Vision status and reading test results in adolescents in Norway

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Abstract

Uncorrected vision anomalies may cause headaches and may affect reading and academic performance. The purpose of this study was to quantify the frequency of vision anomalies, frequency of eye examinations, and use of corrective eye wear in adolescents in Norway, and to explore whether such vision anomalies affect reading test results or frequency of headaches.

A cross-sectional study was performed in 436 adolescents (42.0% males) aged 16–19 years living in South-East Norway. Cycloplegic autorefraction, habitual stereoacuity, and habitual monocular amplitudes of accommodation were measured, and all participants reported the frequency of eye examinations, the use of spectacles and/or contact lens wear, and the frequency of headaches. Reading comprehension and decoding skills were evaluated for a subgroup of the participants (189 participants, 34.4% males) by their performance in national reading tests. Vision anomalies were defined as having refractive errors, poor habitual stereoacuity, or poor habitual amplitude of accommodation in at least one eye.

Overall, 44.0% were classified as having a refractive error, and a total of 61.9% were measured to have vision anomalies. More frequent headaches were associated with poor habitual amplitude of accommodation when adjusted for sex (p=0.04). The frequency of poor reading comprehension was higher in the group of adolescents with vision anomalies (n=109, 31.2%) compared with those with no vision anomalies (n=80, 18.8%; p=0.05). Of those with vision anomalies, 33.5% had never had an eye examination, and 63.9% reported not wearing a correction.

In Norway, there is no mandatory vision screening after 4 years of age. The results here show that a nation-wide programme of regular eye examinations and proper treatment of vision anomalies for all children and adolescents in Norway should be considered. Identifying and treating children with common eye problems in primary and secondary school will improve educational attainment and increase each child's chances of succeeding in further education.

Keywords: Refractive error, accommodation, hyperopia, headache, reading comprehension

Sammendrag

Ukorrigerte synsfeil kan gi hodepine og påvirke lesing og skoleprestasjoner. Hensikten med denne studien var å undersøke forekomsten av synsfeil, hyppigheten av synsundersøkelser og bruken av synskorreksjon blant ungdommer i Norge, samt undersøke om vanlige synsfeil påvirker resultatene på lesetester eller hyppigheten av hodepine.

En tverrsnittstudie ble utført på 436 ungdommer (42,0% menn) i alderen 16–19 år som alle bodde i Sørøst-Norge. Brytningsfeil ble målt under cycloplegi ved hjelp av autorefraktor, det ble målt habituell visus og habituell akkommodasjonsamplitude, og alle deltakerne rapporterte om hyppigheten av synsundersøkelser, bruken av briller og/eller kontaktlinser, samt hyppigheten av hodepine. For et utvalg av ungdommene (189 deltakere, 34,4% menn) ble leseforståelse og ordavkodingsferdigheter undersøkt ved hjelp av resultater fra nasjonale kartleggingsprøver i lesing. Synsfeil ble definert som å ha en brytningsfeil og/eller redusert habituelt stereosyn eller redusert habituell akkommodasjonsamplitude på minst ett øye.

Totalt ble 44,0% klassifisert som å ha en brytningsfeil og 61,9% ble klassifisert som å ha en synsfeil. Resultatene viste at det var en sammenheng mellom hyppig hodepine og redusert akkommodasjonsamplitude, når forskjellen mellom kjønn ble justert for (p = 0,04). Forekomsten av redusert leseforståelse var høyere blant ungdommene som hadde synsfeil (n=109, 31,2%) sammenlignet med de uten synsfeil (n=80, 18,8%; p = 0,05). Blant ungdommene med synsfeil, hadde 33,5% aldri hatt en synsundersøkelse, og 63,9% rapporterte at de ikke brukte synskorreksjon.

I Norge er det ingen obligatorisk oppfølging av syn etter at et barn er 4 år. Resultatene fra denne studien viser derimot at innføring av et nasjonalt system for gjennomføring av regelmessige synsundersøkelser og behandling av synsfeil for alle barn og ungdommer i Norge bør vurderes. Å identifisere og behandle barn med vanlige synsproblemer – i grunnskolen og i videregående skole – vil både forbedre skoleprestasjonene og øke sjansene for å lykkes i videreutdanning.

Nøkkelord: Brytningsfeil, akkommodasjon, hypermetropi, hodepine, leseforståelse

Introduction

Perseverance and efficient performance at school requires good visual acuity, as well as sustained accommodation and convergence (Narayanasamy et al., 2016). Common vision anomalies that remain untreated have been reported to affect reading and academic performance, in particular uncorrected hyperopia (Kulp et al., 2016; Narayanasamy et al., 2015a; Rosner & Rosner, 1997; Shankar et al., 2007; van Rijn et al., 2014), uncorrected astigmatism (Harvey et al., 2016; Narayanasamy et al., 2015b), and reduced stereoacuity (Kulp et al., 2016). Furthermore, vision anomalies have been reported to be more prevalent in children and adolescents with dyslexia compared with controls (Vikesdal et al., 2020), and hyperopia, astigmatism, and strabismus are reported to be associated with attention deficit hyperactivity disorder (Reimelt et al., 2018).

