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

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

4
5 Short title: Reading speed as an objective measure of improvement following vitrectomy for
6 symptomatic vitreous opacities

7
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25

- 26 • Study concept and design: Edwin H. Ryan, Aurèlie Calabrèse, Linda Lam
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- 28 • Analysis and interpretation of data: Aurèlie Calabrèse, Edwin H. Ryan
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- 30 • Drafting of the manuscript: Aurèlie Calabrèse, Edwin H. Ryan, Linda A. Lam
- 31 • Critical revision of the manuscript: Aurèlie Calabrèse, Edwin H. Ryan, Linda A. Lam,
- 32 Christine Pulido, Steven R. Bennett

33

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37

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40 publication of this article. In addition, Dr. Calabrese reports receiving royalties for sales of the
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43 vitrectomy surgery from Alcon Surgical.

44

45

46

47

48 **Abstract**

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

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

57 **Results:** In patients with non-opacified lenses (N=10), maximum reading speed increased
58 significantly from 138 to 159 words per minute after complete removal of SVO by vitrectomy
59 (95%CI = [14, 29], $p < 0.001$).

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

63

64 **Keywords**

65

66 Vitrectomy, symptomatic vitreous opacities, lens opacity, reading speed, daily-life function, functional
67 improvement, objective measurement

68

69 **Background and Objective**

70 Patients with symptomatic vitreous opacities (SVO) experience visual impairment from multiple
71 dense particles floating in the vitreous gel, which often cast a mobile dark shadow on the retina.
72 However, standard objective measures of visual function, such as Snellen visual acuity, remain
73 often excellent in the presence of SVO^{1,2}. Nonetheless, patients with SVO report significant
74 visual improvement after their removal by vitrectomy^{3,4}. For instance, previous studies have
75 shown post-operative improvement in subjective visual quality of life^{5,6}. These results were
76 obtained with the National Eye Institute Visual Function Questionnaire (NEI-VFQ), which
77 assesses the level of difficulty experienced by individuals with chronic eye diseases during daily-
78 living activities, such as driving or reading⁷.

79

80 To complement such subjective evaluations, there is a need for establishing a quantifiable
81 measure to assess objectively (1) the impairment in visual function caused by SVO and (2) the
82 improvement in visual function following vitrectomy³. First, such a clinical measure would help
83 detect patients with functional impairment from vitreous floaters. Second, it would bring
84 valuable insight to help resolve the existing controversy over vitrectomy's clinical relevance. So
85 far, intraocular straylight⁸ and contrast sensitivity⁶ have been proposed as independent objective
86 measures of visual perception with symptomatic floaters. Despite their impact on vision-related
87 quality of life, these measures do not evaluate daily life function directly.

88

89 A frequent complaint from patients with prominent opacities is interference with ease of reading.
90 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 print⁵. 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 media¹⁵, 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.

108

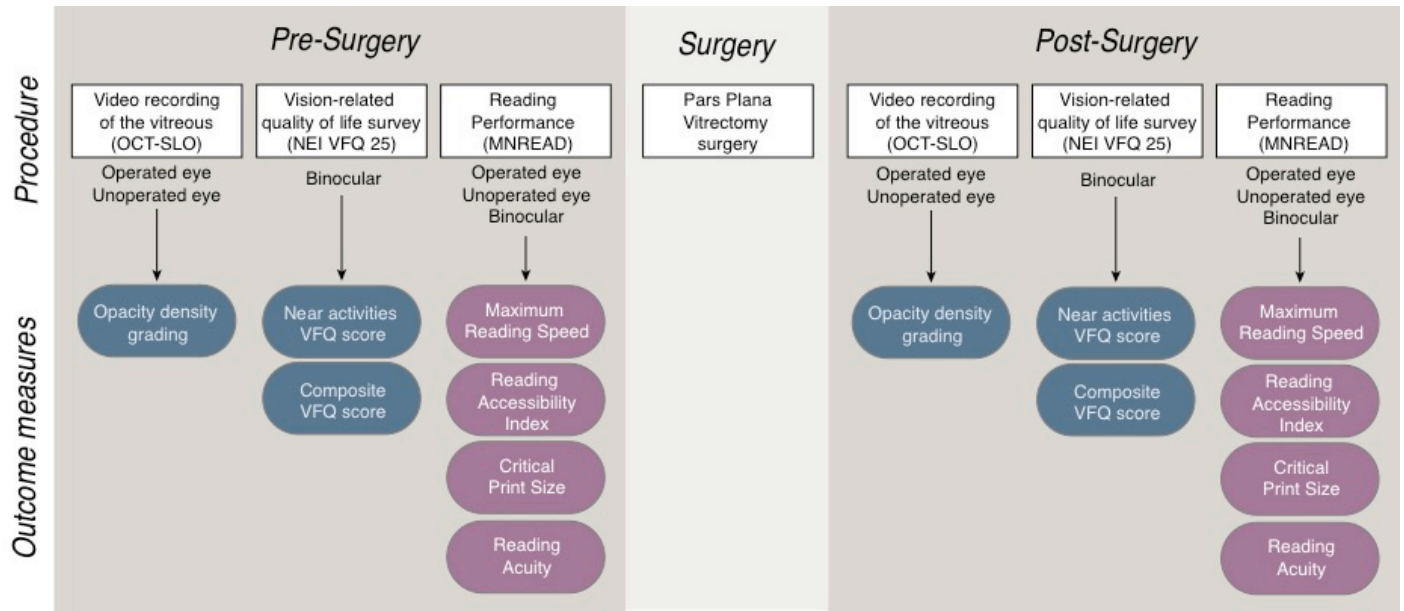
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110

