Reading Speed as an Objective Measure of Improvement Following Vitrectomy for Symptomatic Vitreous Opacities

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Reading speed as a reliable outcome measure to assess visual improvement following vitrectomy for symptomatic vitreous opacities in patients with clear lenses

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Declaration of Conflicting Interests

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43   vitrectomy surgery from Alcon Surgical.

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Abstract

Background and Objective: There is currently no objective measure of the visual deficits experienced by patients with symptomatic vitreous opacities (SVO) that would also correlate with the functional improvement they report following vitrectomy. This study aims to determine whether reading speed can be used as a reliable outcome measure to assess objectively the impact of both SVO and vitrectomy on patients' visual performance.

Study Design/Materials and Methods: 20 adult patients seeking surgery for SVO were included. Measures of visual function were obtained before and after vitrectomy using the ETDRS acuity chart, the NEI-VFQ and the MNREAD.

Results: In patients with non-opacified lenses (N=10), maximum reading speed increased significantly from 138 to 159 words per minute after complete removal of SVO by vitrectomy (95%CI = [14, 29], p < 0.001).

Conclusion: Reading speed is impaired with SVO, and improves following vitrectomy in phakic and pseudophakic eyes with clear lenses. Reading speed is a valid objective measure to assess the positive effect of vitrectomy for SVO on near-distance daily life activities.

Keywords

Background and Objective

Patients with symptomatic vitreous opacities (SVO) experience visual impairment from multiple dense particles floating in the vitreous gel, which often cast a mobile dark shadow on the retina. However, standard objective measures of visual function, such as Snellen visual acuity, remain often excellent in the presence of SVO[1,2]. Nonetheless, patients with SVO report significant visual improvement after their removal by vitrectomy[3,4]. For instance, previous studies have shown post-operative improvement in subjective visual quality of life[5,6]. These results were obtained with the National Eye Institute Visual Function Questionnaire (NEI-VFQ), which assesses the level of difficulty experienced by individuals with chronic eye diseases during daily-living activities, such as driving or reading[7].

To complement such subjective evaluations, there is a need for establishing a quantifiable measure to assess objectively (1) the impairment in visual function caused by SVO and (2) the improvement in visual function following vitrectomy[3]. First, such a clinical measure would help detect patients with functional impairment from vitreous floaters. Second, it would bring valuable insight to help resolve the existing controversy over vitrectomy's clinical relevance. So far, intraocular straylight[8] and contrast sensitivity[6] have been proposed as independent objective measures of visual perception with symptomatic floaters. Despite their impact on vision-related quality of life, these measures do not evaluate daily life function directly.

A frequent complaint from patients with prominent opacities is interference with ease of reading. Even if unilateral, these patients often complain of interference with binocular visual function[9,10].

91   Patients usually report moderate or extreme difficulty in reading small print[5]. In the low-vision

92   literature reading speed is already considered a strong objective predictor of visual ability and

93   vision-related quality of life for patients with ocular disorders, such as macular

94   degeneration[11,12,13,14]. Here we conducted a prospective study to test whether reading

95   performance can also be used as reliable outcome measure to investigate the impact of SVO and

96   therapeutic vitrectomy on patients' visual performance.

97

98   Our main objective was to investigate whether reading performance, evaluated with the

99   standardized MNREAD test, could provide an objective measure of functional improvement in

100   patients with SVO treated with pars plana vitrectomy. To this aim, we compared pre and post-

101   operative measures of (1) vision-related quality of life (subjectively obtained with the NEI VFQ)

102   and (2) reading performance (objectively obtained with the MNREAD test). Given that reading

103   performance is rapidly degraded with reduced contrast from cloudy ocular media[15], these

104   comparisons were performed while controlling for patients' lens status (clear vs. mildly

105   opacified). Additionally, we investigated whether a potential improvement in these subjective

106   and objective measures following vitrectomy would be correlated with pre-operative opacity

107   severity.

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109

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Patients/Materials and Methods

Patients

Patients over 21 years old were included in the present work if they (1) elected to undergo

vitrectomy, (2) presented symptoms consistent with examination findings of dense opacities for

at least 6 months, (3) had visual acuity of 20/80 (0.6 logMAR) or better in both eyes before

surgery and (4) did not experience a significant drop in acuity in the non-operated eye between

the pre- and post-surgery measurements. Phakic and pseudophakic patients were included, as

well as patients with or without a vitreous detachment. History of scleral buckle for retinal

detachment (RD) was acceptable if the macula was not involved. If an epiretinal membrane was

noted on OCT but not clinically visible or deemed significant, patients were included in the

study. Patients were excluded if they had history of cognitive impairment, macula-off RD, severe

glaucoma, macular degeneration, diabetic macular edema, or other confounding ocular disorders.

A total of 20 patients were recruited, tested and treated at two different sites: 11 at a private

retina practice in Minnesota and 9 at an academic retina practice in California. Figure 1

illustrates the protocol sequence. Institutional Review Board (IRB)/Ethics Committee approval

was obtained and written informed consent was obtained before the study from each patient

according to IRB guidelines. The study also complied with tenets of the Declaration of Helsinki