Hyperopia is often associated with anisometropia, binocular dysfunctions, and an increased risk of amblyopia (Cotter et al., 2011; Ip et al., 2008; Klimek et al., 2004; Kulp et al., 2014; Pascual et al., 2014). Since low-to-moderate degrees of hyperopia do not necessarily reduce visual acuity in children and adolescents (Mutti, 2007), hyperopia is prone to remain undetected. A comprehensive eye examination with the use of cycloplegia is usually needed to detect the correct refractive error (Morgan et al., 2015; Sun et al., 2018; Zhu et al., 2016).

Hyperopia has been reported to be the most prevalent refractive error in adolescents in Norway, whereas the prevalence of myopia was found to be low (L. A. Hagen et al., 2018). Even though Norway is a highly developed country with a well-established welfare system, there is no mandatory vision screening after a child is 4 years old (Norwegian Directorate of Health, 2006). Beyond this age, the child's guardians are solely responsible for initiating and ensuring appropriate follow-up of eye health and visual function in their children. As a consequence, in Norway, some children and adolescents with common vision anomalies may never have had their eyes examined and may therefore not have been offered treatment that could have

improved their visual acuity, their perseverance for doing near work, or their ability to read for longer periods. Proper treatment of common vision anomalies has been reported to reduce symptoms such as asthenopia, tiredness, and headache (Abdi & Rydberg, 2005; Sterner et al., 2006). To our knowledge, there are no previous reports of the prevalence of common vision anomalies, frequency of eye examinations, and use of corrective eye wear in adolescents in Norway.

The purpose of this study was to quantify the frequency of common vision anomalies, the frequency of eye examinations, and the use of spectacles and/or contact lenses, as well as to explore the association between (i) vision anomalies and headaches (often a symptom of vision anomalies), and (ii) vision anomalies and reading test results, in 16–19 years old adolescents in Norway.

Methods

A cross-sectional study was performed in 2015–2016 on 439 adolescents aged 16–19 years (mean ± *SD* age: 16.7 ± 0.9 years; 41.9% males) living in South-East Norway. The majority of the participants (89.5%) were of Northern European Caucasian ethnicity. Cycloplegic autorefraction was measured in all participants with a Huvitz HRK-8000A Auto-REF Keratometer (Huvitz Co. Ltd., Gyeonggi-do, Korea) 15–20 minutes after administering 1% cyclopentolate hydrochloride (Minims single dose; Bausch & Lomb UK Ltd., Kingston, England); 1 drop was used in eyes with blue to green irides and 2 drops in eyes with green to brown irides. This was to ensure that sufficient depth of cycloplegia was reached with minimal amount of side effects for the participants. The depth of cycloplegia was monitored by a trained optometrist, who evaluated the dilation of the pupil, before performing the autorefraction. If sufficient depth of cycloplegia was not reached after 15–20 minutes, an additional drop of cyclopentolate was administered. The participants were recruited at two upper secondary schools, and all measurements were performed at the schools by a group of five qualified optometrists. Details on recruitment, as well as the prevalence of refractive errors and ocular biometry data have been presented previously (L. A. Hagen et al., 2018).

Habitual stereoacuity was measured as retinal disparities ranging from 15 to 480 seconds of arc (″) with the TNO Stereotest (Laméris Ootech, WC Ede, Netherlands) at 40 cm distance. Habitual monocular amplitude of accommodation was measured in dioptres (D) three times for each eye by the push-up method using the Royal Air Force (RAF) ruler (Burns et al., 2020). The mean of the three measurements was used in the analyses.

A face-to-face interview was performed to gather information on age, sex, ethnicity, and frequency of eye examinations. The participants responded to a questionnaire related to the use of corrective eye wear (spectacles and/or contact lenses) and the frequency of headaches when reading or doing near work. The questionnaire used in the study can be found online – in the Norwegian language (L. A. Hagen et al., 2020). Three participants did not respond to the questionnaire and were excluded from further analyses. This gave a total study sample of 436 adolescents (16.7 ± 0.9 years; 42.0% males; 89.7% of Northern European Caucasian ethnicity).

A reading test was administered by the school teachers with the aim to identify students with poor reading skills (defined as test score below an acceptable level), while the test was not designed to distinguish students with medium and good reading skills. The reading test used was a standardised national assessment ["Obligatorisk kartleggingsprøve, Lesing, Vg1"; The Norwegian Directorate for Education and Training, Norway (Utdanningsdirektoratet, 2014)] taken by the students at the time they entered upper secondary school (age 15–16 years). Reading comprehension was tested by a complex subject text and a fictional text – both with related questions (max 19 + 15 points) to be answered within 20 and 15 minutes, respectively, while decoding skills were tested with a word chain test of 5 minutes duration (max 74 points). In the analyses here, test scores below acceptance (11, 9, and 41 points, respectively) were defined as fails. Reading test results were available for a subgroup of the participants (189 participants; 43.3% of all, 34.4% males, 93.1% Northern European Caucasians), who all reported having grown up in Norway.