111 **Patients/Materials and Methods**

112 *Patients*

113 Patients over 21 years old were included in the present work if they (1) elected to undergo
114 vitrectomy, (2) presented symptoms consistent with examination findings of dense opacities for
115 at least 6 months, (3) had visual acuity of 20/80 (0.6 logMAR) or better in both eyes before
116 surgery and (4) did not experience a significant drop in acuity in the non-operated eye between
117 the pre- and post-surgery measurements. Phakic and pseudophakic patients were included, as
118 well as patients with or without a vitreous detachment. History of scleral buckle for retinal
119 detachment (RD) was acceptable if the macula was not involved. If an epiretinal membrane was
120 noted on OCT but not clinically visible or deemed significant, patients were included in the
121 study. Patients were excluded if they had history of cognitive impairment, macula-off RD, severe
122 glaucoma, macular degeneration, diabetic macular edema, or other confounding ocular disorders.
123 A total of 20 patients were recruited, tested and treated at two different sites: 11 at a private
124 retina practice in Minnesota and 9 at an academic retina practice in California. Figure 1
125 illustrates the protocol sequence. Institutional Review Board (IRB)/Ethics Committee approval
126 was obtained and written informed consent was obtained before the study from each patient
127 according to IRB guidelines. The study also complied with tenets of the Declaration of Helsinki
128 and HIPAA.



129

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

132

133 ***Surgery***

134 20 eyes of 20 patients underwent outpatient three-port 25-gauge pars plana vitrectomy using the
 135 Alcon Constellation system. Inspection of the peripheral retina with indirect ophthalmoscopy and
 136 scleral depression was performed at surgery conclusion. Leaking sclerotomies were sutured.

137 Postoperative examinations were at 1 day, 1-2 weeks, and 4-6 weeks. Presence or absence of a
 138 posterior vitreous detachment (PVD) was confirmed intraoperatively. Visual acuity, intraocular
 139 pressure, dilated funduscopy exam and any postoperative complications including high or low
 140 intraocular pressure, retinal tear or detachment, and/or endophthalmitis were recorded. For each
 141 patient, the non-operated eye served as control.

142

143

144 ***Subjective grading of opacity density***

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

155

156 ***Subjective measure of vision-related quality-of-life***

157 Before and after surgery, patients were interviewed with the NEI-VFQ-25, the 25-item version of
158 the VFQ test⁷. Data were scored using the standard method to calculate: 1-the near activities
159 VFQ score (involving reading) and 2- the composite VFQ score (encompassing many vision-
160 related functions). Scores ranged from 0 to 100, with higher scores representing better function.

161

162 ***Objective measure of reading speed***

163 Before and after surgery, patients' reading performance was measured with the MNREAD acuity
164 chart, a standardized test designed to measure binocular and monocular reading performance¹⁸.

