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## Vision loss and 12-year risk of dementia in older adults: the 3C cohort study

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## 1 ABSTRACT

2 To analyze the longitudinal relationships between vision loss and the risk of dementia in the first 2 years, from 2 to 4  
3 years and beyond 4 years) after inclusion and to determine the roles of depressive symptomatology and engagement in  
4 cognitively stimulating activities in these associations. This study is based on the Three-City (3C) study, a population-  
5 based cohort of 7736 initially dementia-free participants aged 65 years and over with 12 years of follow-up. Near visual  
6 impairment (VI) was measured and distance visual function (VF) loss was self-reported. Dementia was diagnosed and  
7 screened over the 12-year period. At baseline, 8.7% had mild near VI, 4.2% had moderate to severe near VI, and 5.3%  
8 had distance VF loss. Among the 882 dementia cases diagnosed over the 12-year follow-up period, 140 cases occurred  
9 in the first 2 years, 149 from 2 to 4 years and 593 beyond 4 years after inclusion. In Cox multivariate analysis, moderate  
10 to severe near VI was associated with an increased risk of dementia in the first 2 years (HR= 2.0, 95%CI: 1.2 to 3.3)  
11 and from 2 to 4 years (HR=1.8, 95%CI: 1.1 to 3.1) but the association was not significant beyond 4 years after inclusion  
12 even if pointing in similar direction (HR=1.3, 95%CI: 0.95 to 1.9). Mild near VI was associated with an increased risk  
13 of dementia only in the first 2 years (HR=1.6, 95%CI: 1.1 to 2.5). Moreover, self-reported distance VF loss was  
14 associated with an increased risk beyond 4 years after inclusion (HR= 1.5, 95%CI: 1.1 to 2.0) but the association was no  
15 longer significant after taking into account baseline cognitive performances. Further adjustment for engagement in  
16 cognitively stimulating activities only slightly decreased these associations. However, there was an interaction between  
17 vision loss and depressive symptomatology, with vision loss associated with dementia only among participants with  
18 depressive symptomatology. These results suggest that poor vision, in particular near vision loss, may represent an  
19 indicator of dementia risk at short and middle-term, mostly in depressed elderly people.

20

## 21 INTRODUCTION

22 Vision loss (VL) is common in older adults and increases with age. The leading cause of VL is uncorrected refractive  
23 error [1], easily avoidable with corrective eyeglasses, lenses or refractive surgery. VL has been associated with  
24 cognitive impairment, but mainly in cross-sectional studies [2–10], whereas longitudinal studies have shown conflicting  
25 results [11–16]. Furthermore, little is known about the longitudinal association between VL and dementia, with only  
26 one previous study among participants aged 71 and older, showing that those who perceived that their vision was good  
27 or excellent had a lower risk of developing dementia [17].

28 Several hypotheses have been proposed to explain the association between VL and cognitive impairment: 1) VL may  
29 act through factors known to be associated with cognitive decline and dementia, in particular engagement in activities  
30 and depression [18–20]. Thus, VL may decrease the engagement in cognitively stimulating activities or participation in  
31 social life or increase the risk of depression, which may subsequently increase the risk of dementia [21–26]. 2) A lack  
32 of adequate sensory input could lead to neuronal atrophy and thus cognitive impairment [27]. 3) Visually impaired  
33 people may need to allocate more resources to perceive and interpret sensory information and thus have fewer resources  
34 for other cognitive tasks [28]. 4) Alternatively, VL and dementia may share common risk factors as aging [27]. 5)  
35 Finally, vision loss may be one of the early symptoms of dementia as, Alzheimer’s disease (AD), the major cause of  
36 dementia, can affect the visual pathway and result in visual deficits [29].

37 In the present study, we aimed to investigate the longitudinal association between vision loss and the incidence of  
38 dementia. In particular, thanks to a 12-year follow-up period within a large population-based cohort we aimed to study  
39 the associations for several periods of time after inclusion. Moreover, we aimed to explore the roles of depressive  
40 symptomatology and engagement in cognitively stimulating activities in these associations.

41

## 42 **METHODS**

43 This study forms part of the SENSE-Cog multi-phase research program, funded by the European Union Horizon 2020  
44 program. SENSE-Cog aims to promote mental well-being in older adults with sensory and cognitive impairments  
45 (<http://www.sense-cog.eu/>). The first part of this project aims to better understand the links between sensory, cognitive  
46 and mental health in older Europeans.

### 47 Study population

48 This study was based on the Three-City study (3C), a French population-based cohort of 9294 community-dwelling  
49 older adults aged 65 years and over who enrolled between 1999 and 2001. The aim of 3C is to assess the risk of  
50 dementia and cognitive decline due to vascular risk factors. The methodology of the 3C study has been described  
51 elsewhere [30]. Briefly, participants were recruited from the electoral rolls of three French cities: Bordeaux (n=2104),  
52 Dijon (n=4931) and Montpellier (n=2259). Data were collected during face-to-face interviews; trained  
53 neuropsychologists administered standardized questionnaires and performed clinical examinations at baseline and 2, 4,  
54 7, 10 and 12 years later. Sociodemographic characteristics, lifestyle, cardiovascular risk factors, vision, and depressive  
55 symptomatology were assessed at each interview. A complete functional and cognitive evaluation with systematic  
56 screening for dementia was also conducted. Moreover, blood samples and participation in leisure activities were  
57 collected at baseline.