Spherical equivalent refractive errors (SER = sphere + ½ cylinder) in both eyes were used to categorize the refractive error. Myopes were defined as having SER ≤ −0.75D in at least one eye, moderate-to-high hyperopes as having SER ≥ +2.00D in at least one eye, and low hyperopes as having +1.00D ≤ SER < +2.00D in at least one eye – the latter was given that there were no myopia or moderate-to-high hyperopia in the other eye. Emmetropes were defined as having −0.75D < SER < +1.00D in both eyes, except from the emmetropes who had more than 1.00DC astigmatism in at least one eye who were categorized as having astigmatism only. Anisometropia was defined as a difference in SER ≥ 1.00D between the two eyes. Poor stereoacuity was defined as habitual stereoacuity poorer than 120″, and poor accommodation was defined as habitual monocular amplitude of accommodation lower than 8D in at least one eye; this is 2–3D less than Hofstetter's minimum age formula: 15 − (0.25 × age) for 16–19-year-olds (Cacho-Martínez et al., 2014). In two participants, habitual monocular amplitude of accommodation was measured in one eye only due to amblyopia in the other eye; both participants were categorized as having poor habitual amplitude of accommodation. Accommodation data is missing for one male participant. Binocular visual dysfunction (BVD) was defined as having poor habitual stereoacuity (poorer than 120″) and/or poor habitual amplitude of accommodation (lower than 8D in at least one eye).

Differences in prevalence and mean values between groups were assessed by the chi-square test and Welch's two independent sample *t*-tests. Ordinal logistic regression analyses were performed with the frequency of headache as the dependent outcome variable, and odds ratios (OR) and 95% confidence intervals (CI) are presented. The significance level was set at 0.05. All statistical analyses were performed using R statistical software, version 3.6.1 (R Core Team, 2019).

The study followed the tenets of the Declaration of Helsinki and was approved by the Regional Committee for Medical and Health Research Ethics in Southeast Norway. All participants gave informed consent prior to inclusion in the study.

Results

Refractive errors, stereoacuity, and accommodation

Table 1 summarizes the frequency of refractive errors in all participants and grouped by sex. Overall, 44.0% were classified as having a refractive error in at least one eye. There was a tendency that refractive errors were more common in females than males [47.0% vs 39.9%; $\chi^2(1)=2.2$, $p=0.14$], and myopia was significantly more prevalent in females than males [14.2% vs 7.1%; $\chi^2(1)=5.4$, $p=0.02$]. Astigmatism (more than 1.00DC in at least one eye) and anisometropia were present in 11.9% and 3.2% of all participants, respectively, with higher frequency in the moderate-to-high hyperopes (34.5% and 34.5%, respectively) and myopes (34.7% and 8.2%, respectively) compared with the low hyperopes (6.3% and 0.0%, respectively). Anisometropia was not present in the group of emmetropes.

Habitual stereoacuity poorer than 120″ was found in 14.9% [females: 12.7%, males: 18.0%; $\chi^2(1)=2.4$, $p=0.12$], whereas ha-

bitual amplitude of accommodation lower than 8D was found in 25.3% (of n=235; accommodation data is missing for one male participant) [females: 27.7%, males: 22.0%; $\chi^2(1)=1.8$, $p=0.18$]. Table 2 shows that poor habitual stereoacuity and/or poor habitual amplitude of accommodation was most frequent in moderate-to-high hyperopes (poor stereoacuity only: 17.2%, poor amplitude of accommodation only: 41.4%, combination of both: 24.1%). The mean habitual monocular amplitude of accommodation in the best eye was significantly poorer in those who were moderate-to-high hyperopes (n=29; 8.6±2.0 D) compared with those who were not [n=407; 10.5±2.2 D, Welch's $t(32.7)=4.77$, $p<0.001$]. In the group of emmetropes, 9.0% had poor habitual stereoacuity only, 20.1% had poor habitual amplitude of accommodation only, whereas 2.9% had a combination of both. This gives a total of 270 participants (61.9% of all; females: 64.8%; males: 57.4%) who had refractive error and/or binocular visual dysfunction (BVD; defined as poor habitual stereoacuity and/or poor habitual amplitude of accommodation).

Table 1: *Prevalence of refractive errors in all participants and grouped by sex.*

	All (n=436)		Females (n=253)		Males (n=183)	
	%	n	%	n	%	n
Emmetropia	56.0	244	53.0	134	60.1	110
Refractive errors overall	44.0	192	47.0	119	39.9	73
Low hyperopia	21.8	95	23.7	60	19.1	35
Moderate-high hyperopia	6.7	29	5.1	13	8.7	16
Myopia	11.2	49	14.2	36	7.1	13
Astigmatism only	4.4	19	4.0	10	4.9	9

Overall, regular headaches were reported by 8.5%, while 66.1% reported rarely experiencing headaches. Significantly more females than males reported regular headache [regular headache: females 12.6%, males 2.7%; rare headache: females 57.3%, males 78.1%; $\chi^2(2)=24.2$, $p<0.001$]. As shown in Table 3, more frequent headaches were associated with poor habitual amplitude of accommodation (model A; p = 0.04) and having moderate to high hyperopia (model B; p = 0.04), when adjusted for sex.