165 Test measures were obtained with the MNREAD app running on an iPad¹⁹. 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 app¹⁸: (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

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

203

204 ***Surgery***

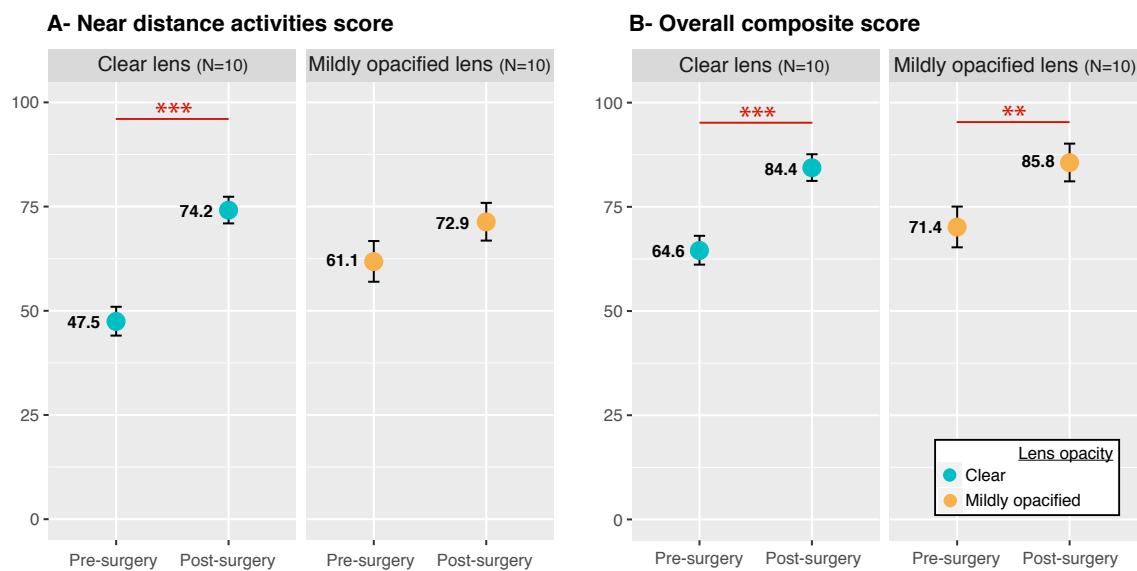
205 No complications were seen. No cataract progression was observed in phakic patients during the
206 short period of follow-up (6 weeks). Complete removal of the central vitreous opacities was
207 documented by examination and video SLO in all 20 cases. Prior to surgery, OCT-SLO grading
208 of opacity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

210

211 ***Visual function***

212 In the operated eye, mean visual acuity was 0.11 ± 0.16 logMAR before surgery and 0.09 ± 0.16
213 logMAR after surgery. The difference between pre- and post-op visual acuity was not significant
214 ($p = 0.36$). Both NEI-VFQ scores improved significantly after vitrectomy, but this improvement
215 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