58 Among the 8250 participants who were without prevalent dementia at baseline and were followed up at least once  
59 during the 12-year follow-up period, 7736 had baseline data for both distance and near vision loss and were thus,  
60 included in this study (Figure 1).

### 61 Diagnosis of dementia

62 Dementia was actively diagnosed at baseline and at each follow-up visit using a 3-step procedure. The first step  
63 consisted of a cognitive evaluation made by the neuropsychologist through a series of psychometric tests including at a  
64 minimum the MMSE [31], the Isaacs set test and the Benton Visual Retention Test [32,33]. Participants suspected of  
65 having dementia, based on either their neuropsychological performance or decline relative to a previous examination,  
66 were then examined by a senior neurologist to establish a clinical diagnosis. Finally, an independent committee of  
67 neurologists and geriatricians reviewed all potential cases of dementia with all available information in order to obtain a  
68 consensus on the diagnosis and etiology, according to the DSM-IV and the NINCDS-ADRDA criteria [34,35].

### 69 Vision loss

70 Binocular near visual acuity was assessed using the Parinaud scale (a Jaeger-like reading test commonly used in  
71 France). Assessments were carried out using presenting vision with usual optical correction (i.e., their personal  
72 spectacles) where applicable, with a standardized reading distance of 33 cm. Mild near visual impairment (VI) was  
73 classified by Parinaud 3 or 4 (Snellen equivalent 20/30-20/60) and moderate to severe near VI by Parinaud > 4 (Snellen  
74 equivalent < 20/60). Distance visual function (VF) loss was self-reported, defined as an inability or difficulty in  
75 recognizing a familiar face at 4 meters, using presenting optical correction if any.

#### 76 Leisure activities

77 Leisure activities were assessed at baseline using two different self-administered questionnaires. In Bordeaux, 28  
78 activities were assessed, 12 of which were considered cognitively stimulating activities: going to the cinema, painting,  
79 sculpting, going to the theater, reading literature, reading newspapers, acting as a director of an association (sporting,  
80 cultural or political), playing board games, doing crossword puzzles, and travelling. One point was awarded for each  
81 activity performed [36]. In Dijon and Montpellier, 6 cognitively stimulating activities were considered among 19  
82 activities assessed: reading, doing crossword puzzles, playing cards, going to the cinema/theater, practicing an artistic  
83 activity and managing an association (sporting, cultural or political). Participants were asked about the monthly  
84 frequency (0= never or rarely; 1= 1-3 per month; 2= 1 per week; 3=  $\geq 2$  per week) that they engaged in each activity,  
85 except for reading, for which participants were asked about the daily frequency (0= <1 hour per day; 1= 1-2 hours per  
86 day; 2= >2 hours per day). Cognitively stimulating activities scores were calculated by summing the item scores [37].  
87 Due to the difference in assessments between the centers, cognitively stimulating activities scores were standardized (Z-  
88 score) for the analyses.

#### 89 Depressive symptomatology

90 Depressive symptomatology at baseline was evaluated using the Center for Epidemiologic Studies Depression Scale  
91 (CESD) questionnaire, a 20-item self-report rating scale designed to evaluate the frequency of depressive symptoms  
92 experienced over the past week. Each item is scored from 0 (rarely) to 3 (most of the time). Thus, the total CESD score  
93 ranges from 0 to 60, increasing with the level of severity of depressive symptomatology. As previously validated,  
94 scored of  $\geq 17$  for men and  $\geq 23$  for women were used to define depressive symptomatology [38,39].

#### 95 Potential confounders

96 The following sociodemographic factors were considered: age, gender, educational level (elementary school without  
97 diploma, short secondary school and higher levels), living alone and monthly income (<1500€, 1500-2300€, >€2300,

98 refusal to answer). As other sensory impairments may also have an impact on dementia risk [40], self-reported hearing  
99 loss, classified in three categories (no, mild and moderate to severe) was also considered. Other potential confounders  
100 included cardiovascular risk factors: hypertension (systolic blood pressure  $\geq 140$  mmHg and/or diastolic blood pressure  
101  $\geq 90$  mmHg using the mean of two measures and/or antihypertensive medication), history of cardiovascular ischemic  
102 disease, history of stroke, hypercholesterolemia (cholesterol  $\geq 6.20$  mmol/L and/or hypolipemiant treatment),  
103 hypertriglyceridemia (triglycerides  $\geq 1.7$  mmol/L), diabetes (normal, hyperglycemia (fasting glycemia [6.1-7.0[ mmol/L,  
104 diabetes (fasting glycemia  $\geq 7.0$  mmol/L and/or antidiabetic treatment)), smoking habits (never, former, current), and  
105 body mass index (BMI) (weight/height<sup>2</sup>) in four categories ( $<21$ ,  $27-29.9$ ,  $\geq 30$  vs  $21-26.9$ ). Additionally, APOE  
106 genotype (at least one  $\epsilon 4$  allele vs no  $\epsilon 4$ ) was also taken into account.