Table 2: *Frequency (%) of binocular vision dysfunction (BVD) grouped by refractive error.*

	n	Poor stereoacuity only	Poor accommodation only	Both	No BVD
All	435*	9.0	19.5	5.7	65.7
Emmetropes	244	9.0	20.1	2.9	68.0
Low hyperopes	94*	8.5	18.1	8.5	64.9
Moderate-high hyperopes	29	17.2	41.4	24.1	17.2
Myopes	49	6.1	8.2	4.1	81.6
Astigmatism only	19	5.3	15.8	5.3	73.7

Note: BVD = binocular visual dysfunction [defined as poor habitual stereoacuity (TNO > 120") and/or poor habitual amplitude of accommodation (less than 8D in at least one eye)]
* Accommodation data is missing for one participant

Frequency of eye examinations and use of corrective eye wear

Table 4 summarizes the self-reported frequency of eye examinations and the use of corrective eye wear overall and grouped by refractive error. Overall, 39.0% reported never having had an eye examination, whereas 47.7% reported having had an eye examination within the last three years. A total of 33.5% of those with refractive errors and/or BVD reported never having had an eye examination; significantly more males than females [41.9% vs 28.0%; $\chi^2(1)=5.5$, $p=0.02$].

Overall, 72.0% reported never wearing any correction, whereas 14.0% reported wearing a correction frequently. Corrective eye wear was most frequently worn by the myopes (frequent wear: 71.4%). In those with refractive errors and/or BVD, 63.9% reported never wearing any correction. More males (71.4%) than females (59.1%) of those with refractive errors and/or BVD reported never wearing any correction, but the association between the frequency of wearing corrective eye wear and sex did not reach significance [$\chi^2(2)=4.4$, $p=0.11$].

Reading test results

Reading test results were available in a subsample (n=189). Of these, 25.9% failed at least one of the reading comprehension texts, with no difference in the frequency of fails between females and males (25.8% vs 26.2%). There was a near significant association between failing at least one of the reading comprehension texts and having a refractive error and/or BVD [31.2% fail in those with refractive error and/or BVD (n=109) vs 18.8% fail in those without refractive error and/or BVD (n=80); $\chi^2(1)=3.7$, $p=0.05$]. When restricting the analyses to the group of participants who reported never wearing a correction (n=123), the association between failing at least one of the reading comprehension texts and having a refractive error and/or BVD reached significance [29.5% fail in those with refractive error and/or BVD (n=61) vs 14.5% fail in those without refractive error and/or BVD (n=62); $\chi^2(1)=4.0$, $p=0.04$]. In those who reported not wearing a correction, mean score on the reading comprehension texts was significantly lower in those with refractive error and/or BVD (n=61; 25.1 ± 4.9 points) compared to those without refractive errors and/or BVD [n=62; 28.3±7.3 points, Welch's $t(104.3)=2.82$, $p=0.006$].

Decoding skills were tested with a word chain test, and overall, 18.5% failed this test. There were more males than females who failed the decoding skills test [27.7% vs 13.7%; $\chi^2(1)=5.5$, $p=0.02$], but no associations were found between failing the decoding skills test and having a refractive error and/or BVD.

Discussion

This is the first report that explores the frequency of refractive errors, and accommodative and binocular visual dysfunctions – and the associations between these common vision anomalies, headaches and reading test results – in a representative sample of 16–19 years old adolescents in South-East Norway. Regular headaches were more frequent in females than males and were found to be associated with poor habitual accommodation. Refractive errors and/or accommodative or binocular visual dysfunctions were revealed in more than 60% of the adolescents – with a higher frequency of poor reading comprehension in those with vision anomalies compared to those with normal visual function. This is in line with several other reports that show that common eye problems interfere with learning (Harvey et al., 2016; Kulp et al., 2016; Narayanasamy et al., 2015a; Rosner & Rosner, 1997; Shankar et al., 2007; van Rijn et al., 2014). Learning difficulties that arise in primary or secondary school will affect the chances of success in further education. It is therefore a societal concern when, of the adolescents in Norway who had vision anomalies, about 30% reported never having had an eye examination, and about 60% reported not wearing a refractive correction.

Hyperopia is known to be associated with accommodative and binocular vision anomalies, as well as increased risk of amblyopia (Cotter et al., 2011; Klimek et al., 2004; Kulp et al., 2014; Pascual et al., 2014). In the adolescents in Norway, hyperopia

Table 3: *Ordinal logistic regression models with the frequency of headache ("regular", "sometimes" or "rare") as the outcome variable and "sex" as a potential confounder.*

Outcome variable:	Model A				Model B		
Frequency of headache	β	OR (2.5 - 97.5 CI)	*p*		β	OR (2.5 - 97.5 CI)	*p*
Potential confounder: Sex, female	0.71	2.03(1.51 – 2.76)	<0.001	Sex, female	0.76	2.14(1.58 – 2.92)	<0.001
Predictor: Accommodation, poor	0.34	1.40(1.02 – 1.91)	0.04	Moderate-high hyperopia	0.80	2.23(1.02 – 4.75)	0.04

Note: Model A: the state of habitual amplitude of accommodation (poor vs normal) as predictor. Model B: moderate-to-high hyperopia in at least one eye as predictor. Odds ratios (OR) and confidence intervals (CI) are presented.

