Title
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Journal
Optometry and Vision Science, 94(4)

ISSN
1040-5488

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Publication Date
2017-04-01

DOI
10.1097/opx.0000000000001049

Peer reviewed

HHS Public Access

Author manuscript

Optom Vis Sci. Author manuscript; available in PMC 2018 April 01.

Published in final edited form as:

Optom Vis Sci. 2017 April ; 94(4): 487–495. doi:10.1097/OPX.0000000000001049.

Lens Opacity and Hydrogen Sulfide in a New Zealand Geothermal Area

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Abstract

Purpose—Hydrogen sulfide (H_2S) is a highly toxic gas with well-established, acute irritation effects on the eye. The population of Rotorua, New Zealand, sited on an active geothermal field has some of the highest ambient H_2S exposures in the world. Evidence from ecological studies in Rotorua has suggested that H_2S is associated with cataract. The purpose of the present study was, using more detailed exposure characterization, clinical examinations and anterior eye photography, to more directly investigate this previously reported association.

Methods—Enrolled were 1637 adults, ages 18–65, from a comprehensive Rotorua primary care medical register. Patients underwent a comprehensive ophthalmic examination, including pupillary dilation and lens photography to capture evidence of any nuclear opacity, nuclear color, and cortical and posterior subcapsular opacity. Photographs were scored for all four outcomes on the LOCS III scale with decimalized interpolation between the exemplars. H_2S exposure for up to the last 30 years was estimated based on networks of passive samplers set out across Rotorua and knowledge of residential, workplace and school locations over the 30 years. Data analysis using linear and logistic regression examined associations between the degree of opacification and nuclear color or cataract (defined as a LOCS III score ≥ 2.0) in relation to H_2S exposure.

Results—No associations were found between estimated H_2S exposures and any of the four ophthalmic outcome measures.

Conclusions—Overall, results were generally reassuring. They provided no evidence that H_2S exposure at the levels found in Rotorua is associated with cataract. The previously found association between cataract and H_2S exposure in the Rotorua population seems likely to be attributable to the limitations of the ecological study design. These results cannot rule out the possibility of an association with cataract at higher levels of H_2S exposure.

Keywords

lens opacity; cataract; hydrogen sulfide; geothermal; New Zealand

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Hydrogen sulfide (H_2S) is an acutely toxic gas emitted from a number of natural sources and industrial processes that include geothermal areas, sewage treatment plants, paper mills, oil and gas refineries and CAFOs (concentrated animal feeding operations, sometimes referred to as “factory farms”). It is often recognized by its distinctive “rotten eggs” smell with an odor threshold for most people in the low parts-per-billion (ppb) range. However, ability to recognize that smell is diminished by the disabling effect of the gas on the olfactory nerves, as exposure concentration increases to around 150–200 ppm. [1] Eye irritation is one of the earliest occurring symptoms as acute exposure to H_2S increases. There is some variation in the concentration at which it is reported as starting, ranging from 25 ppb to 100 ppm, possibly depending on individual susceptibility and the duration of exposure. [2] Such exposures occur mainly in industrial situations and are associated with substantial releases of the gas. However, the effect of H_2S on the eye is less clear in settings where there is lower level, long-term ambient exposure to H_2S, such as occurs in the city of Rotorua, New Zealand.

Rotorua, with a population in excess of 55,000, is regarded generally as the city with the largest population experiencing continuous ambient exposure to H_2S. Not all residents are equally exposed, as the main emission sources of H_2S are along a line that stretches from the Whakarewarewa geothermal area, a popular tourist area, to Lake Rotorua, an old volcanic caldera. This line passes along Fenton Street, the main business street of Rotorua. Hence, people who have low H_2S exposure at home may be relatively highly exposed to the gas when working downtown. Apart from the large exposed population, Rotorua has particular advantages as a place to study possible H_2S effects. Unlike industrial sources of H_2S there are no co-emitted gases that might confound any findings, other emissions being mostly carbon dioxide and water vapor. Also, from the authors’ observations, there is little local concern about possible health effects of the emissions. Such concern, when present, can impact symptom reporting and influence willingness to participate in a study.

A previous study based on 1981–1990 New Zealand hospital discharge data,[3] found a standardized incidence ratio (SIR) of 1.12 (95% CI: 1.05–1.19) for disorders of the eye and adnexa (ICD-9 codes 360–379) for the Rotorua population relative to the rest of New Zealand. For cataract the SIR was 1.26 (95% CI: 1.14–1.38). A follow-up study using 1993–96 hospital data and data on residence in high, medium and low H_2S exposure areas found an exposure-response relationship for disorders of the eye and adnexa [4]. This result was dominated by cataract, for which the SIRs for low, medium and high H_2S exposure areas were 1.71 (1.50–1.95), 1.95 (1.52–2.46) and 2.41 (95% CI: 2.01–2.85), respectively [cataract results not included in the publication]. However, studies such of these, which rely on routinely collected data, have many limitations and need to be independently confirmed, preferably with purposively collected clinical data and individual exposure measures.

The purpose of the present study was, using more detailed exposure characterization, clinical examinations and anterior eye photography, to more directly investigate whether long-term, ambient exposure to H_2S is associated with increased levels of lenticular changes and cataract. Knowledge of whether H_2S is a risk factor for these ophthalmic outcomes is important for establishing acceptable levels of exposure to this gas.

METHODS

Ethics Statement

This research followed the tenets of the Declaration of Helsinki. Study procedures received Institutional Review Board approvals from the Northern Ethics Committee in New Zealand and from the University of California, Berkeley, for the University of California sites. We obtained written informed consent from all participants before they participated.