### 107 Statistical analysis

108 Cox proportional hazards models with delayed entry (using age as time-scale) were used to compare the baseline  
109 characteristics of participants according to incident dementia and to estimate the risk of dementia associated with vision  
110 loss, providing hazard ratios (HR) and 95% confidence intervals (CI). For participants who developed dementia, time of  
111 event was determined at the middle of the interval between the visit when dementia was diagnosed and the last visit  
112 prior to dementia diagnosis. Participants who did not develop dementia were censored at the last follow-up visit. Near  
113 and distance vision loss were analyzed in separate models. In order to assess whether vision loss had a constant effect  
114 over time, vision loss was modelled by a time-dependent variable represented by a step function. The effects of vision  
115 loss on the risk of dementia were estimated in the first 2 years, from 2 to 4 years and beyond 4 years after inclusion.  
116 Supplementary analysis using other periods of time (the first 4 years, from 4 to 7 years and beyond 7 years after  
117 inclusion) was also performed. The multivariate model included the following covariates: center, gender, educational  
118 level, self-reported hearing loss, living alone, income, cardiovascular risk factors and ApoE4 genotype. A total of 276  
119 participants had missing data for at least one covariate. To avoid excluding these participants and limit thus selection  
120 bias we performed multiple imputation for missing values [41].  
121 To further assess the robustness of our analyses to potential reverse causation, we carried out a sensitivity analysis  
122 additionally adjusted for baseline cognitive status. A z-score of global cognition at baseline was computed, including  
123 performances on the MMSE, Isaacs Set Test and Benton Visual Retention Test.

124 We further studied the effects of engagement in cognitively stimulating activities and depressive symptomatology on  
125 the relationships between vision and dementia, these two factors being potentially associated with both vision and  
126 dementia. We first searched for a potential interaction between these two factors and vision loss on the risk of dementia



127 and then presented accordingly either adjusted or stratified analyses. The analyses were performed using SAS software  
128 (version 9.3; SAS Institute Inc., Cary, NC, USA).

## 129 **RESULTS**

### 130 Study sample

131 At baseline, the mean age of the 7736 participants was 73.9 years; 61.3% were women, 39.5% had a high educational  
132 level, and 12.6% had depressive symptomatology (Table 1). The mean MMSE score was 27.4 (SD 1.9). A total of 882  
133 participants developed dementia over the 12-year follow-up period (median= 9.1 years, range= 0.6 – 13.5) with an  
134 incidence of 14.5 cases per 1000 person-years. Participants who ultimately developed dementia were older, less  
135 educated, had lower income, more self-reported hearing loss, more vascular risk factors, more depressive  
136 symptomatology, reported less engagement in cognitively stimulating activities, were more often APOE4 carriers and  
137 had lower MMSE scores at baseline. They had also more often near VI and distance VF loss.

### 138 Vision loss and risk of incident dementia

#### 139 • *Main analysis*

140 Among the 7736 participants, 671 (8.7%) had mild near VI, 325 (4.2%) moderate to severe near VI and 413 (5.3%)  
141 distance VF loss. Among the 882 cases of dementia occurred over the 12-year follow-up, 140 cases occurred before the  
142 first follow-up time ( in the first 2 years), 149 between the first and the second follow-up time ( from 2 to 4 years) and  
143 593 after the second follow-up time (beyond 4 years). In the analyses adjusted for all the potential confounders (Table  
144 2), mild near VI was associated with an increased risk of dementia only in the first 2 years (HR=1.6, 95%CI: 1.1 to 2.5).  
145 Moderate to severe near VI was associated with an increased risk of dementia in the first 2 years (HR= 2.0, 95%CI: 1.2  
146 to 3.3) and from 2 to 4 years (HR=1.8, 95%CI: 1.1 to 3.1), but the risk was not significantly increased beyond 4 years  
147 although there was a trend (HR= 1.3, 95%CI: 0.95 to 1.9). Distance VF loss was associated with an increased risk of  
148 dementia only beyond 4 years (HR= 1.5, 95%CI: 1.1 to 2.0). In sensitivity analysis additionally adjusted for baseline  
149 global cognition, results were almost unchanged for near vision although the association between mild near VI and  
150 dementia in the first 2 years was no longer significant (Supplementary table 1, HR=1.5, 95%CI: 0.98 to 2.4, p=0.06).  
151 However, distance VF loss was no longer significantly associated with dementia beyond 4 years (HR= 1.3, 95%CI: 0.94  
152 to 1.8). In the supplementary analysis using other cut-offs (<4 years, 4-7 years and ≥7 years) we found a significant  
153 effect of vision loss on dementia for moderate to severe near VI only in the first 4 years after inclusion (HR=1.88,

154 95%CI 1.29;2.73,  $p=0.001$ ); after 7 years the increased risk associated with distance VF loss was only borderline  
155 significant (HR=1.55, 95%CI 0.99;2.44,  $p=0.055$ ) (Supplementary table 2).

