and outcome measures, underscore the need for more research to better understand how refractive errors impact child development.

Amblyopic children who had undergone conventional treatments, such as receiving optical correction if required, demonstrated improved motor skills following binocular training intervention (dichoptic binocular therapy).[39] This type of intervention has been shown to increase visual acuity in the amblyopic eye and to improve stereoacuity by adjusting contrast to balance input between the amblyopic and fellow eye, thereby reducing suppression.[40] Consistent with our hypothesis (Figure 1), higher quality visual feedback (e.g., improved visual acuity in the amblyopic eye) enhances binocular summation (i.e., an improved signal-to-noise-ratio when both eyes work together),[41] resulting in improved motor performance as demonstrated in the study by Webber, et al.[39]

A higher amplitude of accommodation was associated with improved steering accuracy (Figure 5), confirming the study hypothesis. This is consistent with previous studies that have reported enhanced motor performance across various tasks (e.g., bead-threading) with increased accommodative function (both amplitude and facility).[11–13] However, the association between amplitude of accommodation and steering task in the current study showed modest significance, compared to previous studies.

The discrepancy may be attributed to several factors. First, differences in tasks employed could play a role. Here, motor tasks were conducted using a stylus on a flat surface (2D), whereas previous studies utilised pegboard,[12,13] bead-threading[11,12] and subtests of Bruininks-Oseretsky Test of Motor Proficiency,[13] which all targets other aspects of motor function (e.g., reaching, grasping and balance).

Second, there were differences in study populations. The cited studies investigated slightly younger children, ranging from 5 to 14 years, and included children with typically normal development[11] as well as those with developmental coordination disorder[13] and reading difficulties.[12] Notably, the latter two studies compared the performance on the motor tasks with controls. The current study sampled a cohort representative of a school vision program, encompassing children with a wide range of visual statuses, ranging from normal to mild, moderate or severe anomalies.

In short, the current study was based on population statistics and used sophisticated measures of sensorimotor control that allows to pick up subtle differences across the population.[19] This was important in an experimental approach designed to detect performance differences in a task that could be completed by all participants.

Strengths and limitations

A strength of this study was that an objective and sensitive tool was used to assess sensorimotor control. Hill, et al.[42] have argued that research using questionnaires, such as parental-[43] and self-reports[44] or one-to-one motor assessments,[45] can be affected by inter-rater reliability problems,[46] in addition to having coarse classification of motor development, either normal or abnormal.[17,47] Another strength of the study was the inclusion of a population with an NVA above the threshold (median NVA −0.02 logMAR) of reduced NVA (exceeding 0.11 to 0.27 logMAR) shown previously to impact performance on the sensorimotor tasks.[14]

One limitation of the current study is an inability to establish the direction of causality. The results are strongly suggestive of a causal link between common vision anomalies and sensorimotor deficits. However, it cannot rule out a common genetic reason for reduced sensorimotor ability and vision anomaly,[8] or the possibility that impaired sensorimotor function underlies the visual anomalies. In relation to the latter, the development of motor skills plays a crucial role in providing infants with opportunities for exploration, such as manual interaction with objects, and later crawling, that are closely linked to the advancement of visual object processing.[48] Limited motor development, therefore, may restrict these experiences, potentially leading to less optimal visual development. Longitudinal studies are needed to further explore these relationships and determine causality.

Another limitation relates to an inability to control for multiple factors that affect sensorimotor processing. For example, sensorimotor function in children is known to be influenced by sex,[18,37] but sex was not included as a part of the analysis of covariance owing to the relatively small number of participants. It is noted, however, that the effect size of sex is weak[18] and the study was designed to detect population differences associated with vision anomalies above and beyond other factors that influence sensorimotor performance.

Conclusion

Vision anomalies impact sensorimotor processing in children aged 7 to 16. Importantly, the study investigated the impact of anomalies that were not sufficiently severe to prevent children completing the sensorimotor tasks. The presence of a vision anomaly would, however, be expected to introduce noise into the feedback loops that underpin sensorimotor learning. It follows that vision anomalies have the potential to impact the development and refinement of precise sensorimotor control, and it is expected that this will be manifest across a population.

Moreover, the results provide a plausible explanation for the impact of vision anomaly on the quality of life, education, mental health, and wellbeing in a child.[1,2] It is well established that sensorimotor processes play an important role in childhood development,[4,5] thus the presence of noise generated through vision anomalies (such as reduced accommodative function) would prevent the refinement of sensorimotor control and impact negatively on motor skill development.