Participants

We enrolled 1637 adults, ages 18–65, who reported having lived in Rotorua for at least the last 3 years. Recruitment procedures have previously been described. [5] In brief, the basis for recruitment was a comprehensive primary care medical register from which patients (potential participants) were selected using a geographically stratified method. This method was used to ensure that the distribution of residential H_2S exposures was balanced across previously defined "high", "medium" and "low" H_2S exposure areas. [5, 6] Persons unable to speak and write English were excluded, as were blind people, pregnant women, and anyone who, because of disability, was unable to visit the study clinic. For the cataract investigation, anyone with bilateral aphakia or pseudophakia was also excluded. In cases where participants had unilateral lens replacement, data for the other eye were used in the analysis.

Potential study participants were recruited approximately equally from the three defined H_2S exposure areas. This stratification was merely intended to ensure a good variation in participant H_2S exposures and was not used in the statistical analysis of the collected data.

Participants attended the study clinic, where they responded to a questionnaire and underwent a series of clinical procedures and tests, including respiratory,[7] neuropsychologic,[6] and an ophthalmic examination. Here, we report results associated with the ophthalmic examination. The questionnaire inquired about demographics and personal data, as well as residential, school and workplace histories (locations and dates) going back 30 years. The study clinic was in a low H_2S exposure area of Rotorua. On average, total participation time was about 2.5 hours.

Crystalline Lens Evaluation

As part of a comprehensive examination by a trained optometrist, the pupils were dilated with 1% tropicamide and 2.5% phenylephrine for eye evaluation with ophthalmoscopy and slit lamp examination (Haag-Streit BQ 900). The anterior chamber angle was evaluated before dilation to avoid the rare risk of acute angle closure glaucoma.

The lenticular examination with the slit-lamp did not take place until a participant's pupils had dilated for at least 20 minutes. With the slit beam the examiner acquired digital photographs of cross-sectional views for nuclear opalescence (NO) and nuclear color (NC) evaluation, and then retro-illumination photographs. For the latter a light beam was strategically directed through the pupil to create a "red-eye" effect, so that opacifications and optical irregularities of the lens due to cortical (C) or posterior subcapsular (PSC) opacification show as patterns of dark shadows against the red background.

For the cross-sectional photographs, the light turret of the slit-lamp was locked at an angle of 45° to the clinician's left of the microscope and camera system and the beam width was 0.1 mm. The subject's fixation was directed towards a fixed point on the microscope. For the retro-illumination photographs, the direction and position of the illumination beam was adjusted by the clinician so that the beam entered the eye near the right-hand edge of the subject's pupil and the light reflected from the retina caused the pupil to appear to be filled with bright reddish light. For the first retro-illumination photograph, the clinician focused the observation system on the anterior surface of the lens, and for the second, the microscope was focused on the posterior surface.

The digital lens grading photographs were recorded onto compact disks and transferred to the School of Optometry at Berkeley for grading by two examiners (IB and RDM). The examiners assigned severity scores to the four categories of cataract based on their judgment in relation to the exemplar photographs of the Lens Opacity Classification System III (LOCS III), which was used as the basis for assigning severity scores.[8]

The reference exemplar photographs have 6 numbered severity steps for nuclear opalescence and nuclear color, and there are 5 exemplars each for the cortical and posterior subcortical (PSC) cataracts. A fine grading scale was applied by using decimals to interpolate between the integer values of the LOCS III severity references. [9] So, for nuclear opalescence and nuclear color possible scores are 0.0 to 6.0 in increments of 0.1; for cortical cataract and PSC, possible scores range from 0.0 to 5.0, again in increments of 0.1. For anyone who did not have their pupils dilated, only nuclear opacity and nuclear color were evaluated, as the undilated pupil did not afford a sufficient view of any cortical or PSC opacity.

The two graders had previously worked together to ensure consistency of their opacity scoring on the LOCS III scale. [10] Periodically, the two graders independently assigned severity scores to the same set of photographs and the scores were compared and differences were discussed until a consensus score was agreed upon. Graders assigned severity scores independently within sessions that typically lasted between one and two hours. At the beginning of each grading session, the grader assigned scores for a set for which consensus scores had previously been established. The grader then compared the newly assigned scores with the consensus values. This process provided checks of consistency and guarded against unwitting shifts of criteria.

Exposure Estimation

Exposure assessment has previously been explained in some detail. [5] Briefly, we estimated H_2S concentrations at each participant's home, workplace and school locations in Rotorua using data from H_2S monitoring networks set out across the city during 3 two-week periods —summer and winter, 2010, and winter, 2011. Results were used to calculate weighted average H_2S concentrations at each geographic location of workplaces, homes and schools. For calculation of mean concentrations and to avoid overweighting the winter results, the two winter concentrations were each allocated 25% weight and the summer concentration 50% weight.

For the present analysis, since cataract formation is a chronic gradual process, a long-term H_2S exposure metric is most appropriate. The metric used was based on reported residential, workplace and school locations over the 30 years prior to participation, including dates of beginning and ending residence, employment and school attendance, collected by questionnaire. We calculated this metric for the last 30 years because questionnaire pre-testing proved it a practical length of time about which to inquire. The H_2S exposure is calculated as the mean time-weighted average exposure based on hours at work or school, and assuming the remainder was spent at home. Since actual H_2S exposure measurements were made only at around the time of the study, the exposure metric unavoidably assumes that the distribution of H_2S sources and emissions remained approximately constant over the previous 3 decades. All locations outside Rotorua were assigned a zero H_2S concentration.