and HIPAA.
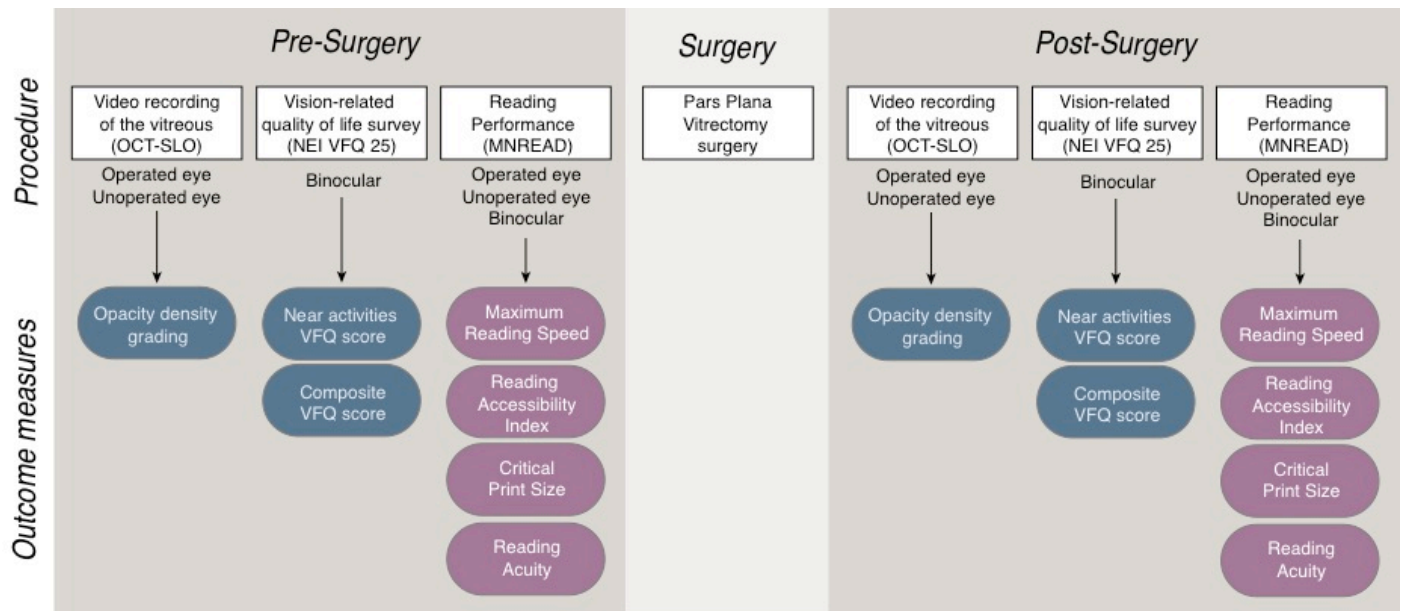
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Figure 1: Protocol schematic showing the different test procedures along with the resulting outcome measures.
Subjective measures are represented in blue; objective measures are represented in pink.

132

Surgery

20 eyes of 20 patients underwent outpatient three-port 25-gauge pars plana vitrectomy using the

Alcon Constellation system. Inspection of the peripheral retina with indirect ophthalmoscopy and

scleral depression was performed at surgery conclusion. Leaking sclerotomies were sutured.

Postoperative examinations were at 1 day, 1-2 weeks, and 4-6 weeks. Presence or absence of a

posterior vitreous detachment (PVD) was confirmed intraoperatively. Visual acuity, intraocular

pressure, dilated funduscopic exam and any postoperative complications including high or low

intraocular pressure, retinal tear or detachment, and/or endophthalmitis were recorded. For each

patient, the non-operated eye served as control.

Subjective grading of opacity density

Before and after surgery, patients went through video recording of the vitreous using the infrared confocal scanning laser ophthalmoscope (SLO) combined with optical coherence tomography (OCT)[16,17]. The movie created with this technique reveals motion of the shadows projected by the opacities onto the retinal surface, enabling a subjective grading of the opacity density. Recording was performed in each eye. Patients were instructed to look to one side and then re-fixate, which set the vitreous opacities in motion. This step was repeated to each side several times. The pre and post-surgery videos were assessed by two experienced, masked surgeons and given a score of 0-3, with 0 corresponding to no floaters and 3 corresponding to very dense floaters (see supplementary material for a pre-op movie graded as 2 and a post-op movie graded as 0).

Subjective measure of vision-related quality-of-life

Before and after surgery, patients were interviewed with the NEI-VFQ-25, the 25-item version of the VFQ test[7]. Data were scored using the standard method to calculate: 1-the near activities VFQ score (involving reading) and 2- the composite VFQ score (encompassing many vision-related functions). Scores ranged from 0 to 100, with higher scores representing better function.

Objective measure of reading speed

Before and after surgery, patients' reading performance was measured with the MNREAD acuity chart, a standardized test designed to measure binocular and monocular reading performance[18].

165   Test measures were obtained with the MNREAD app running on an iPad[19]. Viewing distance

166   was 60 cm and screen luminance was set to 200cd/m2. Patients went through six iterations of the

167   test (operated eye, non-operated eye and binocular, each condition being repeated twice), all in

168   black print on white background. MNREAD testing was performed pre-operatively and again 4-

169   8 weeks after surgery. For each test performed, the four MNREAD measures were estimated

170   internally by the app[18]: (1) Maximum Reading Speed (MRS), (2) Critical Print Size (CPS), (3)

171   Reading Acuity (RA) and (4) reading ACCessibility index (ACC - a single-valued measure that

172   represents one's visual access to commonly encountered printed material, ranging from 0 (i.e. no

173   access to print) to 1 (i.e. average normal access) or above)[20].

174

175   ***Statistical analysis***

176   Pre and post-operative scores of NEI-VFQ were compared with a Wilcoxon signed-rank test. For

177   each of the four MNREAD parameters, a different linear mixed-effects model including data

178   from all 20 patients was designed to compare values before and after vitrectomy for the operated

179   eye, the non-operated eye and the binocular condition[21,22]. To control for covariate factors, the

180   following variables were also included in the models: binocular lens opacity ('clear' vs. 'mild

181   opacity'), presence of epiretinal membrane (ERM) in the operated eye ('yes' vs. 'no'), presence

182   of SVO in the non-operated eye ('yes' vs. 'no'), presence of posterior vitreous detachment

183   (PVD) in the non-operated eye ('yes' vs. 'no') and testing location ('Minnesota' vs.