Longitudinal research is required to confirm the direction of causality and determine whether the correction of vision anomalies produces long term improvements in sensorimotor processing. It is also necessary to assess how sensorimotor impairments affect acquiring daily living skills. In the meantime, it is arguable that a child presenting with even mild motor deficits should have their vision assessed and vice versa. Supporting optimal childhood visual and sensorimotor development warrants a cautious approach, and the results highlight the importance of considering optical correction for hyperopes exceeding +1.50 D (non-cycloplegic), especially when motor deficits are present.

Acknowledgements

The authors would like to thank Stuart J. Gilson for technical support, Kenneth Knoblauch for statistical support, Randi Mork for help with CKAT data collection and Hilde E. Wedde for project administration. The authors would also like to thank the staff and pupils at the participating schools, as well as optometry students who contributed to data collection.

AI tool (OpenAI, ChatGPT, Version GPT-4, October 2023) was used for grammar and readability only. No text was generated automatically. All content was reviewed and verified by the investigators.

Disclosure statement

Co-author MMW is a co-holder of a patent for the custom software used to collect data in the current study (CKAT), details as follows: Mon-Williams, M., Williams, J.H.G., Plumb, M. and Wilson, A. ‘Apparatus and method for the assessment of neurodevelopmental disorders’. (PCT/GB2007/001931) held by University Court of the University of Aberdeen. European Patent No. 07732951.4; USA Patent No. 12/302174.

All other authors declare no competing interests.

Funding

The study was supported by the University of South-Eastern Norway through funding from the Norwegian Ministry of Education and Research.

ORCID

Tina R. Johansen http://orcid.org/0009-0005-8756-1031
Hilde R. Pedersen http://orcid.org/0000-0003-3946-6687
Rigmor C. Baraas http://orcid.org/0000-0003-3259-7617
Cecilie O. Bjørset http://orcid.org/0000-0001-8847-3299
Rachel O. Coats http://orcid.org/0000-0003-4415-408X
Lene A. Hagen http://orcid.org/0000-0002-9017-4519
Gro Horgen http://orcid.org/0000-0001-8879-1131
Ellen Svarverud http://orcid.org/0000-0002-0768-9010
Hanne-Mari Schiøtz Thorud http://orcid.org/0000-0002-4045-0909
Mark Mon-Williams http://orcid.org/0000-0001-7595-8545
Trine Langaas http://orcid.org/0000-0001-6494-3911