Table 4: *Frequency (%) of eye examinations and use of corrective eye wear, overall and grouped by refractive error.*

	Eye examination (%)			Corrective eye wear (%)		
	Recent	> 3 years old	Never	Frequent	Sporadic	Never
All (*n*=436)	47.7	13.3	39.0	14.0	14.0	72.0
Emmetropes						
With no BVD (*n*=166)	35.5	16.3	48.2	3.6	11.5	84.9
With BVD (*n*=78)	47.4	12.8	39.7	5.1	18.0	76.9
Low hyeropes*						
With no BVD (*n*=61)	31.2	13.1	55.7	1.6	9.8	88.5
With BVD (*n*=33)	54.6	15.2	30.3	9.1	12.1	78.8
Moderate-high hyperopes (*n*=29)	75.9	3.5	20.7	41.4	24.1	34.5
Myopes (*n*=49)	87.8	10.2	2.0	71.4	18.4	10.2
Astigmatism only (*n*=19)	47.4	10.5	42.1	0.0	10.5	89.5
All with refractive error and/or BVD						
All (*n*=29)	55.0	11.5	33.5	20.5	15.6	63.9
Females (*n*=164)	59.8	12.2	28.0	22.6	18.3	59.1
Males (*n*=105)	47.6	10.5	41.9	17.1	11.4	71.4

Note: BVD = binocular visual dysfunction (defined as poor habitual stereoacuity and/or poor habitual amplitude of accommodation).

* Accommodation data is missing for one participant.

was the most common refractive error (L. A. Hagen et al., 2018), and the results here confirmed high frequency of poor habitual amplitude of accommodation (65.5%), poor habitual stereoacuity (41.3%), astigmatism (34.5%), and anisometropia (34.5%) in the moderate-to-high hyperopes (see Results and Table 2). Since most children are hyperopic at birth and in early childhood (Mutti et al., 2018), it is likely that the moderate-to-high hyperopic adolescents have had a hyperopic refractive error throughout their whole life. When left untreated, hyperopia and accommodative or binocular vision anomalies may cause headaches and tiredness (Abdi & Rydberg, 2005; Borsting et al., 2003; Sterner et al., 2006) reducing near work perseverance and therefore academic performance (Kulp et al., 2016; Narayanasamy et al., 2015a; Palomo-Álvarez & Puell, 2008; Shankar et al., 2007; van Rijn et al., 2014).

Regular headaches were, in the adolescents in Norway, reported by more females (12.6%) than males (2.7%). These results were comparable with a previous report on regular headache (defined as more than 6 days per month) in young adults in Norway [11.6% and 4.4% in 20–29 years old females (*n*=4002) and males (*n*=3106), respectively] (K. Hagen et al., 2000). Another study in adolescents in Norway (age 12–18 years) reported headaches to be a major health issue that caused loss of up to nine days of activity each year (Krogh et al., 2015). In the mentioned study regular headaches (more than 1 day per week) were present in 21.0% of females (*n*=276) and 9.5% of males (*n*=212) (Krogh et al., 2015). For migraine, several studies have reported a higher frequency in females than males, whereas for other headache categories, the difference between females and males seems to be smaller (Buse et al., 2013; Stovner et al., 2006). Note that the data in our study did not differentiate between migraine and other headache categories.

More frequent headaches were found to be associated with poor habitual amplitude of accommodation, and with moderate-to-high hyperopia, when corrected for sex (see Table 3). The association between regular headaches and moderate-to-high hyperopia may be a consequence of the high frequency of poor habitual amplitude of accommodation in the moderate-to-high hyperopes (65.5%; see Table 2), partly caused by uncorrected hyperopic refractive errors that exceed the individuals' accommodation ability. Common consequences of poor accommodation are reduced visual acuity at near (blurred text when reading) and asthenopia (Abdi & Rydberg, 2005; Borsting et al., 2003; Sterner et al., 2006). Other factors could, however, also have affected the reported frequency of headaches. A previous study in 13–18 years old adolescents in Norway (*n*=5847) found negative lifestyle factors such as being overweight, smoking, and low levels of physical activity to be associated with regular headaches (Robberstad et al., 2010), but did not include any measurements of refractive errors or visual function. While 9% of the adolescents in our study experienced regular headaches, 66% reported rarely experiencing headaches. Since headaches may impair daily functioning in activities such as reading and learning, it is important to identify the adolescents who suffer from headaches at an early stage and to offer appropriate treatment. The associations found in this study, between regular headaches and poor amplitude of accommodation as well as moderate-to-high hyperopia, show the importance of a comprehensive eye examination to identify possible vision anomalies in these cases.