184   'California'). The same random structure was chosen for all four models and included a random

185   intercept for "eyes nested within patients", assuming a different baseline performance level for

186   each patient and each eye. Post-hoc pairwise comparisons were performed using Tukey's

187 correction. In the Results section, mean values estimated by the models and post-hoc pairwise

188 comparisons are reported with their 95% confidence intervals (95%CI) and p-values.

189

190

191 **Results**

192 *Patients*

193 Preoperative clinical examination revealed the presence of SVO and clinical evidence of PVD in

194 all patients. Thirteen patients had bilateral but asymmetric opacities noted on clinical

195 examination, and were asymptomatic in the fellow eye. Six patients had concurrent minimally

196 significant epiretinal membrane. One patient had a history of scleral buckling for a macula-

197 sparing retinal detachment. Vitreous opacities symptoms had been present for 6 to 24 months.

198 Table 1 presents the patients' preoperative individuals characteristics.

Patient ID	Location	Gender	Age	Lens opacity in both eyes	Operated eye				Non-operated eye		
					Pathology	SVO	Acuity	OCT-SLO Opacity grading	Pathology	SVO	Acuity
P1	Minnesota	M	58	Clear	PVD	Yes	20/25	2	ERM	No	20/25
P2	Minnesota	M	59	Clear	PVD	Yes	20/20	1.5	--	Yes	20/25
P3	California	M	61	Clear	PVD	Yes	20/20	3	ERM	No	20/40
P4	Minnesota	M	62	Clear	PVD+ ERM	Yes	20/20	1.5	Scleral buckling + ERM	No	20/20
P5	Minnesota	M	64	Clear	PVD+ ERM	Yes	20/15	2	PVD	Yes	20/25
P6	Minnesota	F	64	Clear	PVD	Yes	20/25	2.5	--	Yes	20/20
P7	Minnesota	F	64	Clear	PVD	Yes	20/20	2.5	PVD	Yes	20/25
P8	Minnesota	F	68	Clear	PVD	Yes	20/30	1	PVD	Yes	20/15
P9	California	M	69	Clear	PVD	Yes	20/20	2.5	PVD	Yes	20/20
P10	Minnesota	F	72	Clear	PVD	Yes	20/25	2	PVD	Yes	20/25
P11	California	F	32	Mild opacity	PVD	Yes	20/25	1	PVD	Yes	20/80

P12	California	M	52	Mild opacity	PVD+ ERM	Yes	20/25	2.5	Vitreous Syneresis	No	20/20
P13	California	M	54	Mild opacity	PVD+ ERM	Yes	20/40	3	NPDR	No	20/20
P14	California	F	54	Mild opacity	PVD	Yes	20/25	2.5	PVD	Yes	20/80
P15	Minnesota	M	63	Mild opacity	PVD+ ERM	Yes	20/40	2.5	ERM	Yes	20/25
P16	California	M	63	Mild opacity	PVD+ ERM	Yes	20/80	2	ERM	No	20/25
P17	Minnesota	M	64	Mild opacity	PVD	Yes	20/20	2.5	Vitreous Syneresis	Yes	20/20
P18	California	F	65	Mild opacity	PVD	Yes	20/30	2.5	PVD	Yes	20/25
P19	California	F	67	Mild opacity	PVD	Yes	20/30	2.5	ERM	No	20/25
P20	Minnesota	M	68	Mild opacity	PVD	Yes	20/20	1.5	PVD	Yes	20/25

199

Table 1: Patients' individual characteristics prior to surgery. SVO stands for symptomatic vitreous opacities; ERM stands for epiretinal membrane. PVD stands for posterior vitreous detachment; NPDR stands for non-proliferative diabetic retinopathy; Visual acuity is given in Snellen notation.

Surgery

No complications were seen. No cataract progression was observed in phakic patients during the short period of follow-up (6 weeks). Complete removal of the central vitreous opacities was documented by examination and video SLO in all 20 cases. Prior to surgery, OCT-SLO grading of opacity was on average 2.2, ranging from 0 to 3 (Table 1). After vitrectomy, opacity grading score was 0 for all 20 patients.

Visual function

In the operated eye, mean visual acuity was 0.11±0.16 logMAR before surgery and 0.09±0.16 logMAR after surgery. The difference between pre- and post-op visual acuity was not significant ($p = 0.36$). Both NEI-VFQ scores improved significantly after vitrectomy, but this improvement was dependent on the lens opacity (Figure 2). Among patients with clear lenses (N=10), the

216 average near activities sub-score went from 47.5 to 74.2. This significant increase of 26.7 points

217 (95%CI = [16.2, 37.1], p < 0.001) corresponds to an overall 56.2% improvement (Figure 2A-

218 left). For patients with opacified lenses however (N=10), vitrectomy did not improve the near

219 activities sub-score. For patients with clear lenses, the average pre-op composite score was 64.6

220 and increased by 19.8 points (95%CI = [13.9, 25.7], p < 0.001) after vitrectomy, representing a

221 30.6% improvement (Figure 2B-left). The improvement was somewhat smaller for patients with

222 opacified lenses, whose score went from 71.4 to 85.8, representing a significant gain of 20.2%

223 (14.4 points, 95%CI = [-6.3, 23.4], p = 0.003). The overall improvement for both subgroups on

224 the composite score was 26.3%. There was no correlation between the opacity grading score

225 prior surgery and the amount of NEI-VFQ score improvement following surgery (Pearson's