156 • *Engagement in cognitively stimulating activities*

157 There was no interaction between vision loss and cognitively stimulating activities, thus to analyze the effects of  
158 engagement in cognitively stimulating activities on the associations between vision loss and dementia we additionally  
159 adjusted for these activities. Engagement in cognitively stimulating activities was evaluated for 7089 participants, this  
160 relatively large number of missing data (8.4%) being due to the evaluation by self-questionnaire. At baseline,  
161 participants with near VI had lower mean scores of engagement in cognitively stimulating activities, with scores  
162 decreasing as the severity of VI increased (0.08 (95% CI: 0.06 to 0.11) for no near VI, -0.14 (95% CI: -0.22 to -0.06)  
163 for mild VI, -0.38 (95% CI:-0.49 to -0.26)for moderate to severe VI,  $p<0.0001$  adjusted for age). After additional  
164 adjustment for these activities in the multivariate model (Table 3, model B), mild near VI was still associated with an  
165 increased risk of dementia in the first 2 years (HR=1.7, 95%CI: 1.0 to 2.8). Moderate to severe near VI was also  
166 associated with an increased risk of dementia from 2 to 4 years (HR=1.8, 95%CI: 1.1 to 3.3) but the risk was no longer  
167 significant beyond 4 years (HR=1.7, 95%CI: 0.9 to 3.2). As in the previous model distance VF loss was associated with  
168 an increased risk only beyond 4 years (HR=1.4, 95%CI 1.0 to 2.0). Compared to results observed in the same sample  
169 (Table 3, Model A), HRs were only slightly decreased after this adjustment for cognitively stimulating activities.

170 • *Depressive symptomatology*

171 Analyses stratified on depressive symptomatology showed an interaction between depressive symptomatology and  
172 vision loss. At baseline, distribution of depressive symptomatology differed according to near VI ( $p=0.0040$ ):  
173 participants with moderate to severe near VI had more often depressive symptomatology (15.6% (95%CI; 11.7 to 20.1)  
174 vs 12.4% (95%CI: 11.6 to 13.2) for those without near VI) and had a higher proportion of missing evaluations of their  
175 depressive symptomatology (5.2% (95% CI: 3.1 to 8.2) vs 2.1% (95%CI: 1.8 to 2.5)). Among the 6610 participants  
176 without depressive symptoms at baseline, 700 developed a dementia over the follow-up compared to 150 of the 951  
177 participants with depressive symptoms. The risks of dementia associated with visual loss were significantly increased  
178 only among participants with depressive symptomatology and not in those without. Indeed, moderate to severe near VI  
179 was associated with an increased risk in the first 2 years (HR=2.9, 95%CI 1.0 to 7.9) and beyond 4 years (HR=3.1,  
180 95%CI 1.5 to 6.5); the risk from 2 to 4 years tended to be increased but not significantly (HR=2.6, 95%CI 0.9 to 7.9).  
181 Distance VF loss was associated with an increased risk of dementia only beyond 4 years (HR=2.8, 95%CI 1.5 to 5.3).

182

**183 DISCUSSION**

184 Within a large population-based cohort followed up over 12 years, we found that moderate to severe near VI was  
185 associated with an increased risk of dementia in the first 2 years and from 2 to 4 years after adjusting for multiple  
186 potential confounders, whereas mild near VI was associated with dementia only in the first 2 years. Less engagement in  
187 cognitively stimulating activities only slightly decreased these associations. However, stratified analyses on depressive  
188 symptomatology showed an interaction between vision loss and depressive symptomatology, such that moderate to  
189 severe near visually impaired participants had an increased risk of dementia in the first 2 years, from 2 to 4 years (at the  
190 limits of the significance) and beyond 4 years only when depressive symptomatology was present, with a nearly three-  
191 fold increased risk. Participants self-reporting distance VF loss had an increased risk of dementia only beyond 4 years,  
192 but that association was no longer significant after taking into account baseline cognitive performances.

193 Most of the previous research in this area has focused on cognition rather than dementia [2–16]. Within cross-sectional  
194 studies, the results show either a significant association between VI and cognition [2–8] or no association [9,10]. In  
195 longitudinal studies, significant associations between VI and cognitive decline have been found [12,14–16], using  
196 different assessments of VI, either a measure of contrast sensitivity[12], a measure of presenting near VA [14] or  
197 presenting distance VA [16] or self-reported decline in near or distance vision [15]. Regarding distance vision, however,  
198 other studies using measures of presenting distance VA [14] or best-corrected distance VA [11,13] have not found any  
199 association, or they found an association only when decline in distance vision was considered [13]. However, the  
200 cognitive tests have differed between studies, with some including items requiring vision [12,15,16] whereas others  
201 have used blind versions of cognitive tests [11,14]. Only one study presented results according to several cognitive  
202 tests. The authors found significant associations between measured decline in distance vision and several cognitive tests  
203 exploring speed, executive functions and memory, but all of them required visual capacities. In contrast, there was no  
204 association with the only test not requiring vision, i.e., the verbal fluency test [13].

205 In addition, to our knowledge, only one study has explored the longitudinal association between VL and risk of  
206 dementia [17], focusing only on self-reported VL without exploring the potential factors involved in that association. In  
207 this American retrospective study on 625 older adults aged 71 years and older, who were followed up over 8.5 years,  
208 the authors found that participants who reported their corrected (if applicable) vision as good or excellent at baseline  
209 had a reduced 63% risk of dementia after adjusting for potential confounders. However, there was no indication about  
210 the kind of vision (near or distance) studied and the authors did not evaluate the effect of vision loss on dementia risk  
211 over time.