A higher frequency of poor reading comprehension and a lower mean reading comprehension test score were found in the adolescents in Norway with uncorrected vision anomalies compared to those with normal visual function. This is in line with previous reports of a higher frequency of vision anomalies in children and adults who have difficulties reading (Palomo-

Álvarez & Puell, 2008; Quaid & Simpson, 2013; Vikesdal et al., 2020). No associations were found between decoding skills and having refractive errors, accommodative or binocular vision dysfunctions in the adolescents in Norway. In line with this, correction of hyperopia in 9–10 years old children has been reported to improve reading fluency, however, not decoding of words (van Rijn et al., 2014). van Rijn et al. (2014) suggested poor accommodation to have a greater impact on the speed and fluency of reading – skills that are important for reading comprehension – than on the ability to identify single words such as in decoding tasks.

Since undetected vision anomalies may cause reduced visual function and consequently affect performance at school, it is of great concern that, of the adolescents in Norway with refractive errors, accommodative anomalies, or binocular vision dysfunctions, as many as 30% reported never having had an eye examination and furthermore, that around 60% of the adolescents with vision anomalies did not wear a correction (see Table 4). Reports show that 25% of upper secondary school students in Norway have not completed their upper secondary education (3 years full-time) within five years, and more males (30%) than females (19%) drop out of upper secondary education (Statistics Norway, 2019). Note that both dropouts of upper secondary education (Statistics Norway, 2019) and the lack of eye examinations and corrective eye wear (Table 4) were more prevalent in males compared with females. There are no reports of the association between vision anomalies and dropouts of upper secondary school in Norway, but it is plausible that early detection and proper treatment of common eye and vision problems could have made reading and learning easier for some of these students, and possibly helped them to reach their educational goals (Dudovitz et al., 2016). The high frequency of undetected vision anomalies in adolescents in Norway underscores the importance of having a well-established system for detection, correction, and follow-up of vision problems in schoolchildren at an early age – and as soon as the need develops. A well-established system must ensure that each individual child has the best visual conditions, with the aim to facilitate optimal ocular development and the best possible academic performance.

A limitation in this study was that the reading test results were restricted to a single test in a subgroup of the participants, which may make the test results vulnerable to confounding factors such as distractions, motivation, and interest. However, the results in this study were in line with previous studies on the association between reading and common vision anomalies (Palomo-Álvarez & Puell, 2008; Quaid & Simpson, 2013; Vikesdal et al., 2020).

Conclusion

This study revealed refractive errors, accommodative anomalies, or binocular vision dysfunctions in about 60% of 16–19-year-olds in Norway. Poor reading comprehension was more frequent in those with vision anomalies compared to those with normal visual function, headaches were found to be associated with poor accommodation, and about 30% of the adolescents with vision anomalies had never had an eye examination. These results suggest that a better public health system to detect and treat vision anomalies in children and adolescents in Norway is needed. A well-established system that ensures the performance of a comprehensive eye examination with cycloplegia and a proper choice of treatment for children and adolescents who need it, will make education easier for school children and students who suffer from vision anomalies.

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References

Abdi, S., & Rydberg, A. (2005). Asthenopia in schoolchildren, orthoptic and ophthalmological findings and treatment. *Documenta Ophthalmologica*, *111*(2), 65–72. https://doi.org/10.1007/s10633-005-4722-4

Borsting, E., Rouse, M. W., Deland, P. N., Hovett, S., Kimura, D., Park, M., & Stephens, B. (2003). Association of symptoms and convergence and accommodative insufficiency in school-age children. *Optometry*, *74*(1), 25–34.

Burns, D. H., Allen, P. M., Edgar, D. F., & Evans, B. J. W. (2020). Sources of error in clinical measurement of the amplitude of accommodation. *Journal of Optometry*, *13*(1), 3–14. https://doi.org/10.1016/j.optom.2019.05.002

Buse, D. C., Loder, E. W., Gorman, J. A., Stewart, W. F., Reed, M. L., Fanning, K. M., Serrano, D., & Lipton, R. B. (2013). Sex differences in the prevalence, symptoms, and associated features of migraine, probable migraine and other severe headache: Results of the American Migraine Prevalence and Prevention (AMPP) study. *Headache*, *53*(8), 1278–99. https://doi.org/10.1111/head.12150

Cacho-Martínez, P., García-Muñoz, Á., & Ruiz-Cantero, M. T. (2014). Is there any evidence for the validity of diagnostic criteria used for accommodative and nonstrabismic binocular dysfunctions? *Journal of Optometry*, *7*(1), 2–21. https://doi.org/10.1016/j.optom.2013.01.004

Cotter, S. A., Varma, R., Tarczy-Hornoch, K., McKean-Cowdin, R., Lin, J., Wen, G., Wei, J., Borchert, M., Azen, S. P., Torres, M., Tielsch, J. M., Friedman, D. S., Repka, M. X., Katz, J., Ibironke, J., & Giordano, L. (2011). Risk factors associated with childhood strabismus: The multi-ethnic pediatric eye disease and baltimore pediatric eye disease studies. *Ophthalmology*, *118*(11), 2251–2261. https://doi.org/10.1016/j.ophtha.2011.06.032