235 *Reading performance*

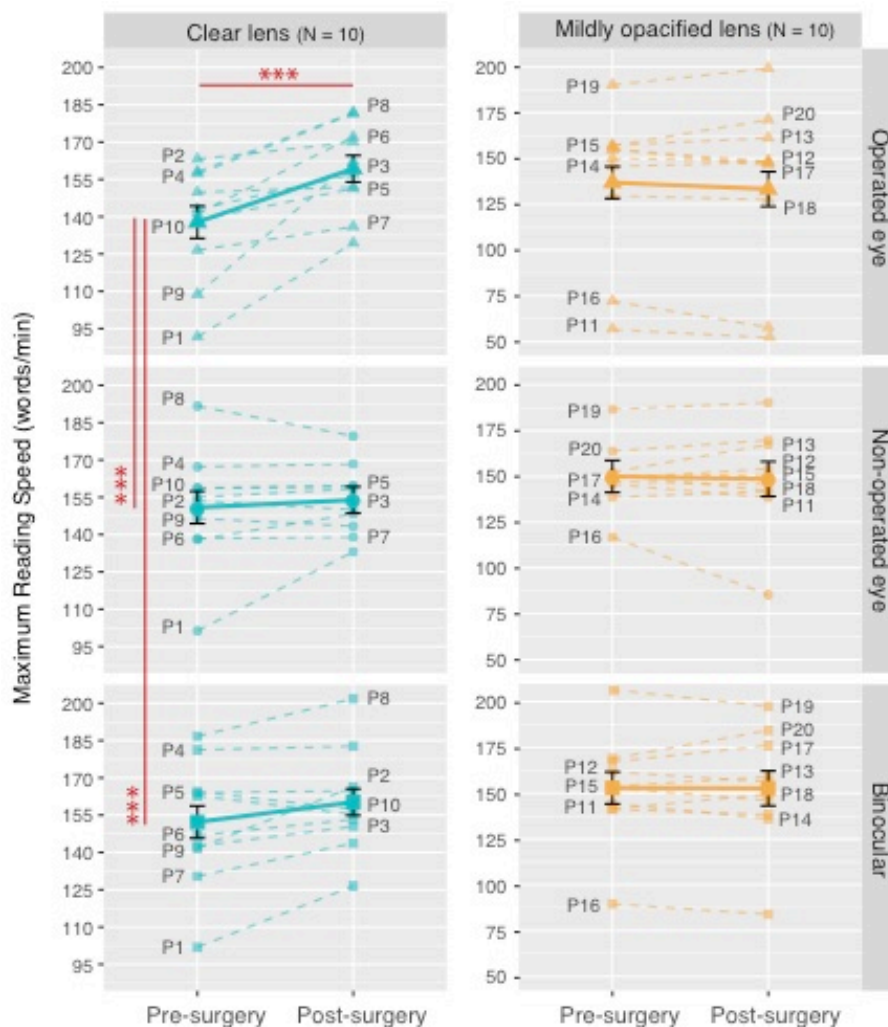
236 Maximum Reading Speed (MRS)

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

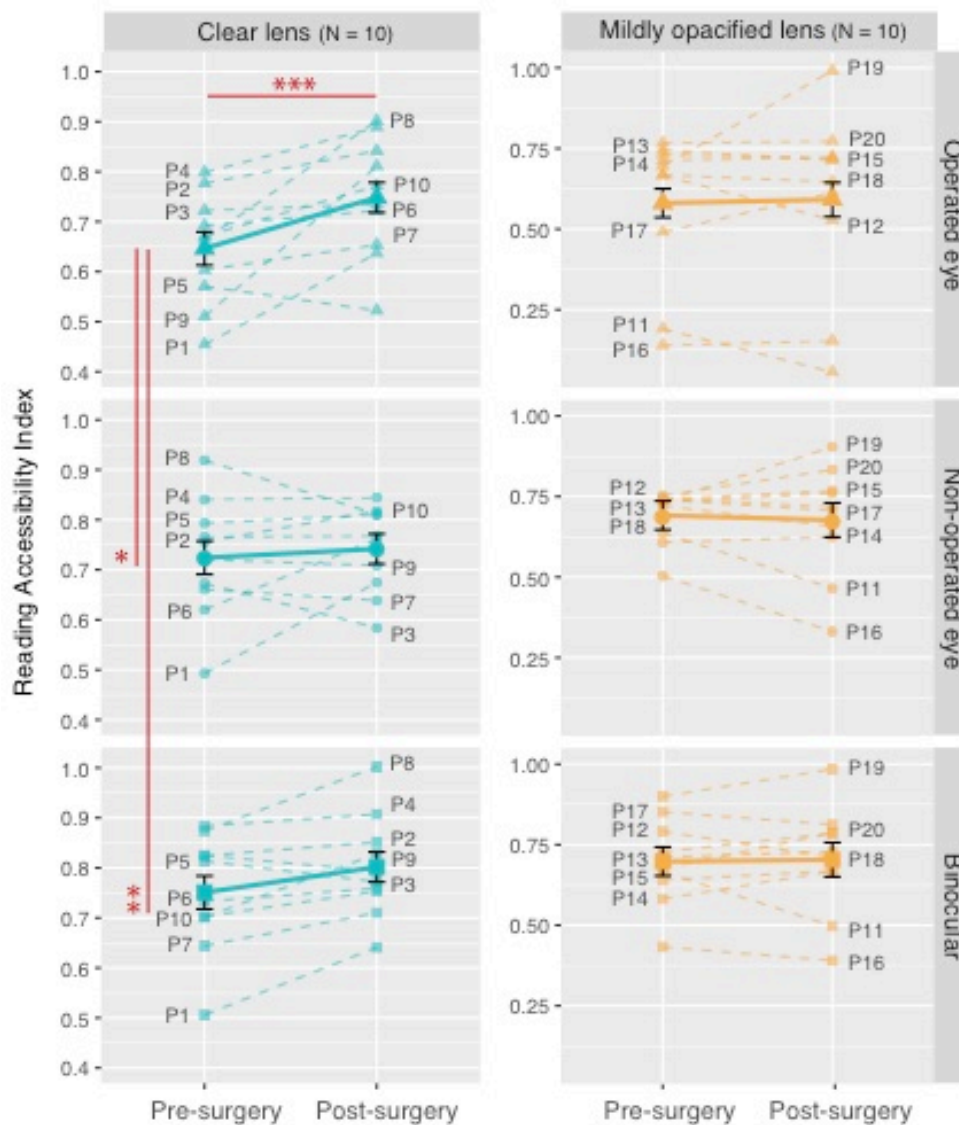
267 Reading Accessibility Index (ACC)