226 correlation coefficients was -0.36 and -0.39 for the near activities sub-score and the composite
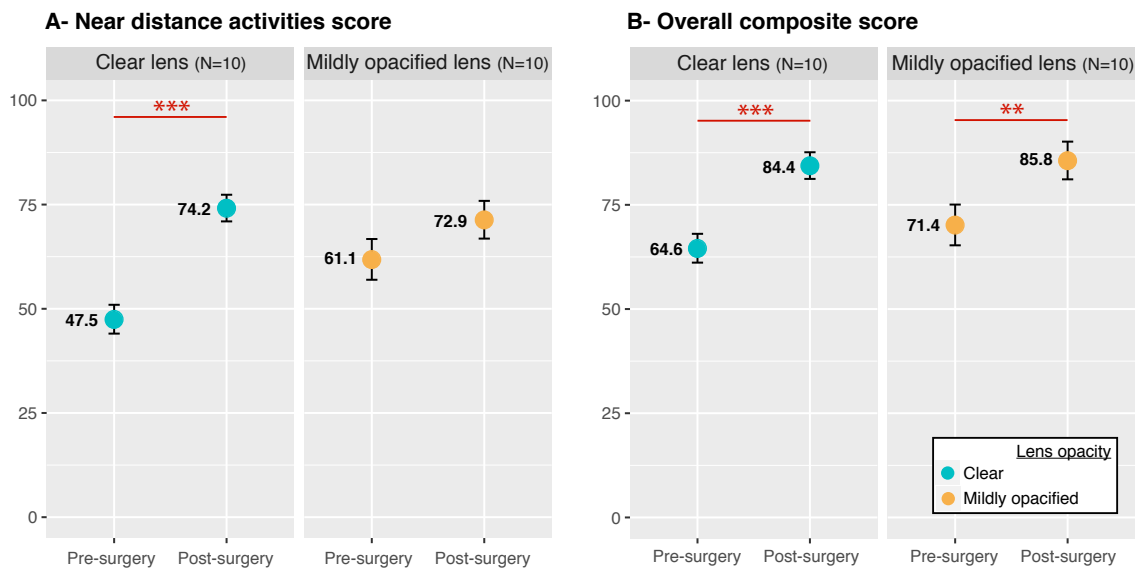
227 score respectively).

228

229 **Figure 2: Pre and post-operative NEI-VFQ scores grouped by lens opacity status. Points show the**
230 **mean estimates for the near activity sub-score (A) and the overall composite score (B), both before**
231 **and after surgery, as estimated by the mixed effects models, for patients with clear lenses in blue**

232 **(N=10) and patients with mildly opacified lenses in orange (N=10). Error bars represent the 95%**
233 **confidence intervals.**

234

Reading performance

236 <u>Maximum Reading Speed (MRS)</u>

237 First, we included data from all 20 patients in the mixed-effects model without any distinction on

238 their lens opacity status. MRS before surgery was on average 137 words/minute (wpm) for the

239 operated eye (95%CI = [125, 149]). It was significantly higher by 13 wpm in the non-operated

240 eye (95%CI = [5, 22], p = 0.003) and by 15 wpm in the binocular condition (95%CI = [7, 24], p

241 < 0.001). After surgery, MRS in the operated eye increased significantly to 146 wpm (i.e. a 9

242 wpm increase; 95%CI = [3, 15], p = 0.007). Post-operatively, MRS did not change significantly

243 in the non-operated eye (1 wpm increase; 95%CI = [-12, 14]; p = 0.8) or in the binocular

244 condition (3 wpm increase; 95%CI = [-9, 17]; p = 0.23).

245 Second, we included an interaction between the "surgery" and "lens opacity" factors in the

246 model. For patients with clear lenses only (N=10), MRS prior surgery was on average 138

247 words/minute (wpm) for the operated eye (95%CI = [120, 156]; Figure 3-left panel). It was

248 significantly higher by 13 wpm in the non-operated eye (95%CI = [6, 20], p < 0.001) and by 14

249 wpm in the binocular condition (95%CI = [7, 22], p < 0.001). After surgery, MRS in the

250 operated eye increased significantly to 159 wpm (i.e. a 21 wpm increase; 95%CI = [14, 29], p <

251 0.001). In the non-operated eye, MRS did not change post-operatively, with a non-significant

252 increase of 3 wpm (95%CI = [-7, 39], p = 0.43). In the binocular condition, the limited increase

253 of 8 wpm following vitrectomy barely reached significance (95%CI = [-0.38, 45], p = 0.04).

254 For patients with mildly opacified lenses (N=10), there was no significant difference in MRS

255 before and after surgery in any of the three conditions tested (operated eye, un-operated eye and

256 binocular; Figure 3-right panel).