Year-by-year H_2S exposure estimates were first created for each of the last 30 years, or fewer for participants younger than age 30. Using geocoded H_2S concentrations, plus reported daily hours at work and hours at school, a time-weighted average H_2S exposure concentration was estimated for each year. For the main analysis, up to 30 yearly concentration estimates were averaged, including zeroes for years when participants did not live in Rotorua.

Statistical Analysis

The initial analysis was descriptive and examined the mean nuclear opacity, nuclear color, cortical, and posterior subcapsular LOCS III scores for participants categorized according to basic demographic variables and a number of known risk factors for cataract, including tobacco smoking and alcohol intake, income and education as indicators of socio-economic status, and self-reported diabetes diagnosis, after averaging scores across eyes and across graders. Thirty-year mean H_2S exposures were categorized into quartiles for regression analysis, as has been done previously. [6] ANOVA and Chi-square tests were used to examine differences between the categories.

For each participant LOCS III scores were determined from photographs by one of the graders for nuclear opacity, nuclear color, cortical, and posterior subcapsular for each eye. For the purposes of the analysis, we defined “cataract” as a LOCS III score ≥ 2.0 for any of these 4 categories (NO, NC, C, PSC). We constructed a directed acyclic graph (DAG)[11] based on known risk factors. Age and smoking are the only variables that need to be controlled for in the analysis to provide regression estimates of the H_2S exposure on the outcome. Age categorized into 5 blocks (18–29, 30–40, 40–50, 50–60, and 60+ years). Smoking was included as a categorical variable (never, former and current smoker). Age and smoking were examined using linear regressions for yearly average exposure to H_2S and right/left eye average LOCS III scores for nuclear opacity, nuclear color, cortical and posterior subcapsular opacities and, separately, using logistic regressions for LOCS III scores ≥ 2.0, defined as cataract. Age and smoking were associated with both the exposure and outcomes, at the $p \leq 0.1$ level. We also included gender and race in the model, to examine their relationship with the outcome.

Since the outcome scores obtained from the two eyes of a person are likely to be positively correlated, their inclusion in the same statistical model is inconsistent with the assumption of

statistical independence, and may result in inappropriately small variances. We addressed this by using a cluster option in the multivariate risk models. This option adjusts for within-cluster correlation and provides robust standard errors and unbiased 95% confidence intervals for the mean scores.

Linear multivariate regression models including eye as a cluster variable were used to estimate associations of exposures with outcomes of nuclear opacity, nuclear color, cortical, and posterior subcapsular LOCS III scores and logistic regressions models were used for the cataract (LOCS III ≥ 2.0) outcomes.

RESULTS

Participation rates have been previously described.[5, 7] Briefly, of the 3,522 eligible people contacted, 1,927 (54.7%) agreed to participate. However, because of field-work timeframe constraints, the final number of actual participants was 1,639. Of these, six were excluded because of missing data for the present analysis. 100 were excluded because it was not possible to evaluate their lens either due to difficulty reading the photos or because they had intra-ocular lenses. An additional 64 were not analyzed for cortical or posterior subcapsular cataracts because subjects declined pupillary dilation. A total of 1558 were evaluated for nuclear opacity and color and 1494 were assessed for cortical or posterior subcapsular cataracts. Table 1 shows, by H_2S exposure and covariate categories, the distribution of LOCS III scores for the three types of lens opacity and nuclear color. There is no obvious pattern with increasing H_2S exposure, but, as would be expected, there are clear monotonic trends of increasing LOCS scores with increasing age. Females generally have higher LOCS scores than males and diabetics have higher scores in all categories than non-diabetics. Diabetes is a known risk factor for cataract and female sex has been consistently associated with higher rates of cataract in other studies.[12] There is some evidence for an association with ethnicity.

There were differences in the severity scores for the left and right eyes across all types of opacity and nuclear color but, except for nuclear color, the average differences were very small.

Table 2 shows multivariate linear regression analyses of the opacity types and nuclear color. The model does not include diabetes, alcohol, education, income, education or smoking. Based on analysis of the DAG, adjustment only by age and smoking was necessary to obtain a non-confounded estimate of the effect of H_2S exposure on the outcome. Additionally, when tested in models (not shown), the other variables did not substantially change the estimates for H_2S exposure. Therefore those variables were unlikely to be confounding the results, from either a theoretical or empirical perspective. The regression results show no evidence of an association between H_2S exposure and LOCS score in any of the four outcome categories. They do, however, confirm expected relationships with age and sex. Evidence of protective associations for Maori relative to European race/ethnicity for nuclear opacity and nuclear color are apparent, but the converse is the case for cortical cataract and PSC. Unexpected relationships with laterality of the eye are also apparent for all outcomes

except cortical cataract. For nuclear opacity and color, the right eye is associated with higher LOCS scores, but the converse is true for PSC.

We also carried out an analysis with logistic regression, after classifying LOCS scores as "cataract" (LOC III score ≥ 2) or "not cataract". Table 3 shows the distribution of cataract according to study variables.

Patterns are similar to those shown in Table 1, except that there is some evidence of monotonically increasing relationships of H_2S exposure quartile with cataract for nuclear opacity and nuclear color. There are few participants classified as having cataract according to cortical and PSC opacity scores. For that reason, Table 4, which shows the results of adjusted logistic regression analyses, treating participants with cataract as "cases", is limited to nuclear opacity and nuclear color. It largely confirms the patterns shown in Table 3: there is no evidence of associations with H_2S exposure, there are strong associations with age, Maori appears protective relative to European ethnicity, females are at greater risk than males, and the left eye appears to be at lower cataract risk than the right eye.