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).



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

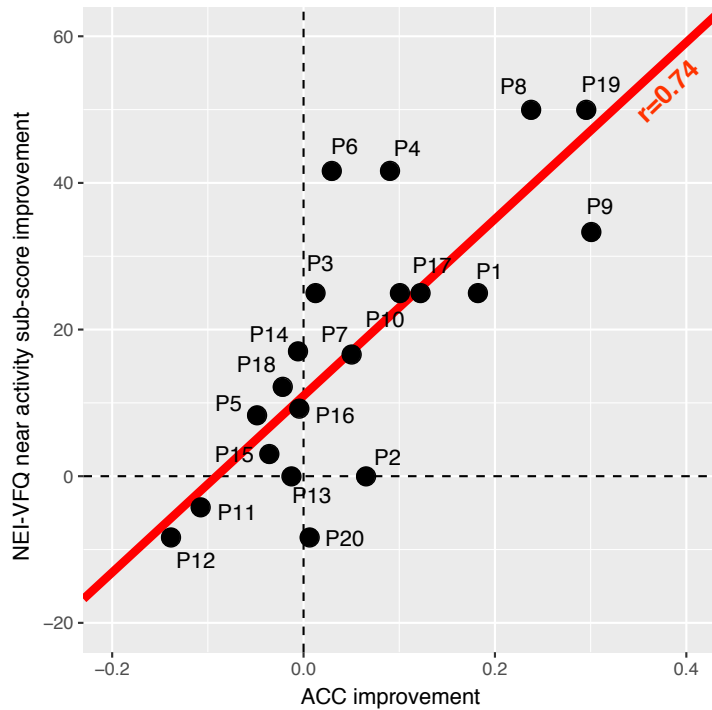
299 Critical Print size (CPS) and Reading Acuity (RA)

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

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

314

315 Discussion

316

317 The symptomatic relief experienced by patients following vitrectomy has been demonstrated
 318 before by the use of the NEI-VFQ subjective test^{5,6}. Our study confirmed the literature results,
 319 with a significant overall improvement of 26% on the test composite score. This value is in line
 320 with previously reported improvement results, ranging from 19% to 29%, in patients treated for
 321 symptomatic floaters^{6,23}. The present analysis also revealed a significant interaction between the
 322 impact of surgery on the VFQ scores and the opacity status of the patient's lenses. For near
 323 distance activities, vitrectomy only improved patients' score if their lenses were clear, whereas
 324 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 threshold²⁴, 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 surgery⁵. 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

394

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397

398

399 **Ethical Approval**

400 This study was conducted in accordance with the Declaration of Helsinki. Ethical approval for

401 this study was obtained from the Institutional Review Board (IRB) at the University of South

402 Carolina. The collection and evaluation of all protected patient health information was performed

403 in a Health Insurance Portability and Accountability Act (HIPAA)-compliant manner.

404

405 **Statement of Informed Consent**

406 Written informed consent was obtained before the study from each patient according to IRB

407 guidelines, including permission for publication of all videos included herein.

408

409

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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

503 **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

505 Table 1: Patients' individual characteristics prior to surgery. SVO stands for symptomatic

506 vitreous opacities; ERM stands for epiretinal membrane. PVD stands for posterior vitreous

507 detachment; NPDR stands for non-proliferative diabetic retinopathy; Visual acuity is given in

508 Snellen notation.

509

510 **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.