Dudovitz, R. N., Izadpanah, N., Chung, P. J., & Slusser, W. (2016). Parent, teacher, and student perspectives on how corrective lenses improve child well-being and school function. *Maternal and Child Health Journal volume*, *20*(5), 974–83. https://doi.org/10.1007/s10995-015-1882-z

Hagen, K., Zwart, J. A., Vatten, L., Stovner, L. J., & Bovim, G. (2000). Prevalence of migraine and non-migrainous headache–head-HUNT, a large population-based study. *Cephalalgia*, *20*(10), 900–6. https://doi.org/10.1046/j.1468-2982.2000.00145.x

Hagen, L. A., Gilson, S. J., & Baraas, R. C. (2020). The Questionnaire used in Hagen et al. Prevalence and Possible Factors of Myopia in Norwegian Adolescents. Scientific Reports 2018. https://doi.org/10.23642/usn.11890626

Hagen, L. A., Gjelle, J. V. B., Arnegard, S., Pedersen, H. R., Gilson, S. J., & Baraas, R. C. (2018). Prevalence and possible factors of myopia in Norwegian adolescents. *Scientific Reports*, *8*(1), 13479. https://doi.org/10.1038/s41598-018-31790-y

Harvey, E. M., Miller, J. M., Twelker, J. D., & Davis, A. L. (2016). Reading fluency in school-aged children with bilateral astigmatism. *Optometry and Vision Science*, *93*(2), 118–25. https://doi.org/10.1097/opx.0000000000000779

Ip, J. M., Robaei, D., Kifley, A., Wang, J. J., Rose, K. A., & Mitchell, P. (2008). Prevalence of hyperopia and associations with eye findings in 6- and 12-year-olds. *Ophthalmology*, *115*(4), 678–685.e1. https://doi.org/10.1016/j.ophtha.2007.04.061

Klimek, D. L., Cruz, O. A., Scott, W. E., & Davitt, B. V. (2004). Isoametropic amblyopia due to high hyperopia in children. *Journal of the American Association for Pediatric Ophthalmology and Strabismu*, *8*(4), 310–3. https://doi.org/10.1016/j.jaapos.2004.05.007

Krogh, A. B., Larsson, B., & Linde, M. (2015). Prevalence and disability of headache among norwegian adolescents: A cross-sectional school-based study. *Cephalalgia*, *35*(13), 1181–91. https://doi.org/10.1177/0333102415573512

Kulp, M. T., Ciner, E., Maguire, M., Moore, B., Pentimonti, J., Pistilli, M., Cyert, L., Candy, T. R., Quinn, G., & Ying, G. S. (2016). Uncorrected hyperopia and preschool early literacy: Results of the Vision in Preschoolers-Hyperopia in Preschoolers (VIP-HIP) study. *Ophthalmology*, *123*(4), 681–9. https://doi.org/10.1016/j.ophtha.2015.11.023

Kulp, M. T., Ying, G. S., Huang, J., Maguire, M., Quinn, G., Ciner, E. B., Cyert, L. A., Orel-Bixler, D. A., & Moore, B. D. (2014). Associations between hyperopia and other vision and refractive error characteristics. *Optometry and Vision Science*, *91*(4), 383–9. https://doi.org/10.1097/opx.0000000000000223

Morgan, I. G., Iribarren, R., Fotouhi, A., & Grzybowski, A. (2015). Cycloplegic refraction is the gold standard for epidemiological studies. *Acta Ophthalmologica*, *93*(6), 581–5. https://doi.org/10.1111/aos.12642

Mutti, D. O. (2007). To emmetropize or not to emmetropize? the question for hyperopic development. *Optometry and Vision Science*, *84*(2), 97–102. https://doi.org/10.1097/OPX.0b013e318031b079

Mutti, D. O., Sinnott, L. T., Lynn Mitchell, G., Jordan, L. A., Friedman, N. E., Frane, S. L., & Lin, W. K. (2018). Ocular component development during infancy and early childhood. *Optometry and Vision Science*, *95*(11), 976–985. https://doi.org/10.1097/opx.0000000000001296

Narayanasamy, S., Vincent, S. J., Sampson, G. P., & Wood, J. M. (2015a). Impact of simulated hyperopia on academic-related performance in children. *Optometry and Vision Science*, *92*(2), 227–36. https://doi.org/10.1097/opx.0000000000000467

Narayanasamy, S., Vincent, S. J., Sampson, G. P., & Wood, J. M. (2015b). Simulated astigmatism impairs academic-related performance in children. *Ophthalmic & Physiological Optics*, *35*(1), 8–18. https://doi.org/10.1111/opo.12165

Narayanasamy, S., Vincent, S. J., Sampson, G. P., & Wood, J. M. (2016). Visual demands in modern australian primary school classrooms. *Clinical and Experimental Optometry*, *99*(3), 233–40. https://doi.org/10.1111/cxo.12365