DISCUSSION

Cataract, which usually forms as a gradual opacification or loss of transparency of the lens of the eye, is the leading cause of blindness worldwide, particularly in developing countries. The major known risk factors are aging and sunlight exposure and, for unexplained reasons, the condition tends to occur more frequently in women.[12] Studies have shown that, also for unknown reasons, African Americans and Caribbeans have higher prevalences of cortical opacity compared with Caucasians and lower prevalences of nuclear and PSC opacity.[12] Somewhat similarly in this study, compared with Europeans, Maori had lower prevalence of nuclear opacity and higher prevalence of cortical opacity, but also higher prevalence of PSC opacity (Table 1).

Despite the known risk factors, the causative factors behind a substantial proportion of cataract remains to be discovered. H_2S is a small, highly reactive molecule, which combines with proteins. It is plausible that it could penetrate the cornea and slowly react with lens proteins to cause opacity. If H_2S exposure is a cataract risk factor then it is important to find that out, as many people around the world are exposed to H_2S from a variety of sources, including geothermal areas, industrial and waste treatment facilities, and concentrated animal feeding operations.

H_2S, at least at concentrations above 25 ppm, is well-recognized as a cause of conjunctivitis and blepharospasm [2]. These are mainly acute effects and few studies have looked at possible effects of longer-term exposure, such as cataract. The previous study that examined this was set in Rotorua and utilized routinely collected data-- hospital discharge records. It found evidence of an association of cataract with H_2S exposure.[4]

The present study found no evidence of an association between long-term H_2S exposure and cataract, for any of the 3 opacity types or nuclear color. This is reassuring, but it is necessary to consider whether uncontrolled confounding or selection or information biases could have been responsible for the apparent absence of effect. To negatively confound results, a causal

factor for cataract would need to be inversely associated with H_2S exposure. It is difficult to imagine what this factor would be. The obvious possibility to consider is sunlight exposure, since ultraviolet light is a major risk factor for cataract. For such an exposure to negatively confound a cataractogenic effect of H_2S, the two exposures would need to be negatively correlated. It is possible to conceive of scenarios that might tend towards this. For example, people working inside buildings in downtown Rotorua, a high exposure area, might be exposed to less sunlight. However, it does not seem plausible that such confounding would completely negate the association between H_2S and cataract, if such an association did exist.

The issue of selection bias has been addressed in previous publications from this study. [5–7] It is important to consider since the participation rate was about 55%. It is always possible that those who did not take part were in some way systematically different to those who agreed to participate—in such a way that it could account for the lack of association with H_2S in this study. To achieve that impact, the differential participation would need to have been associated with the level of H_2S exposure. However, we found no indication that was the case. Selection bias related to willingness to participate seems unlikely to account for the lack of association in the study.

Two other possibilities deserve at least brief discussion. Firstly, the question arises whether persons with aphakia or pseudoaphakia, excluded from the study, could have had cataracts caused by H_2S. If that were the case, it would be very unlikely that there was no evidence in the study of increasing levels of opacity associated with H_2S exposure. A similar consideration applies to the restriction of study participation to persons aged 65 and younger. We cannot completely exclude the possibility that older persons may be susceptible to a cataractogenic effect of H_2S. For example, the α-crystallin lens protein appears to serve as a molecular chaperone to prevent denaturation of lens proteins, thereby preventing cataract formation.[13] Since the α-crystallin concentration in the lens decreases with age, any cataractogenic effect of H_2S would likely be more pronounced in the elderly.[14] Although an α-crystallin threshold concentration effect is conceivable, it again seems likely that a cataractogenic effect of H_2S would have been apparent at younger ages in terms of increased opacity.

The third major area of consideration is information bias, which could involve misclassification of either exposure or outcome. Considering first outcome: since we found expected associations of all the opacity and color measures with other known cataract predictors, particularly age, this does not provide support for a hypothesis that outcome misclassification could account for the lack of H_2S effect. One possible source of outcome information bias is related to the difference in LOCS III scores for the right and the left eyes. We can conceive of two possible explanations for this. First, it could be an artifact of the examination process, related to the angles of the slit lamp beam relative to the axis of the ophthalmoscopic photographs. The angle of the illumination beam came from the participant's temporal side for the right eye photographs and from the nasal side for the left eye. Also, it is possible that there was an order effect because the right eye photographs were always acquired and graded first. The second possibility is a lateral difference in cataract susceptibility. There is some precedent for this: a study of 56 Turkish individuals with cortical cataract showed cataract forming earlier in the dominant eye. [15] The study did not

examine other forms of cataract or nuclear color, possibly because the authors postulated a mechanism that involved formation of vacuoles and clefts in the fibers of the lens cortex. In the absence of stronger evidence for lateral susceptibility, we consider that the most likely explanation is the setup arrangement for the ophthalmic examination. In any case, when the results for the left and right eyes were considered separately, they provided no more evidence for a relationship with H_2S than did the results with the eyes combined.