212 Several hypotheses have been proposed to explain the association between vision and dementia, either in favor of a  
213 direct role of VL or via confounding factors, measurement bias and common processes [27,28]. To limit the impact of  
214 potential confounders, we adjusted for numerous factors, including age, socio-economic factors, hearing impairment  
215 and vascular factors. Although residual confounds cannot be totally excluded, none of these adjustments explained the  
216 association. Moreover, as previous authors suggested that VL could be one of the first symptoms of dementia [42], we  
217 adjusted for baseline cognitive performance, and we assessed whether vision loss had a constant effect over time, by  
218 modeling the effect of vision loss on the risk of dementia in the first 2 years, from 2 to 4 years and beyond 4 years after  
219 inclusion. The risk of dementia associated with near vision loss was indeed higher in the two first periods than beyond 4  
220 years. Thus, reverse causation cannot be excluded and some participants were probably in a pre-dementia phase with  
221 their visual impairment being one of the symptoms of this pre-dementia phase. However, although not significant, there  
222 was a trend to an association between near vision loss and dementia beyond 4 years in the main analysis. Moreover,  
223 near vision loss was associated with a significantly increased risk beyond 4 years among participants with depressive  
224 symptoms, with a three-fold increased risk. In addition, distance VF loss tended also to be associated with an increased  
225 risk beyond 4 years, suggesting that vision loss could be a risk factor of dementia.

226 Previous studies have also suggested that the effect of VL on dementia may be achieved through intermediate factors, in  
227 particular decreased engagement in cognitively stimulating activities [22,25] or an increased level of depressive  
228 symptomatology [23,24]. In our population, in spite of decreased engagement in cognitively stimulating activities by  
229 participants with near VI, taking into account these activities only slightly explained the association between near VI  
230 and dementia. We cannot exclude that the measurement of activities was not accurate enough or occurred not timely in  
231 the relationship between VI and dementia, but it seems not to be the main factor involved. On the contrary, depressive  
232 symptomatology seems to be particularly involved in the relationship between vision loss and dementia. Indeed, an  
233 interaction between vision loss and depressive symptomatology was found with a risk of dementia for visually impaired  
234 participants significantly increased only for those with depressive symptomatology. As such, VL could worsen the risk  
235 of dementia in participants with pre-existing depressive symptoms. The mechanisms of this interaction need to be  
236 further explored to understand if there are potential underlying pathophysiological mechanisms, or if it acts through  
237 environmental or social factors, for example, social isolation and its consequences on recourse to care. Moreover,  
238 whether depression is a risk factor or a prodromal symptom of dementia is still unknown [43]. Thus, this increased risk  
239 of dementia in participants with vision loss and depressive symptoms could also reflect at least partly the onset of  
240 dementia more so than a real increased risk. Furthermore, the direction of the relation between visual impairment and

241 depression is still uncertain, but previous papers from the 3C-Study showed an increased risk of depressive  
242 symptomatology or suicidal ideation in participants with visual loss ([23,44]).

243 Our results have some limitations. Even after attempting to explore possible factors involved and in spite of a  
244 longitudinal design with 12 years of follow-up, the temporal sequence between visual loss, engagement in cognitively  
245 stimulating activities and depression is difficult to evaluate. Indeed, all of these factors can change over time. Moreover,  
246 distance vision was self-reported using a single question; thus, it is less accurate than other standard measures. Indeed,  
247 the meaning of 4-meters distance is really difficult to estimate and may vary from one participant to another. Moreover  
248 self-reported ability of vision loss probably varies according to cognitive capacities. However, surprisingly the  
249 association between distance VF loss and dementia was observed only beyond 4 years, even if it was no longer  
250 significant after adjustment for global cognition. For near vision, the test used (the Parinaud chart) required the ability  
251 to read, which can potentially be impaired in cognitive impairment. However, the association between near VI and  
252 dementia remained after additionally adjusting for baseline cognition. In addition, other parameters of vision, such as  
253 contrast sensitivity or visual field, are probably important to study but were not available in our study. Moreover, we  
254 did not have information about best-corrected visual acuity neither about the cause of the decreased near vision loss,  
255 which could be due to under corrected refractive error or eye-diseases such as glaucoma or age-related macular  
256 degeneration. Indeed, some studies have suggested that dementia and some eye diseases could share common age-  
257 related pathogenesis [45]. However, our objective was to study the association between vision loss (evaluated with  
258 visual acuity used in daily life) and dementia, whatever the cause of vision loss. Beyond clinical diagnosis of dementia,  
259 it would be of great interest to document whether vision loss is associated with imaging markers of Alzheimer's disease  
260 and dementia. Within a subsample of the 3C-Bordeaux participants we failed to find a cross-sectional association  
261 between vision loss and hippocampus volume. However, these analyses deserve to be further explored and replicated on  
262 a larger sample. Finally, engagement in cognitively stimulating activities was assessed using self-administered  
263 questionnaires, with some missing data. As expected, the participants answering the questionnaire were younger, more  
264 educated, had less cardiovascular risk factors and better cognition at baseline. However, the associations were almost  
265 unchanged in this subsample.

266 The strengths of our results are attributable to a large population-based cohort with a long period of follow-up, a  
267 baseline measure of presenting binocular near visual acuity using a standardized scale and an adjustment for numerous  
268 major potential confounding factors. Moreover, we actively screened for dementia using validation by an independent  
269 committee. We explored factors – namely, depressive symptomatology and engagement in cognitively stimulating

270 activities – that may be involved in the association between VL and risk of dementia. Finally, we assessed the effect of  
271 vision loss on dementia over time.