Norwegian Directorate of Health. (2006). Retningslinjer for undersøkelse av syn, hørsel og språk hos barn [in norwegian]. https://www.helsedirektoratet.no/retningslinjer/helsestasjons-og-skolehelsetjenesten/helsestasjon-05-ar/horsel-syn-og-sprak/Unders%C3%B8kelse%20av%20syn,%20h%C3%B8rsel%20og%20spr%C3%A5k%20hos%20barn%20%E2%80%93%20Nasjonal%20faglig%20retningslinje.pdf

Palomo-Álvarez, C., & Puell, M. C. (2008). Accommodative function in school children with reading difficulties. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *246*(12), 1769–1774. https://doi.org/10.1007/s00417-008-0921-5

Pascual, M., Huang, J., Maguire, M. G., Kulp, M. T., Quinn, G. E., Ciner, E., Cyert, L. A., Orel-Bixler, D., Moore, B., & Ying, G. S. (2014). Risk factors for amblyopia in the vision in preschoolers study. *Ophthalmology*, *121*(3), 622–9.e1. https://doi.org/10.1016/j.ophtha.2013.08.040

Quaid, P., & Simpson, T. (2013). Association between reading speed, cycloplegic refractive error, and oculomotor function in reading disabled children versus controls. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *251*(1), 169–87. https://doi.org/10.1007/s00417-012-2135-0

R Core Team. (2019). R: A language and environment for statistical computing. https://www.R-project.org

Reimelt, C., Wolff, N., Hölling, H., Mogwitz, S., Ehrlich, S., & Roessner, V. (2018). The underestimated role of refractive error (hyperopia, myopia, and astigmatism) and strabismus in children with ADHD. *Journal of Attention Disorders*, 1087054718808599. https://doi.org/10.1177/1087054718808599

Robberstad, L., Dyb, G., Hagen, K., Stovner, L. J., Holmen, T. L., & Zwart, J. A. (2010). An unfavorable lifestyle and recurrent headaches among adolescents: The HUNT study. *Neurology*, *75*(8), 712–7. https://doi.org/10.1212/WNL.0b013e3181eee244

Rosner, J., & Rosner, J. (1997). The relationship between moderate hyperopia and academic achievement: How much plus is enough? *Journal of the American Optometry Association*, *68*(10), 648–50.

Shankar, S., Evans, M. A., & Bobier, W. R. (2007). Hyperopia and emergent literacy of young children: Pilot study. *Optometry and Vision Science*, *84*(11), 1031–8. https://doi.org/10.1097/OPX.0b013e318157a67a

Statistics Norway. (2019). Completion rates of pupils in upper secondary education. https://www.ssb.no/en/utdanning/statistikker/vgogjen

Sterner, B., Gellerstedt, M., & Sjöström, A. (2006). Accommodation and the relationship to subjective symptoms with near work for young school children. *Ophthalmic & Physiological Optics*, *26*(2), 148–55. https://doi.org/10.1111/j.1475-1313.2006.00364.x

Stovner, L. J., Zwart, J. A., Hagen, K., Terwindt, G. M., & Pascual, J. (2006). Epidemiology of headache in Europe. *European Journal of Neurology*, *13*(4), 333–45. https://doi.org/10.1111/j.1468-1331.2006.01184.x

Sun, Y. Y., Wei, S. F., Li, S. M., Hu, J. P., Yang, X. H., Cao, K., Lin, C. X., Du, J. L., Guo, J. Y., Li, H., Liu, L. R., Morgan, I. G., & Wang, N. L. (2018). Cycloplegic refraction by 1% cyclopentolate in young adults: is it the gold standard? The Anyang University Students Eye Study (AUSES). *British Journal of Ophthalmology*. https://doi.org/10.1136/bjophthalmol-2018-312199

Utdanningsdirektoratet. (2014). Retningslinjer for gjennomføring av kartleggingsprøver for Vg1 høsten 2014. https://www.udir.no/globalassets/upload/kartleggingsprover/vg1_2014/retningslinjer-kp-vg1-2014-bm.pdf

van Rijn, L. J., Krijnen, J. S., Nefkens-Molster, A. E., Wensing, K., Gutker, E., & Knol, D. L. (2014). Spectacles may improve reading speed in children with hyperopia. *Optometry and Vision Science*, *91*(4), 397–403. https://doi.org/10.1097/opx.0000000000000206

Vikesdal, G. H., Mon-Williams, M., & Langaas, T. (2020). Optometric disorders in children and adults with dyslexia. *Scandinavian Journal of Educational Research*, *64*(4), 601–611. https://doi.org/10.1080/00313831.2019.1595715

Zhu, D., Wang, Y., Yang, X., Yang, D., Guo, K., Guo, Y., Jing, X., & Pan, C. W. (2016). Pre- and postcycloplegic refractions in children and adolescents. *PLoS One*, *11*(12), e0167628. https://doi.org/10.1371/journal.pone.0167628