Most likely to impact detection of any association with cataract would be the possibility of H_2S exposure misclassification. There was almost certainly some such misclassification since we calculated our H_2S exposure estimates on the basis of where and when participants lived, worked and went to school. We could not account for the complexities of daily movement patterns and our estimates were based on an assumption that H_2S emission sources stayed reasonably constant over the last 30 years. On the other hand, since we have previously found evidence of plausible associations with respiratory measures, [5, 7] it suggests that our exposure metrics are reflecting real exposures. In any case, the exposure metrics used here are much more detailed than the simple, essentially ecological measures of H_2S exposure used in the previous study based on hospital discharge data that suggested an association with cataract[4]. That study classified subjects as currently living in suburbs with “high”, “medium” or “low” ambient exposure levels. No account was taken of possible exposures at work, school or other places and was based on current residential address only. Also, subjects were limited to those who entered the New Zealand public hospital system. This may have led to inclusion of a higher proportion of people with exposure to known cataract risk factors, including tobacco smoking and heavy drinking.

In conclusion, our results are generally reassuring. They provide no evidence that H_2S exposure at the levels found in Rotorua is associated with cataract. The previously found association between cataract and H_2S exposure in the Rotorua population [4] seems likely to be attributable to the limitations of the ecological study design. Of course, our results cannot rule out the possibility of an association with cataract at higher levels of H_2S exposure.

Acknowledgments

This work was supported by the National Institute of Environmental Health Sciences of the National Institutes of Health (grant number R01ES014038). Support for the study was also provided by the Regional Councils Environment Bay of Plenty and Environment Waikato. The authors thank Shane Iremonger (Environment Bay of Plenty) and Nick Kim (Environment Waikato), and Dr. Phil Shoemack (Medical Officer of Health, Bay of Plenty District Health Board) for assistance.

Thanks to Melinda Sando, Dr. Sandra Linenberger, Fiona Paignton, Kataraina George, Nerene Lynskey, John McKeogh and Dr. Peter Turner for data collection and management. Assistance with participant recruitment and data management was provided by the Rotorua Area Primary Health Service (RAPHS). Thanks to Kirsten Stone, David Bradford, Chris Walmsley, Jennifer Anastasi and Miranda Whitwell.

The authors declare they have no actual or potential competing financial interests.

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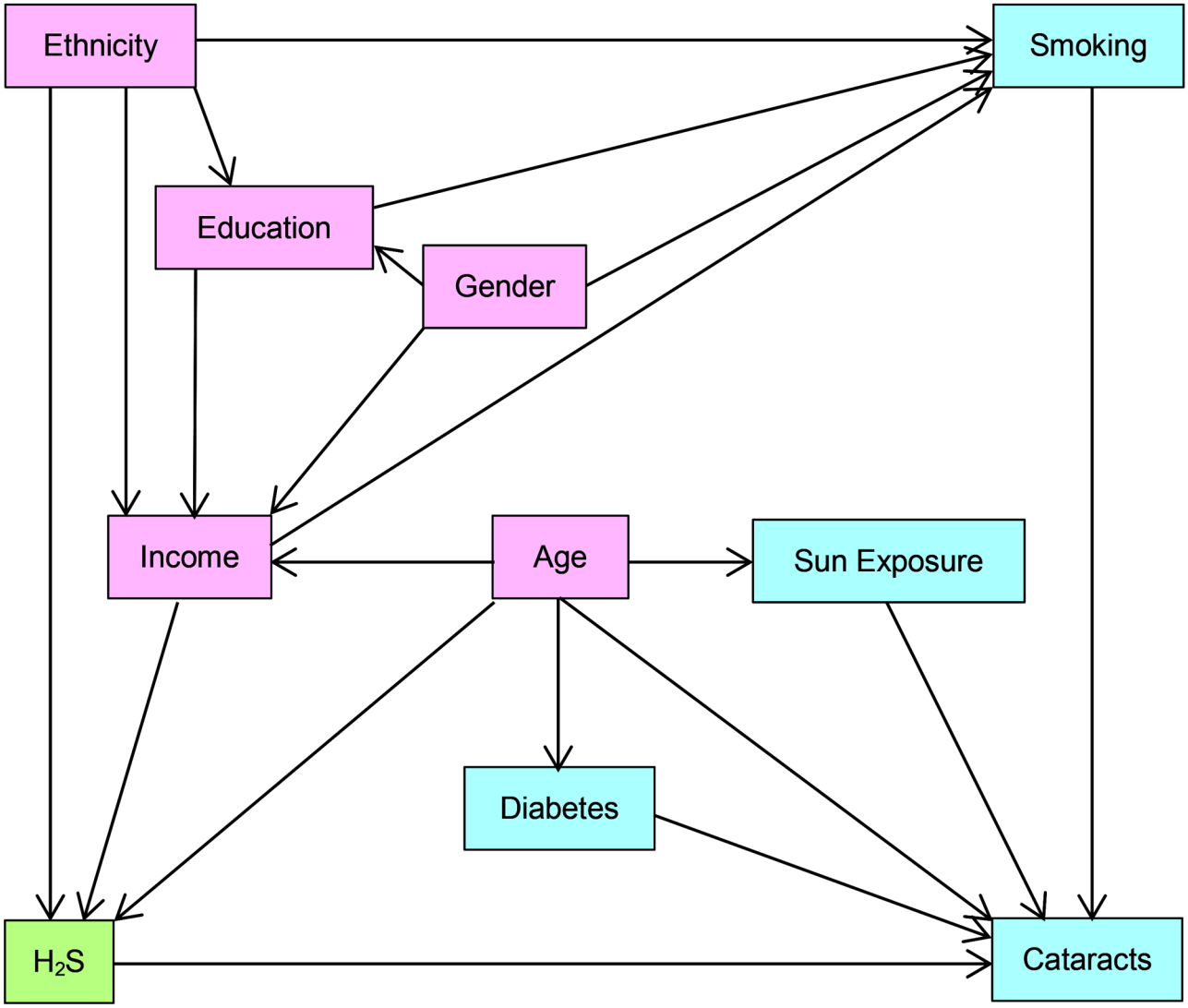

Figure 1.