257 For all 20 patients there was no correlation between the opacity grading score in the operated eye

258 prior surgery and the amount of MRS improvement following surgery (Pearson's correlation
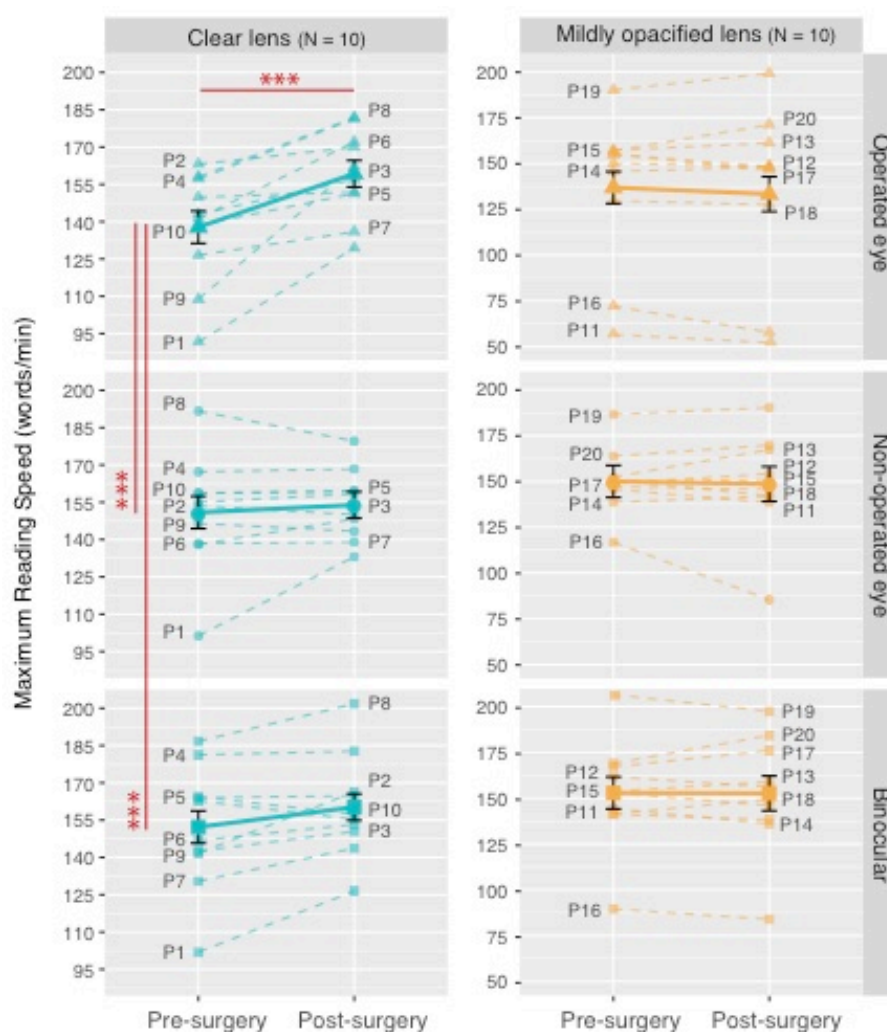
259 coefficients was -0.13).

260

261 Figure 3: **Effect of pre/post-surgery condition on MRS for the operated eye (top – triangles), the**
262 **non-operated eye (center - circles) and the binocular condition (bottom – squares) grouped by lens**
263 **opacity: clear (left – blue) vs. mildly opacified (right - orange). Solid lines connect the estimates for**

264 **each sub-group as given by the mixed-effects model. Errors bars (black) represent their standard**
265 **errors. Dashed lines connect the MRS values for each patient, numbered from P1 to P20.**
266

267 <u>Reading Accessibility Index (ACC)</u>

268 As for MRS, we first included data from all 20 patients in the mixed-effects model, without any

269 distinction on their lens opacity status. Before surgery, ACC was on average 0.61 for the

270 operated eye (95%CI = [0.55, 0.68]). It was significantly higher by 0.09 wpm in the non-

271 operated eye (95%CI = [0.04, 0.15], p = 0.002) and by 0.11 in the binocular condition (95%CI

272 = [0.05, 0.17], p < 0.001). After surgery, ACC in the operated eye increased significantly to 0.67

273 (i.e. a 0.06 increase; 95%CI = [0.01, 0.10], p = 0.01). Post-operatively, ACC did not change

274 significantly in the non-operated eye (0.002 increase; 95%CI = [-0.09, 0.09]; p = 0.95) or in the

275 binocular condition (0.03 increase; 95%CI = [-0.06, 0.12]; p = 0.22).

276 Second, we included an interaction between the "surgery" and "lens opacity" factors in the

277 model. For patients with clear lenses only (N=10), ACC was 0.65 in the operated eye before

278 surgery (95%CI = [0.56, 0.74], p < 0.001; Figure 4 - left). It was marginally but significantly

279 better for the non-operated eye, with a value of 0.72 (0.07 difference; 95%CI = [0.01, 0.14], p =

280 0.02) and significantly better in the binocular condition, with a value of 0.75 (0.1 difference;

281 95%CI = [0.04, 0.17], p = 0.002). Following surgery, ACC was significantly increased by 0.1 in

282 the operated eye (95%CI = [0.05, 0.16], p < 0.001), reaching a value of 0.75. In the non-operated

283 eye, ACC remained unchanged after surgery (0.01 difference; 95%CI = [-0.09, 0.28], p = 0.5).

284 In the binocular condition, ACC increased by 0.05 after vitrectomy but this change did not reach

285 significance (95%CI = [-0.03, 0.34], p = 0.06).

286   For patients with mildly opacified lenses (N=10), there was no significant difference in ACC

287   before and after surgery in any of the three conditions tested (operated eye, un-operated eye and

288   binocular; Figure 4 – right panel).