References

1. Pirindhavellie G-P, Yong AC, Mashige KP, et al. The impact of spectacle correction on the well-being of children with vision impairment due to uncorrected refractive error: a systematic review. BMC Public Health. 2023;23:1575. doi: 10.1186/s12889-023-16484-z
2. Birch EE, Castañeda YS, Cheng-Patel CS, et al. Associations of eye-related quality of life with vision, visuomotor function, and self-perception in children with strabismus and anisometropia. Invest Ophthalmol Vis Sci. 2020;61(11):22. doi: 10.1167/iovs.61.11.22
3. Kumaran SE, Khadka J, Baker R, et al. Functional limitations recognised by adults with amblyopia and strabismus in daily life: a qualitative exploration. Ophthalmic Physiol Opt. 2019;39:131–140. doi: 10.1111/opo.12610
4. Barnett LM, Webster EK, Hulteen RM, et al. Through the looking glass: a systematic review of longitudinal evidence, providing new insight for motor competence and health. Sports Med. 2022;52:875–920. doi: 10.1007/s40279-021-01516-8
5. Grissmer D, Grimm KJ, Aiyer SM, et al. Fine motor skills and early comprehension of the world: two new school readiness indicators. Dev Psychol. 2010;46:1008–1017. doi: 10.1037/a0020104
6. Bays PM, Wolpert DM. Computational principles of sensorimotor control that minimize uncertainty and variability. J Physiol. 2007;578:387–396. doi: 10.1113/jphysiol.2006.120121
7. Sánchez-González MC, Palomo-Carrión R, De-Hita-Cantalejo C, et al. Visual system and motor development in children: a systematic review. Acta Ophthalmol. 2022;100:e1356–e1369. doi: 10.1111/aos.15111
8. Atkinson J, Nardini M, Anker S, et al. Refractive errors in infancy predict reduced performance on the movement assessment battery for children at 3½ and 5½ years. Dev Med Child Neurol. 2005;47:243–251. doi: 10.1017/S0012162205000472
9. Roch-Levecq A-C, Brody BL, Thomas RG, et al. Ametropia, preschoolers' cognitive abilities, and effects of spectacle correction. Arch Ophthalmol. 2008;126(2):252–258. doi: 10.1001/archophthalmol.2007.36
10. Kulp MT, Ciner E, Maguire M, et al. Attention and visual motor integration in young children with uncorrected hyperopia. Optom Vis Sci. 2017;94:965–970. doi: 10.1097/OPX.0000000000001123
11. Niechwiej-Szwedo E, Thai G, Christian L. Contribution of stereopsis, vergence, and accommodative function to the performance of a precision grasping and placement task in typically developing children age 8–14 years. Hum Mov Sci. 2020;72:102652. doi: 10.1016/j.humov.2020.102652
12. Niechwiej-Szwedo E, Alramis F, Christian LW. Association between fine motor skills and binocular visual function in children with reading difficulties. Hum Mov Sci. 2017;56:1–10. doi: 10.1016/j.humov.2017.10.014
13. Rafique SA, Northway N. Relationship of ocular accommodation and motor skills performance in developmental coordination disorder. Hum Mov Sci. 2015;42:1–14. doi: 10.1016/j.humov.2015.04.006
14. Domkin D, Richter HO, Zetterlund C, et al. Effect of reduced visual acuity on precision of two-dimensional tracing movements. J Optom. 2016;9:93–101. doi: 10.1016/j.optom.2015.03.003
15. Sheppard WEA, Dickerson P, Baraas RC, et al. Exploring the effects of degraded vision on sensorimotor performance. PLOS ONE. 2021;16:e0258678. doi: 10.1371/journal.pone.0258678
16. Cotter SA. Pediatric Eye Disease Investigator Group, Edwards AR et al. Treatment of anisometropic amblyopia in children with refractive correction. Ophthalmology. 2006;113:895–903. doi: 10.1016/j.ophtha.2006.01.068
17. Culmer PR, Levesley MC, Mon-Williams M, et al. A new tool for assessing human movement: the kinematic assessment tool. J Neurosci Methods. 2009;184:184–192. doi: 10.1016/j.jneumeth.2009.07.025
18. Flatters I, Hill LJB, Williams JHG, et al. Manual control age and sex differences in 4 to 11 year old children. PLOS ONE. 2014;9:e88692. doi: 10.1371/journal.pone.0088692
19. Hill LJB, Shire KA, Allen RJ, et al. Large-scale assessment of 7–11-year-olds´ cognitive and sensorimotor function within the Born in Bradford longitudinal birth cohort study [version 2; peer review: 3 approved, 1 approved with reservations]. Wellcome Open Res. 2022;6:53. doi: 10.12688/wellcomeopenres.16429.2
20. Flanagan JR, Vetter P, Johansson RS, et al. Prediction precedes control in motor learning. Curr Biol. 2003;13:146–150. doi: 10.1016/S0960-9822(03)00007-1