Directed acyclic graph showing the possible relationships between exposure, outcome and possible covariates. H_2S, in green, is the exposure, cataract is the outcome, other blue variables are ancestors of the outcome, and pink variables are ancestors of exposure and outcome.

Table 1

Distribution of LOCS III scores (averaged across both eyes and both graders) for all participants, Rotorua, New Zealand.

Characteristic	N (%)[†]	Mean Score (SD)			
		Nuclear Opacity	Nuclear Color	Cortical	PSC
N	1558	1558	1558	1494	1494
Exposure Quartiles					
Q1	397 (25%)	1.45 (0.63)	1.5 (0.63)	0.48 (0.48)	0.14 (0.18)
Q2	386 (25%)	1.44 (0.69)	1.53 (0.70)	0.56 (0.55)	0.14 (0.19)
Q3	394 (25%)	1.54 (0.68)	1.6 (0.72)	0.52 (0.47)	0.13 (0.16)
Q4	381 (24%)	1.49 (0.68)	1.68 (0.72)	0.62 (0.61)	0.16 (0.21)
		p = 0.12	*p < 0.01*	*p < 0.01*	*p = 0.18*
Age (years)					
18–29	160 (10%)	0.98 (0.55)	0.84 (0.42)	0.26 (0.27)	0.08 (0.14)
30–39	291 (19%)	1.17 (0.58)	1.09 (0.46)	0.39 (0.37)	0.11 (0.14)
40–49	435 (28%)	1.40 (0.61)	1.48 (0.55)	0.50 (0.45)	0.13 (0.15)
50–59	446 (29%)	1.70 (0.58)	1.90 (0.56)	0.64 (0.60)	0.16 (0.19)
60–65	226 (15%)	1.93 (0.67)	2.28 (0.56)	0.82 (0.66)	0.21 (0.28)
		p < 0.01	*p < 0.01*	*p < 0.01*	*p < 0.01*
Ethnicity					
European	1249 (80%)	1.54 (0.65)	1.62 (0.69)	0.49 (0.48)	0.13 (0.19)
Maori	251 (16%)	1.14 (0.67)	1.33 (0.67)	0.79 (0.68)	0.19 (0.17)
Other	58 (4%)	1.53 (0.70)	1.72 (0.68)	0.74 (0.58)	0.19 (0.19)
		p < 0.01	*p < 0.01*	*p < 0.01*	*p < 0.01*
Gender					
Female	934 (60%)	1.51 (0.69)	1.59 (0.71)	0.60 (0.55)	0.15 (0.19)
Male	624 (40%)	1.43 (0.64)	1.55 (0.66)	0.46 (0.49)	0.13 (0.18)
		p = 0.02	*p = 0.2*	*p < 0.01*	*p < 0.01*
Smoking Status					
Never-smoker	797 (51%)	1.5 (0.64)	1.54 (0.65)	0.55 (0.53)	0.13 (0.16)

Characteristic	N (%)†	Mean Score (SD)			
		Nuclear Opacity	Nuclear Color	Cortical	PSC
Ex-smoker	448 (29%)	1.54 (0.67)	1.72 (0.71)	0.54 (0.52)	0.15 (0.24)
Current smoker	313 (20%)	1.34 (0.72)	1.47 (0.74)	0.54 (0.56)	0.15 (0.17)
		p < 0.01	*p < 0.01*	*p = 0.99*	*p = 0.14*
Diabetes diagnosed					
No	1490 (96%)	1.47 (0.67)	1.56 (0.69)	0.54 (0.52)	0.14 (0.18)
Yes	68 (4%)	1.56 (0.67)	1.99 (0.55)	0.77 (0.66)	0.22 (0.34)
		p = 0.33	*p < 0.01*	*p < 0.01*	*p < 0.01*
Alcohol Use*					
Never	401 (26%)	1.47 (0.71)	1.54 (0.71)	0.58 (0.58)	0.15 (0.20)
Ever	1157 (74%)	1.48 (0.66)	1.59 (0.69)	0.54 (0.52)	0.14 (0.18)
		p = 0.67	*p = 0.18*	*p = 0.19*	*p = 0.72*
Education					
No secondary qual	204 (13%)	1.47 (0.67)	1.60 (0.73)	0.69 (0.62)	0.17 (0.17)
Secondary qual	357 (23%)	1.48 (0.69)	1.57 (0.71)	0.52 (0.51)	0.13 (0.19)
Trade qual or certificate	597 (38%)	1.45 (0.67)	1.55 (0.67)	0.53 (0.53)	0.13 (0.16)
Bachelors	261 (17%)	1.50 (0.65)	1.58 (0.69)	0.56 (0.51)	0.17 (0.25)
Postgrad	139 (9%)	1.55 (0.65)	1.63 (0.71)	0.47 (0.46)	0.14 (0.16)
		p = 0.61	*p = 0.77*	*p < 0.01*	*p = 0.02*
Income (NZ$)					
<=$20,000	342 (22%)	1.52 (0.74)	1.63 (0.75)	0.58 (0.55)	0.15 (0.20)
$20,001–40,000	448 (29%)	1.44 (0.66)	1.51 (0.69)	0.62 (0.58)	0.15 (0.18)
$40,001–60,000	324 (21%)	1.44 (0.68)	1.55 (0.67)	0.47 (0.45)	0.13 (0.20)
$60,001–80,000	216 (14%)	1.45 (0.60)	1.55 (0.65)	0.54 (0.55)	0.14 (0.18)
>=$80,001	184 (12%)	1.57 (0.62)	1.72 (0.65)	0.46 (0.46)	0.12 (0.16)
Don’t know/Refused	44 (3%)	1.57 (0.60)	1.56 (0.72)	0.51 (0.53)	0.13 (0.13)
		p = 0.14	*p = 0.01*	*p < 0.01*	*p = 0.32*
Eye ‡					