289   For all 20 patients, there was no correlation between the opacity grading score prior surgery in

290   the operated eye and the ACC increase following surgery (Pearson's correlation coefficient was -
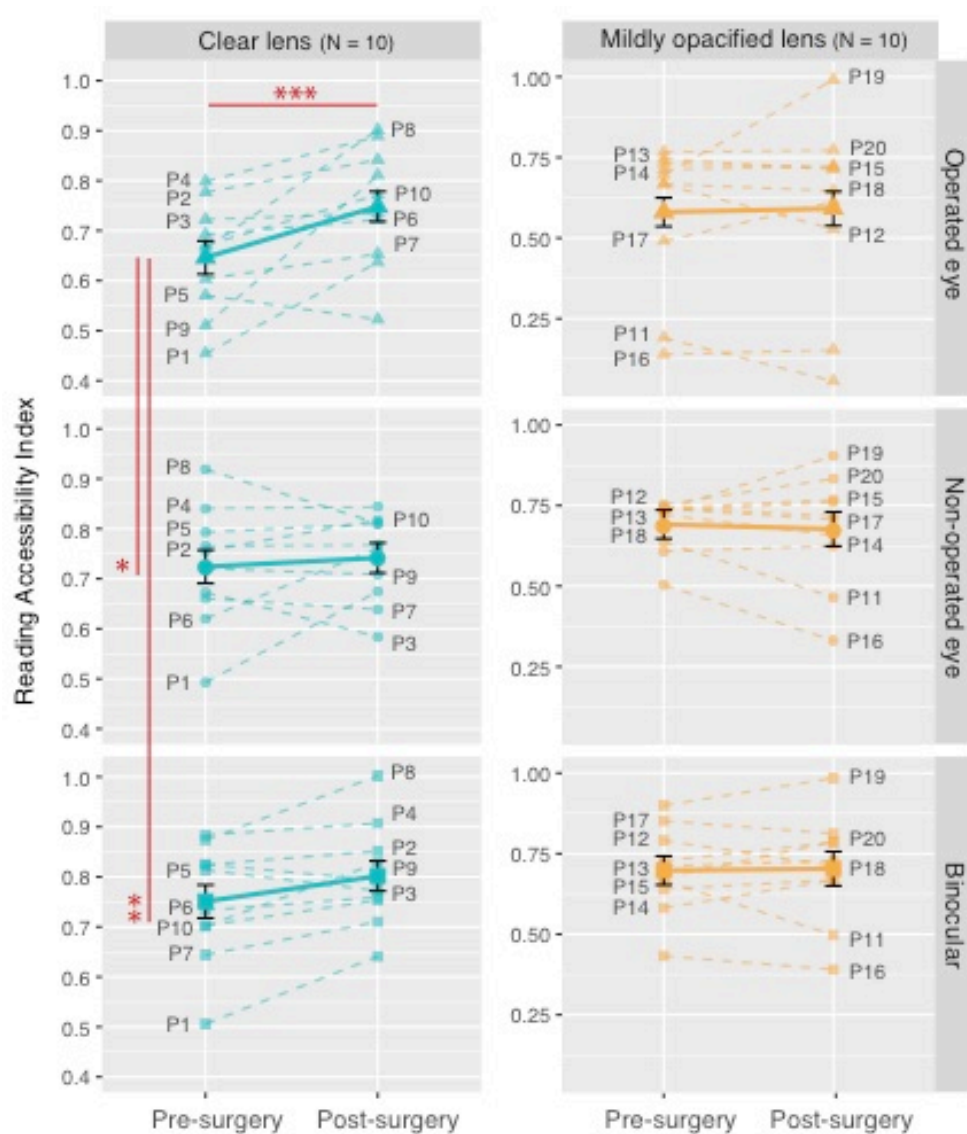
291   0.41).

292

293 **Figure 4: Effect of pre/post-surgery condition on ACC for the operated eye (top – triangles), the**
294 **non-operated eye (center - circles) and the binocular condition (bottom – squares) grouped by lens**
295 **opacity: clear (left – blue) vs. mildly opacified (right - orange).** Solid lines connect the estimates for
296 **each sub-group as given by the mixed effects model. Errors bars (black) represent their standard**
297 **errors. Dashed lines connect the MRS values for each patient, numbered from P1 to P20.**
298

299 Critical Print size (CPS) and Reading Acuity (RA)

300 For both CPS and RA, we found no significant difference between the operated eye and the non-

301 operated eye or the binocular condition before surgery. None of these measures changed

302 significantly after surgery in the tested eyes.

303

304 *Correlation between reading performance change and daily life visual function improvement*

305 Lastly, we inspected the correlation between the improvement in reading performance and the

306 improvement in NEI-VFQ near activities sub-score in the operated eye of all 20 patients. We

307 found no correlation between the percentage of improvement in MRS and the increase in NEI-

308 VFQ near activities sub-score (r = 0.4, 95%CI = [-0.12, 0.75], p = 0.12). On the other hand, the

309 improvement in ACC was significantly correlated with the near activities sub-score (r = 0.74,

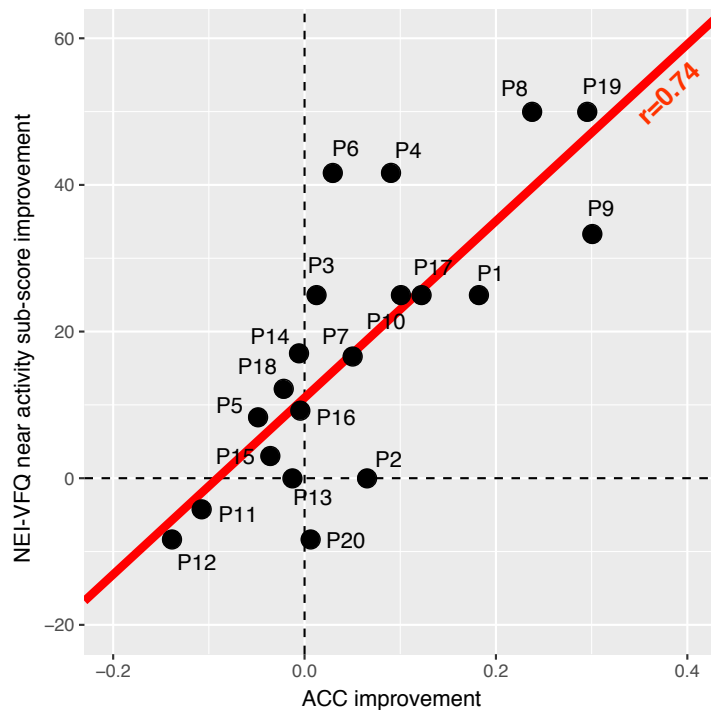310 95%CI = [0.39, 0.90], p = 0.001; Figure 5).