21. Desmurget M, Grafton S. Forward modeling allows feedback control for fast reaching movements. Trends Cogn Sci. 2000;4:423–431. doi: 10.1016/S1364-6613(00)01537-0
22. Deng A, Cesanek E, Domini F. Sensory feedback modulates Weber's law of both perception and action. J Vis. 2024;24(13):10–10. doi: 10.1167/jov.24.13.10
23. Statistics Norway. 09817: immigrants and Norwegian-Born to immigrant parents by immigration category, in total and separately, country background and percentages of the population (M) 2010 – 2025 [Statistics]. 2025.
24. Norwegian Institute of Public Health. Folkehelseprofil 2023 Kongsberg [in Norwegian]. 2023.
25. Convergence Insifficiency Treatment Trial Group. The convergence insufficiency treatment trial: design, methods, and baseline data. Ophthalmic Epidemiol. 2008;15:24–36. doi: 10.1080/09286580701772037
26. Burns DH, Allen PM, Edgar DF, et al. Sources of error in clinical measurement of the amplitude of accommodation. J Optom. 2020;13:3–14. doi: 10.1016/j.optom.2019.05.002
27. Shire KA, Andrews E, Barber S, et al. Starting school: a large-scale start of school assessment within the 'Born in Bradford' longitudinal cohort [version 1; peer review: 1 approved, 1 approved with reservations]. Wellcome Open Res. 2020;5:47. doi: 10.12688/wellcomeopenres.15610.1
28. R Core Team. R: a language and environment for statistical computing. In. Vienna: Austria R Foundation for Statistical Computing; 2024.
29. Pinero-Pinto E, Pérez-Cabezas V, De-Hita-Cantalejo C, et al. Vision development differences between slow and fast motor development in typical developing toddlers: a cross-sectional study. Int J Environ Res Public Health. 2020;17:3597. doi: 10.3390/ijerph17103597
30. Leat SJ. To prescribe or not to prescribe? Guidelines for spectacle prescribing in infants and children. Clin Exp Optom. 2011;94:514–527. doi: 10.1111/j.1444-0938.2011.00600.x
31. Huurneman B, Boonstra FN. Assessment of near visual acuity in 0–13 year olds with normal and low vision: a systematic review. BMC Ophthalmol. 2016;16:215. doi: 10.1186/s12886-016-0386-y
32. Hofstetter H. Useful age-amplitude formula. Optom World. 1950;38(12):42–45.
33. Scheiman M, Wick B. Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders. 5th ed. Philadelphia: Wolters Kluwer; 2020.
34. Venables WN, Ripley BD. Modern applied statistics with S. 4th ed. New York: Springer; 2002.
35. Alramis F, Roy E, Christian L, et al. Contribution of binocular vision to the performance of complex manipulation tasks in 5–13 years old visually-normal children. Hum Mov Sci. 2016;46:52–62. doi: 10.1016/j.humov.2015.12.006
36. Ohlsson J, Villarreal G, Abrahamsson M, et al. Screening merits of the Lang II, Frisby, Randot, Titmus, and TNO stereo tests. J Aapos. 2001;5:316–322. doi: 10.1067/mpa.2001.118669
37. Gaul D, Issartel J. Fine motor skill proficiency in typically developing children: on or off the maturation track? Hum Mov Sci. 2016;46:78–85. doi: 10.1016/j.humov.2015.12.011
38. Bjørset CO, Pedersen HR, Synstelien GO, et al. Non-cycloplegic refraction cannot replace cycloplegic refraction in primary school children. Scand J Optom Vis Sci. 2022;15:1–6. doi: 10.15626/sjovs.v15i2.3645
39. Webber AL, Wood JM, Thompson B. Fine motor skills of children with amblyopia improve following binocular treatment. Invest Ophthalmol Vis Sci. 2016;57:4713–4720. doi: 10.1167/iovs.16-19797
40. Hess RF, Mansouri B, Thompson B. A binocular approach to treating amblyopia: antisuppression therapy. Optom Vis Sci. 2010;87:697–704. doi: 10.1097/OPX.0b013e3181ea18e9
41. Baker DH, Lygo FA, Meese TS, et al. Binocular summation revisited: beyond √2. Psychol Bull. 2018;144:1186–1199. doi: 10.1037/bul0000163
42. Hill LJB, Mushtaq F, O'Neill L, et al. The relationship between manual coordination and mental health. Eur Child Adolesc Psychiatry. 2016;25:283–295. doi: 10.1007/s00787-015-0732-2
43. Wilson BN, Crawford SG, Green D, et al. Psychometric properties of the revised developmental coordination disorder questionnaire. Phys Occup Ther Pediatr. 2009;29:182–202. doi: 10.1080/01942630902784761
44. Harter S, Pike R. The pictorial scale of perceived competence and social acceptance for young children. Child Dev. 1984;55:1969–1982. doi: 10.2307/1129772
45. Henderson SE, Sugden DA, Barnett AL. Movement assessment battery for children-2 second edition (movement ABC-2). London, (UK): The Psychological Corporation; 2007.
46. McDermott PA, Watkins MW, Rhoad AM. Whose IQ is it?—Assessor bias variance in high-stakes psychological assessment. Psychol Assess. 2014;26:207–214. doi: 10.1037/a0034832
47. Venetsanou F, Kambas A, Ellinoudis T, et al. Can the movement assessment battery for children-test be the "gold standard" for the motor assessment of children with developmental coordination disorder? Res Dev Disabil. 2011;32:1–10. doi: 10.1016/j.ridd.2010.09.006
48. Schwarzer G. How motor and visual experiences shape infants' visual processing of objects and faces. Child Dev Perspect. 2014;8(4):213–217. doi: 10.1111/cdep.12093