Characteristic	N (%)†	Mean Score (SD)			
		Nuclear Opacity	Nuclear Color	Cortical	PSC
Right	1558 (100%)	1.54 (0.74)	1.76 (0.80)	0.54 (0.59)	0.13 (0.20)
Left	1558 (100%)	1.42 (0.68)	1.39 (0.66)	0.56 (0.58)	0.15 (0.22)
		p < 0.01	*p < 0.01*	*p = 0.15*	*p < 0.01*

†Number (N) and percentages are for Nuclear Opacity and Color. The smaller number of participants for the cortical and PSC opacity measurements is a result of dilation refusals and difficulties in achieving adequate retrograde illumination.

*"Ever" was defined as having ever consumed an average of at least one drink containing alcohol per week over a period of at least 6 months. "Drink containing alcohol" was defined as a glass of wine, a bottle of beer, or a shot of spirits.

‡The right and left eye outcomes were compared using a paired t-test.

Table 2

Multivariate linear regression analysis models for opacity/color in participants, Rotorua, New Zealand.

	Nuclear Opacity	Nuclear Color	Cortical Opacity	PSC Opacity
	Beta Coefficient (95% CI)	**Beta Coefficient (95% CI)**	**Beta Coefficient (95% CI)**	**Beta Coefficient (95% CI)**
H_2S exposure				
Q1	0.00	0.00	0.00	0.00
Q2	−0.04 (−0.13, 0.04)	−0.03 (−0.10, 0.04)	0.04 (−0.03, 0.11)	0.00 (−0.03, 0.02)
Q3	0.00 (−0.08, 0.08)	−0.05 (−0.12, 0.02)	−0.01 (−0.08, 0.05)	−0.01 (−0.04, 0.01)
Q4	−0.09 (−0.17, −0.01)	−0.05 (−0.12, 0.02)	0.04 (−0.03, 0.11)	0.00 (−0.03, 0.03)
Age (years)				
18–29	0.00	0.00	0.00	0.00
30–39	0.16 (0.06, 0.27)	0.24 (0.15, 0.32)	0.15 (0.09, 0.21)	0.04 (0.01, 0.07)
40–49	0.41 (0.31, 0.51)	0.64 (0.56, 0.72)	0.24 (0.18, 0.30)	0.06 (0.03, 0.09)
50–59	0.71 (0.61, 0.81)	1.07 (0.98, 1.15)	0.41 (0.34, 0.48)	0.09 (0.06, 0.12)
60–65	0.91 (0.79, 1.04)	1.43 (1.33, 1.53)	0.63 (0.53, 0.72)	0.14 (0.10, 0.19)
Ethnicity				
European	0.00	0.00	0.00	0.00
Maori	−0.32 (−0.41, −0.24)	−0.18 (−0.26, −0.1)	0.35 (0.26, 0.44)	0.07 (0.04, 0.09)
Other	0.05 (−0.11, 0.22)	0.22 (0.09, 0.35)	0.30 (0.16, 0.44)	0.06 (0.01, 0.12)
Gender				
Female	0.00	0.00	0.00	0.00
Male	−0.11 (−0.17, −0.05)	−0.07 (−0.13, −0.02)	−0.12 (−0.17, −0.08)	−0.02 (−0.04, −0.01)
Eye				
Right	0.00	0.00	0.00	0.00
Left	−0.11 (−0.14, −0.09)	−0.37 (−0.39, −0.35)	0.02 (−0.01, 0.04)	0.02 (0.01, 0.03)

Table 3

Characteristics of participants with and without cataract (LOCS III scores ≥ 2), Rotorua, New Zealand.

