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

Keywords: Refractive error, accommodation, hyperopia, headache, reading comprehension
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; Sternek 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 stereocuity was defined as habitual stereocuity 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 stereocuity (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, stereocuity, 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%; χ²(1) = 2.2, p = 0.14], and myopia was significantly more prevalent in females than males [14.2% vs 7.1%; χ²(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 stereocuity poorer than 120" was found in 14.9% [females: 12.7%; males: 18.0%; χ²(1) = 2.4, p = 0.12], whereas ha-
bital amplitude of accommodation lower than 8D was found in 
25.3% (of n=233; accommodation data is missing for one male 
participant) [females: 27.7%; males: 22.0%; χ²(1)=1.8, p=0.18]. 
Table 2 shows that poor habitual stereocuity and/or poor 
habitual amplitude of accommodation was most frequent in 
moderate-to-high hyperopes (poor stereocuity only: 17.2%, 
poor amplitude of accommodation only: 41.4%, combination of 
both: 24.1%). The mean habitual monocular amplitude of ac-
comfort 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 stereocuity only, 20.1% had poor habitual am-
plitude of accommodation only, whereas 2.9% had a combination 
of both. This gives a total of 270 participants (61.9% of all; fe-
male: 64.8%; males: 57.4%) who had refractive error and/or

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

<table>
<thead>
<tr>
<th></th>
<th>All (n=436)</th>
<th>Females (n=253)</th>
<th>Males (n=183)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Emmetropia</td>
<td>56.0</td>
<td>244</td>
<td>53.0</td>
</tr>
<tr>
<td>Refractive errors overall</td>
<td>44.0</td>
<td>192</td>
<td>47.0</td>
</tr>
<tr>
<td>Low hyperopia</td>
<td>21.8</td>
<td>95</td>
<td>23.7</td>
</tr>
<tr>
<td>Moderate-high hyperopia</td>
<td>6.7</td>
<td>29</td>
<td>5.1</td>
</tr>
<tr>
<td>Myopia</td>
<td>11.2</td>
<td>49</td>
<td>14.2</td>
</tr>
<tr>
<td>Astigmatism only</td>
<td>4.4</td>
<td>19</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Overall, regular headaches were reported by 8.5%, while 
66.1% reported rarely experiencing headaches. Signifi-
cantly more females than males reported regular headache [regular 
headache: females 12.6%, males 2.7%; rare headache: females 
57.3%, males 78.1%; χ²(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.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Poor stereocuity only</th>
<th>Poor accommodation only</th>
<th>Both</th>
<th>No BVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>435*</td>
<td>9.0</td>
<td>19.5</td>
<td>5.7</td>
<td>65.7</td>
</tr>
<tr>
<td>Emmetropia</td>
<td>244</td>
<td>9.0</td>
<td>20.1</td>
<td>2.9</td>
<td>68.0</td>
</tr>
<tr>
<td>Low hyperopes</td>
<td>94†</td>
<td>8.5</td>
<td>18.1</td>
<td>8.5</td>
<td>64.9</td>
</tr>
<tr>
<td>Moderate-high hyperopes</td>
<td>29</td>
<td>17.2</td>
<td>41.4</td>
<td>24.1</td>
<td>17.2</td>
</tr>
<tr>
<td>Myopia</td>
<td>49</td>
<td>6.1</td>
<td>8.2</td>
<td>41.1</td>
<td>81.6</td>
</tr>
<tr>
<td>Astigmatism only</td>
<td>19</td>
<td>5.3</td>
<td>15.8</td>
<td>5.3</td>
<td>73.7</td>
</tr>
</tbody>
</table>

Note: BVD = binocular visual dysfunction (defined as poor habitual stereocuity (TND > 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 exa-
minations 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%; χ²(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 (fre-
cquent wear: 71.4%). In those with refractive errors and/or 
BVD, 8.9% 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 
asociation between the frequency of wearing corrective eye wear 
and sex did not reach significance [χ²(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 comprehen-
sion texts, with no difference in the frequency of fails between 
females and males (25.8% vs 26.2%). There was a near sig-
nificant 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=60); χ²(1)=3.7, p=0.05]. When restricting the analyses to 
the group of participants who reported never wearing a cor-
rection (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); χ²(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%; 
χ²(2)=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. Re-
fractive errors and/or accommodative or binocular visual dys-
functions 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; Kulpe 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 af-
flect 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 am-
blyopia (Cotter et al., 2011; Klimek et al., 2004; Kulpe et al., 2014; 
Pascaul et al., 2014). In the adolescents in Norway, hyperopia
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 stereocuity (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 (Mutt 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%) dropout 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).

Acknowledgements

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References


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.