311

Figure 5: Post-operative NEI-VFQ near activity sub-score improvement as a function of post-operative reading accessibility index improvement for all 20 patients.

314

Discussion

316

The symptomatic relief experienced by patients following vitrectomy has been demonstrated

before by the use of the NEI-VFQ subjective test[5,6]. Our study confirmed the literature results,

with a significant overall improvement of 26% on the test composite score. This value is in line

with previously reported improvement results, ranging from 19% to 29%, in patients treated for

symptomatic floaters[6,23]. The present analysis also revealed a significant interaction between the

impact of surgery on the VFQ scores and the opacity status of the patient's lenses. For near

distance activities, vitrectomy only improved patients' score if their lenses were clear, whereas

the overall composite score (which includes both near- and far-distance activities) improved even

325   if the lenses were mildly opacified. To our knowledge, this result was never reported before and

326   suggests that the removal of SVO may have a significant impact on near-distance daily life

327   activities, but only in the absence of cataract or lens opacification. Because near distance

328   activities rely on fine central vision, for which performance is rapidly degraded past a critical

329   contrast threshold[24], SVO removal may not be sufficient to help improve performance if contrast

330   sensitivity is still reduced from lens opacification.

331

332   Our second result is the poor MRS achieved in all 10 patients with SVO and clear lenses (138

333   wpm on average in the operated eye prior surgery) compared to normal values. According to

334   Calabrèse et al., 2016, normal readers between 58 to 68 years old should reach a MRS comprised

335   between 183.2 and 189.2 wpm when reading with one or both eyes[25,26]. This 35% decrease

336   suggests that reading speed may be considered as an objective measure of functional impairment

337   in the presence of SVO. However, this finding should be interpreted with caution, given that

338   other confounding clinical factors (e.g. cognitive or visual) may have also contributed to

339   reducing reading speed.

340

341   Our third outcome is the significant change in MRS, measured after vitrectomy in patients with

342   clear lenses, with a 15% improvement in the operated eye. For these patients, the non-operated

343   eye served as control and showed no improvement post-surgery, confirming that the

344   improvement measured in the fellow eye was not due to a practice effect. More importantly, this

345   improvement did not occur in eyes with mildly opacified lenses, either from cataract (phakic

346   eyes) or posterior capsule opacification (pseudophakic eyes). Taken all together, these results

347   suggest that reading speed may be a valid objective measure to quantify the positive impact of

348   vitrectomy on visual function, but only if contrast sensitivity is not still altered by lens

349   opacification. There is evidence that a main effect of vitrectomy is to restore normal contrast

350   sensitivity function for individuals with clear lenses[6,27]. We hypothesize that for patients with

351   mildly opacified lenses, who experienced no post-surgery improvement in MRS, reduced

352   contrast sensitivity from cloudy ocular media created a bottleneck for any potential increase in

353   reading speed. We noted that binocular MRS was not improved post-surgery. Since, our

354   population was not restricted to patients with non-pathological fellow eyes, we did not expect to

355   see monocular vitrectomy having a significant impact on binocular performance.

356

357   ACC showed the same pattern as MRS, suggesting that this measure, which is potentially

358   quicker to obtain (in terms of testing and calculation time), could be a good alternative in clinical

359   settings where time is often limited. More interestingly, the improvement in ACC induced by

360   vitrectomy was significantly correlated with the improvement in near distance activities score

361   measured with the NEI-VFQ. This result alone suggests that improved reading performance

362   following vitrectomy will also have a positive impact on the overall patients' quality of life. The

363   simple objective assessment of ACC post-operatively may therefore provide some insight to the

364   patient and his/her care team about his/her overall quality of life improvement.

365

366   Surprisingly, neither CPS nor RA were sensitive to the presence of dense floaters. Even more,

367   we found no effect of vitrectomy on any of these measures. In their study of 110 treated eyes,

368   Nie et al., 2013 reported that 71% of their patients had difficulty in reading small print, which

369   markedly improved after surgery[5]. Based on their results, we had hypothesized that RA (i.e. the

370   smallest print one can read) would improve following vitrectomy. However, our results do not

371 support this hypothesis and suggest that these reading measures may not be valid to quantify the

372 impact of floaters on daily visual function.

373

374 We had expected patients with the eyes having the most prominent vitreous opacities to exhibit

375 the greatest improvement in both NEI-VFQ scores and reading performance. This was not the

376 case. In clinical practice, patients with a wide range of vitreous debris are seen, and often

377 individuals with very substantial opacities can be essentially asymptomatic (as in asteroid

378 hyalosis)[28]. Our result, as well as the wide variability in dysfunction among patients with similar

379 vitreous opacities, suggests that the location and motion characteristics of the opacities may be

380 more significant drivers than the level of opacity itself in the decision to seek symptomatic relief

381 with surgery. However, the ability to show the degree of vitreous opacification using the video

382 SLO was found to be helpful for educational purposes, both pre- and post-operatively. First, to

383 show family members dynamically what the patients were seeing. Second, to help persuading

384 patients with significant complaints but mild opacities on SLO testing that surgery would not be

385 prudent. Finally, to document the absence of the opacities post-surgery.

386

387 Our work presents some limitations. The main one is the restricted number of patients. In the

388 future, our results should be replicated with larger sets of patients to confirm our findings.

389 Another limitation is that, given the nature of the MNREAD, the current study only measured

390 fluent reading for short sentences. Therefore, it remains to be determined whether speed is also

391 improved (and to what extent) for spot reading (i.e. for isolated words, such as tag labels) and

392 sustained reading (i.e. for long texts).