## 272 Conclusions

273 This longitudinal population-based study suggests that moderate to severe near VI could represent an indicator of  
274 dementia risk in the subsequent years, particularly in people suffering from depression. These results need to be  
275 replicated in other large longitudinal studies with both measure of near and distance visual acuity, and potential  
276 mediators need to be further explored. A large part of VL is correctable or preventable [46] . However, future  
277 researches and interventional studies are needed to further evaluate whether VL is only an indicator of future dementia  
278 or whether the improvement of VL, may represent a promising opportunity for dementia prevention.

## 279 **COMPLIANCE WITH ETHICAL STANDARDS**

### 280 *Conflict of interest*

281 Authors V. Naël and AC Scherlen are Essilor International employees. Author C. Delcourt is a consultant for Bausch &  
282 Lomb, Novartis, and Laboratoires Théa and has received research grants from Laboratoires Théa. The authors  
283 K. Pérès, JF. Dartigues, L. Letenneur, H. Amieva, A. Arleo, I. Carrière, C. Tzourio, C. Berr and C. Helmer declare that  
284 they have no conflict of interest.

285

### 286 *Research involving Human Participants*

287 All procedures performed in studies involving human participants were in accordance with the ethical standards of the  
288 Kremlin-Bicêtre University Hospital and Sud-Mediterranée III committee and with the 1964 Helsinki declaration and  
289 its later amendments or comparable ethical standards.

290

### 291 *Informed consent*

292 Informed consent was obtained from all individual participants included in the study.

293

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393 **Table 1. Baseline characteristics according to incident dementia over the 12-year follow-up: The Three-City (3C)**  
 394 **cohort study (n=7736)**

	<b>Incident dementia</b> (n=882)	<b>No incident demented</b> (n=6854)	<b>P<sup>a</sup></b>	<b>Total</b>
<b>Age, mean (SD)</b>	76.9 (5.4)	73.6 (5.3)	<b>&lt;0.0001</b>	73.9 (5.4)
<b>Gender: female</b>	575 (65.2)	4165 (60.8)	0.9258	4740 (61.3)
<b>Educational level</b>			<b>&lt;0.0001</b>	
Elementary school without diploma	128 (14.6)	461 (6.7)		589 (7.6)
Short secondary school	446 (50.7)	3642 (53.2)		4088 (52.9)
Higher level	305 (34.7)	2744 (40.1)		3049 (39.5)
<b>Living alone</b>	367 (41.7)	2372 (34.7)	0.9044	2739 (35.5)
<b>Month income</b>			<b>&lt;0.0001</b>	
<€1500	379 (46.5)	2353 (36.5)		2642 (36.3)
€1500 - 2300	214 (26.3)	1840 (28.5)		2054 (28.3)
>€2300	222 (27.2)	2353 (36.5)		2575 (35.4)
<b>Depressive symptomatology</b>			<b>&lt;0.0001</b>	
No	700 (82.4)	5910 (88.1)		6610 (87.4)
Yes	150 (17.7)	801 (11.9)		951 (12.6)
<b>Cognitively stimulating activities, mean (SD)<sup>b</sup></b>	-0.21 (1.0)	0.08 (1.0)	<b>&lt;0.0001</b>	0.05 (1.0)
<b>Smoking habits</b>			0.5045	
Never	586 (66.6)	4183 (61.0)		4769 (61.7)
Past smoker	261 (29.7)	2280 (33.3)		2541 (32.9)
Current smoker	33 (3.8)	390 (5.7)		423 (5.5)
<b>BMI</b>			0.3880	

<21	100 (11.5)	702 (10.3)		802 (10.4)
21-26.9	484 (55.7)	3861 (56.7)		4345 (56.6)
27-29.9	172 (19.8)	1338(19.6)		1510 (19.7)
≥30	113 (13.0)	910 (13.4)		1023 (13.3)
<b>Hypertension (&gt;140/90)</b>	700 (79.4)	5262 (76.8)	0.8041	5962 (77.1)
<b>History of stroke</b>	40 (4.6)	147 (2.2)	<b>&lt;0.0001</b>	187 (2.4)
<b>History of cardiovascular disease</b>	74 (8.5)	410 (6.0)	<b>0.0076</b>	484 (6.3)
<b>Hypercholesterolemia</b>			0.1644	
No	333 (40.4)	2818 (42.3)		3151 (42.1)
Yes	492 (59.6)	3843 (57.7)		4335 (57.9)
<b>Hypertriglyceridemia</b>			<b>0.0030</b>	
No	648 (80.3)	5492 (83.6)		6140 (83.2)
Yes	159 (19.7)	1079 (16.4)		1238 (16.8)
<b>Diabetes</b>			<b>&lt;0.0001</b>	
Normal glycemia	651 (80.8)	5750 (87.4)		6401 (86.7)
Hyperglycemia	32 (4.0)	241 (3.7)		273 (3.7)
Diabetes	123 (15.3)	589 (9.0)		712 (9.6)
<b>APOE4 carrier</b>			<b>&lt;0.0001</b>	
No	587 (73.1)	5306 (80.9)		5893 (80.1)
Yes	216 (26.9)	1253 (19.1)		1469 (20.0)
<b>MMSE, mean (SD)</b>	26.5 (2.1)	27.5 (1.9)	<b>&lt;0.0001</b>	27.4 (1.9)
<b>Hearing loss</b>			<b>0.0180</b>	
No	485 (55.4)	4288 (62.8)		4773 (61.9)
Mild	299 (34.1)	2080 (30.5)		2379 (30.9)
Moderate to severe	92 (10.5)	462 (6.8)		554 (7.2)
<b>Near visual impairment</b>			<b>&lt;0.0001</b>	

No ( $\geq 20/30$ )	698 (79.1)	6042 (88.2)		6740 (87.1)
Mild (20/30 – 20/60)	115 (13.0)	556 (8.1)		671 (8.7)
Moderate to severe ( $< 20/60$ )	69 (7.8)	256 (3.7)		325 (4.2)
<b>Distance visual function loss</b>	77 (8.7)	336 (4.9)	<b>0.0014</b>	413 (5.3)

395 Abbreviations: BMI= Body Mass Index; MMSE= Mini-Mental State Examination; SD= Standard Deviation;

396 Missing data: educational level (n=10), living alone (n=18), income (n=465), depressive symptomatology (n=175),  
 397 smoking (n=3), BMI (n=56), hypertension (n=1), stroke (n=81), hypercholesterolemia (n=250), hypertriglyceridemia  
 398 (n=358), diabetes (n=350), APOE4 (n=374), MMSE (n=35), hearing loss (n=30), cognitively stimulating activities  
 399 (n=647)

400 Unless otherwise indicated, data are expressed as n (%)

401 <sup>a</sup>Cox models for the risk of dementia with age used as the time-scale except for age, which was tested using a 2-tailed T  
 402 test

403 <sup>b</sup> z-score

**Table 2. Risk of dementia by vision loss in the first 2 years, from 2 to 4 years and beyond 4 years after inclusion: The Three-City (3C) cohort study (n=7736)**

	<2 years (n=698)				2-4 years (n=1311)				≥4 years (n=5727)			
	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>
<b>Near visual impairment</b>	140				149				593			
No	96	Ref			113	Ref			489	Ref		
Mild	27	1.63	1.06 – 2.51	<b>0.027</b>	20	1.15	0.71 – 1.86	0.57	68	1.00	0.77 – 1.31	0.99
Moderate to severe	17	1.95	1.16 – 3.28	<b>0.012</b>	16	1.82	1.07 – 3.08	<b>0.027</b>	36	1.34	0.95 – 1.89	0.095
<b>Distance visual function loss<sup>b</sup></b>	13	1.12	0.63 – 1.99	0.70	14	1.22	0.70 – 2.13	0.48	50	1.49	1.11 – 2.00	<b>0.008</b>

Abbreviations: CI= Confidence Interval; HR= Hazard Ratio

<sup>a</sup> Adjusted for center, age, gender, educational level, for hearing loss, living alone, income, depressive symptomatology at baseline, smoking habits, body mass index, hypertension, history of stroke, history of cardiovascular disease, hypercholesterolemia, hypertriglyceridemia, diabetes and APOE4 genotype

<sup>b</sup> Separate models

**Table 3. Risk of dementia by vision loss, with supplementary adjustment for engagement in cognitively stimulating activities: The Three-City (3C) cohort study (n=7089)**

	<2 years (n=611)				2-4 years (n=1190)				≥4 years (n=5288)			
	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>

<b>Model A without adjustment for cognitively stimulating activities<sup>a,b</sup></b>													
<b>Near visual impairment</b>	107				125					518			
No	76	Ref			97	Ref				440	Ref		
Mild	19	1.71	1.03 – 2.84	<b>0.038</b>	14	1.09	0.62 – 1.92	0.75		49	0.95	0.70 – 1.28	0.73
Moderate to severe	12	1.86	1.01 – 3.44	<b>0.048</b>	14	2.00	1.14 – 3.53	<b>0.016</b>		29	1.34	0.91 – 1.96	0.14
<b>Distance visual function loss<sup>c</sup></b>	10	1.19	0.62 – 2.29	0.60	10	1.06	0.55 – 2.02	0.87		42	1.52	1.11 – 2.09	<b>0.010</b>
<b>Model B + adjustment for cognitively stimulating activities<sup>b</sup></b>													
<b>Near visual impairment</b>	107				125					518			
No	76	Ref			97	Ref				440	Ref		
Mild	19	1.69	1.02 – 2.81	<b>0.042</b>	14	1.07	0.61 – 1.88	0.81		49	0.94	0.70 – 1.28	0.70
Moderate to severe	12	1.71	0.92 – 3.16	0.087	14	1.84	1.05 – 3.25	<b>0.035</b>		29	1.27	0.87 – 1.86	0.22
<b>Distance visual function loss<sup>c</sup></b>	10	1.09	0.57 – 2.10	0.80	10	0.98	0.51 – 1.88	0.95		42	1.42	1.03 – 1.95	<b>0.032</b>

Abbreviations: CI= Confidence Interval; HR= Hazard Ratio

<sup>a</sup> Model re-run among participants without missing data on cognitively stimulating activities

<sup>b</sup> Model adjusted for center, age, gender, educational level, hearing loss, living alone, income, smoking habits, body mass index, hypertension, history of stroke, history of cardiovascular disease, hypercholesterolemia, hypertriglyceridemia, diabetes and APOE4 genotype