393

Acknowledgments

Ethical Approval

This study was conducted in accordance with the Declaration of Helsinki. Ethical approval for this study was obtained from the Institutional Review Board (IRB) at the University of South Carolina. The collection and evaluation of all protected patient health information was performed in a Health Insurance Portability and Accountability Act (HIPAA)-compliant manner.

Statement of Informed Consent

Written informed consent was obtained before the study from each patient according to IRB guidelines, including permission for publication of all videos included herein.

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473

474

475   **Figure legends**

476   Figure 1: Protocol schematic showing the different test procedures along with the resulting

477   outcome measures. Subjective measures are represented in blue; objective measures are

478   represented in pink.

479

480   Figure 2: Pre and post-operative NEI-VFQ scores grouped by lens opacity status. Points show

481   the mean estimates for the near activity sub-score (A) and the overall composite score (B), both

482   before and after surgery, as estimated by the mixed effects models, for patients with clear lenses

483   in blue (N=10) and patients with mildly opacified lenses in orange (N=10). Error bars represent

484   the 95% confidence intervals.

485

486   Figure 3: Effect of pre/post-surgery condition on MRS for the operated eye (top – triangles), the

487   non-operated eye (center - circles) and the binocular condition (bottom – squares) grouped by

488   lens opacity: clear (left – blue) vs. mildly opacified (right - orange). Solid lines connect the

489   estimates for each sub-group as given by the mixed-effects model. Errors bars (black) represent

490   their standard errors. Dashed lines connect the MRS values for each patient, numbered from P1

491   to P20.

492

493   Figure 4: Effect of pre/post-surgery condition on ACC for the operated eye (top – triangles), the

494   non-operated eye (center - circles) and the binocular condition (bottom – squares) grouped by

495   lens opacity: clear (left – blue) vs. mildly opacified (right - orange). Solid lines connect the

496   estimates for each sub-group as given by the mixed effects model. Errors bars (black) represent

497   their standard errors. Dashed lines connect the MRS values for each patient, numbered from P1

498   to P20.

499

500   Figure 5: Post-operative NEI-VFQ near activity sub-score improvement as a function of post-

501   operative reading accessibility index improvement for all 20 patients.

502

Tables

Patient ID	Location	Gender	Age	Lens opacity in both eyes	Operated eye				Non-operated eye		
					Pathology	SVO	Acuity	OCT-SLO Opacity grading	Pathology	SVO	Acuity
P1	Minnesota	M	58	Clear	PVD	Yes	20/25	2	ERM	No	20/25
P2	Minnesota	M	59	Clear	PVD	Yes	20/20	1.5	--	Yes	20/25
P3	California	M	61	Clear	PVD	Yes	20/20	3	ERM	No	20/40
P4	Minnesota	M	62	Clear	PVD+ ERM	Yes	20/20	1.5	Scleral buckling + ERM	No	20/20
P5	Minnesota	M	64	Clear	PVD+ ERM	Yes	20/15	2	PVD	Yes	20/25
P6	Minnesota	F	64	Clear	PVD	Yes	20/25	2.5	--	Yes	20/20
P7	Minnesota	F	64	Clear	PVD	Yes	20/20	2.5	PVD	Yes	20/25
P8	Minnesota	F	68	Clear	PVD	Yes	20/30	1	PVD	Yes	20/15
P9	California	M	69	Clear	PVD	Yes	20/20	2.5	PVD	Yes	20/20
P10	Minnesota	F	72	Clear	PVD	Yes	20/25	2	PVD	Yes	20/25
P11	California	F	32	Mild opacity	PVD	Yes	20/25	1	PVD	Yes	20/80
P12	California	M	52	Mild opacity	PVD+ ERM	Yes	20/25	2.5	Vitreous Syneresis	No	20/20
P13	California	M	54	Mild opacity	PVD+ ERM	Yes	20/40	3	NPDR	No	20/20
P14	California	F	54	Mild opacity	PVD	Yes	20/25	2.5	PVD	Yes	20/80
P15	Minnesota	M	63	Mild opacity	PVD+ ERM	Yes	20/40	2.5	ERM	Yes	20/25
P16	California	M	63	Mild opacity	PVD+ ERM	Yes	20/80	2	ERM	No	20/25
P17	Minnesota	M	64	Mild opacity	PVD	Yes	20/20	2.5	Vitreous Syneresis	Yes	20/20
P18	California	F	65	Mild opacity	PVD	Yes	20/30	2.5	PVD	Yes	20/25
P19	California	F	67	Mild opacity	PVD	Yes	20/30	2.5	ERM	No	20/25
P20	Minnesota	M	68	Mild opacity	PVD	Yes	20/20	1.5	PVD	Yes	20/25

504

Table 1: Patients' individual characteristics prior to surgery. SVO stands for symptomatic vitreous opacities; ERM stands for epiretinal membrane. PVD stands for posterior vitreous detachment; NPDR stands for non-proliferative diabetic retinopathy; Visual acuity is given in Snellen notation.

509

Supplementary material

511   Movie 1. Video 1, preoperative video SLO. The video is live streaming of scanning laser

512 ophthalmoscopic images from the Heidelberg OCT machine. This is recorded in "Movie Max"

513 mode, (in avi) then converted to .mov. A patient with prominent vitreous opacities months post

514 scleral buckling was instructed to look left and re-fixate, then look right and re-fixate. Shadows

515 from mobile vitreous opacities were projected on the stabilized retinal surface and thus imaged

516 with the infrared camera.

517

518   Movie 2. Video 2, postoperative video SLO. The video is recorded in the same manner

519 (with saccades) as Video 1, and of the same eye one week post vitrectomy. Absence of

520 shadowing from vitreous opacities is noted.