<sup>c</sup> Separate models

**Table 4. Risk of dementia stratified by depressive symptomatology: The Three-City (3C) cohort study (n=7561)**

	<b>No depressive symptoms (n=6610)</b>											
	<b>&lt;2 years (n=552)</b>				<b>2-4 years (n=1080)</b>				<b>≥4 years (n=4978)</b>			
	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>
<b>Near visual impairment</b>	100				113				487			
No	71	Ref			86	Ref			406	Ref		
Mild	20	1.62	0.98 – 2.68	0.06	16	1.18	0.69 – 2.03	0.54	58	1.02	0.76 – 1.36	0.90
Moderate to severe	9	1.48	0.73 – 2.97	0.28	11	1.70	0.90 – 3.20	0.10	23	1.07	0.70 – 1.63	0.77
<b>Distance visual function loss<sup>b</sup></b>	6	0.80	0.35 – 1.83	0.60	10	1.26	0.66 – 2.42	0.49	35	1.25	0.88 – 1.77	0.22
	<b>Depressive symptoms (n=951)</b>											
	<b>&lt;2 years (n=115)</b>				<b>2-4 years (n=193)</b>				<b>≥4 years (n=643)</b>			
	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>
<b>Near visual impairment</b>	30				28				92			
No	19	Ref			21	Ref			73	Ref		
Mild	6	2.11	0.83 – 5.39	0.12	3	1.07	0.31 – 3.63	0.92	10	1.18	0.59 – 2.37	0.65
Moderate to severe	5	2.87	1.04 – 7.94	<b>0.04</b>	4	2.62	0.87 – 7.89	0.087	9	3.07	1.46 – 6.47	<b>0.003</b>

<b>Distance visual function loss<sup>b</sup></b>	4	1.09	0.37 – 3.17	0.88	4	1.29	0.44 – 3.83	0.64	13	2.83	1.52 – 5.28	<b>0.001</b>
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Abbreviations: CI= Confidence Interval; HR= Hazard Ratio

<sup>a</sup> Adjusted for center, age, gender, educational level, for hearing loss, living alone, income, depressive symptomatology at baseline, smoking habits, body mass index, hypertension, history of stroke, history of cardiovascular disease, hypercholesterolemia, hypertriglyceridemia, diabetes and APOE4 genotype

<sup>b</sup> Separate models



**Supplementary Table 1. Risk of dementia by vision loss in the first 2 years, from 2 to 4 years and beyond 4 years after inclusion with supplementary adjustment for baseline cognitive performance: The Three-City (3C) cohort study (n=7557)**

	<2 years (n=672)				2-4 years (n=1282)				≥4 years (n=5603)			
	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>
<b>Near visual impairment<sup>b</sup></b>	135				146				568			
No	94	Ref			110	Ref			473	Ref		
Mild	26	1.52	0.98 – 2.36	0.06	20	1.12	0.69 – 1.81	0.65	66	0.96	0.73 – 1.25	0.75
Moderate to severe	15	1.77	1.02 – 3.07	<b>0.042</b>	16	2.11	1.24 – 3.58	<b>0.006</b>	29	1.29	0.88 – 1.89	0.20
<b>Distance visual function loss<sup>b</sup></b>	11	0.89	0.48 – 1.65	0.71	14	1.14	0.65 – 2.00	0.64	40	1.30	0.94 – 1.81	0.11

Abbreviations: HR= Hazard Ratio; CI= Confidence Interval

<sup>a</sup> Adjusted for center, age, gender, educational level, hearing loss, living alone, income, smoking habits, body mass index, hypertension, history of stroke, history of cardiovascular disease, hypercholesterolemia, hypertriglyceridemia, diabetes, APOE4 genotype and baseline cognitive performance (computed as a Z-score based on Mini Mental State Examination, Isaacs Set Test and Benton Visual Retention Test)

<sup>b</sup> Separate models

**Supplementary Table 2. Risk of dementia by vision loss in the first 4 years, from 4 to 7 years and beyond 7 years after inclusion: The Three-City (3C) cohort study (n=7736)**

	<4 years (n=2009)				4-7 years (n=902)				≥7 years (n=4825)			
	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>	No of cases	HR	95%CI	P <sup>a</sup>
<b>Near visual impairment</b>	289				331				262			
No	209	Ref			276	Ref			213	Ref		
Mild	47	1.38	1.00 – 1.91	0.0504	35	0.88	0.62 – 1.26	0.50	33	1.17	0.81 – 1.70	0.41
Moderate to severe	33	1.88	1.29 – 2.73	<b>0.001</b>	20	1.22	0.77 – 1.93	0.39	16	1.52	0.91 – 2.53	0.11
<b>Distance visual function loss<sup>b</sup></b>	27	1.17	0.79 – 1.75	0.44	29	1.45	0.99 – 2.12	0.0597	21	1.55	0.99 – 2.44	0.0547

Abbreviations: CI= Confidence Interval; HR= Hazard Ratio

<sup>a</sup> Adjusted for center, age, gender, educational level, for hearing loss, living alone, income, depressive symptomatology at baseline, smoking habits, body mass index, hypertension, history of stroke, history of cardiovascular disease, hypercholesterolemia, hypertriglyceridemia, diabetes and APOE4 genotype

<sup>b</sup> Separate models