	Nuclear Opacity		Nuclear Color		Cortical Opacity		PSC Opacity		Any LOCS >= 2	
	No n(%)	**Yes n(%)**	**No n(%)**	**Yes n(%)**	**No n(%)**	**Yes n(%)**	**No n(%)**	**Yes n(%)**	**No n(%)**	**Yes n(%)**
H_2S exposure quartile										
Q1	308 (78)	89 (22)	305 (77)	92 (23)	370 (98)	9 (2)	378 (100)	1 (0)	186 (45)	225 (55)
Q2	293 (76)	93 (24)	275 (71)	111 (29)	353 (97)	10 (3)	363 (100)	0 (0)	176 (43)	232 (57)
Q3	277 (70)	117 (30)	277 (70)	117 (30)	372 (98)	6 (2)	378 (100)	0 (0)	158 (39)	250 (61)
Q4	284 (75)	97 (25)	241 (63)	140 (37)	356 (95)	18 (5)	373 (100)	1 (0)	152 (37)	254 (63)
	p-value	0.11		< 0.01		0.05		0.58		0.08
Age (years)										
18–29	148 (93)	12 (8)	160 (100)	0 (0)	152 (100)	0 (0)	152 (100)	0 (0)	137 (83)	29 (17)
30–39	263 (90)	28 (10)	279 (96)	12 (4)	275 (100)	1 (0)	276 (100)	0 (0)	210 (69)	95 (31)
40–49	350 (80)	85 (20)	358 (82)	77 (18)	411 (99)	3 (1)	414 (100)	0 (0)	217 (48)	236 (52)
50–59	292 (65)	154 (35)	235 (53)	211 (47)	408 (95)	21 (5)	429 (100)	0 (0)	91 (19)	379 (81)
60–65	109 (48)	117 (52)	66 (29)	160 (71)	205 (92)	18 (8)	221 (99)	2 (1)	17 (7)	222 (93)
	p-value	< 0.01		< 0.01		< 0.01		0.02		< 0.01
Ethnicity										
European	903 (72)	346 (28)	853 (68)	396 (32)	1181 (98)	21 (2)	1200 (100)	2 (0)	522 (40)	782 (60)
Maori	219 (87)	32 (13)	209 (83)	42 (17)	220 (92)	19 (8)	239 (100)	0 (0)	132 (49)	137 (51)
Other	40 (69)	18 (31)	36 (62)	22 (38)	50 (94)	3 (6)	53 (100)	0 (0)	18 (20)	73 (80)
	p-value	< 0.01		< 0.01		< 0.01		0.78		< 0.01
Gender										
Female	672 (72)	262 (28)	645 (69)	289 (31)	868 (97)	29 (3)	896 (100)	1 (0)	397 (41)	583 (59)
Male	490 (79)	134 (21)	453 (73)	171 (27)	583 (98)	14 (2)	596 (100)	1 (0)	275 (42)	378 (58)
	p-value	< 0.01		0.13		0.31		0.77		0.52
Smoking Status										
Never-smoker	591 (74)	206 (26)	585 (73)	212 (27)	750 (98)	19 (2)	769 (100)	0 (0)	348 (42)	481 (58)
Ex-smoker	324 (72)	124 (28)	279 (62)	169 (38)	416 (97)	11 (3)	425 (100)	2 (0)	166 (35)	309 (65)

	Nuclear Opacity		Nuclear Color		Cortical Opacity		PSC Opacity		Any LOCS >= 2	
	No n(%)	**Yes n(%)**	**No n(%)**	**Yes n(%)**	**No n(%)**	**Yes n(%)**	**No n(%)**	**Yes n(%)**	**No n(%)**	**Yes n(%)**
Current smoker	247 (79)	66 (21)	234 (75)	79 (25)	285 (96)	13 (4)	298 (100)	0 (0)	158 (48)	171 (52)
	p-value	0.11		< 0.01		0.23		0.08		< 0.01
Diabetes diagnosed										
No	1113 (75)	377 (25)	1063 (71)	427 (29)	1389 (97)	40 (3)	1428 (100)	1 (0)	658 (41)	934 (59)
Yes	49 (72)	19 (28)	35 (51)	33 (49)	62 (95)	3 (5)	64 (98)	1 (2)	14 (19)	58 (81)
	p-value	0.62		< 0.01		0.39		< 0.01		< 0.01
Alcohol Use										
No	292 (73)	109 (27)	286 (71)	115 (29)	365 (96)	16 (4)	380 (100)	1 (0)	187 (45)	233 (55)
Yes	870 (75)	287 (25)	812 (70)	345 (30)	1086 (98)	27 (2)	1112 (100)	1 (0)	485 (40)	728 (60)
	p-value	0.35		0.67		0.07		0.43		0.1
Education										
No secondary qual	154 (75)	50 (25)	143 (70)	61 (30)	182 (94)	12 (6)	194 (100)	0 (0)	82 (39)	130 (61)
Secondary qual	257 (72)	100 (28)	247 (69)	110 (31)	337 (98)	7 (2)	343 (100)	1 (0)	157 (42)	218 (58)
Trade qual or certificate	455 (76)	142 (24)	429 (72)	168 (28)	557 (97)	18 (3)	575 (100)	0 (0)	265 (43)	358 (57)
Bachelor’s degree	195 (75)	66 (25)	185 (71)	76 (29)	242 (98)	4 (2)	245 (100)	1 (0)	114 (41)	162 (59)
Postgrad degree	101 (73)	38 (27)	94 (68)	45 (32)	133 (99)	2 (1)	135 (100)	0 (0)	54 (37)	93 (63)
	p-value	0.65		0.84		0.03		0.52		0.68
Income (NZ$)										
<=$20,000	238 (70)	104 (30)	220 (64)	122 (36)	321 (96)	13 (4)	333 (100)	1 (0)	141 (40)	215 (60)
$20,001–40,000	345 (77)	103 (23)	329 (73)	119 (27)	409 (96)	17 (4)	426 (100)	0 (0)	202 (43)	272 (57)
$40,001–60,000	251 (77)	73 (23)	233 (72)	91 (28)	304 (99)	3 (1)	306 (100)	1 (0)	150 (45)	187 (55)
$60,001–80,000	165 (76)	51 (24)	163 (75)	53 (25)	201 (96)	8 (4)	209 (100)	0 (0)	103 (45)	124 (55)
>=$80,001	131 (71)	53 (29)	119 (65)	65 (35)	173 (99)	1 (1)	174 (100)	0 (0)	56 (29)	136 (71)
Don’t know/Refused	32 (73)	12 (27)	34 (77)	10 (23)	43 (98)	1 (2)	44 (100)	0 (0)	20 (43)	27 (57)
	p-value	0.11		0.01		0.05		0.75		0.01

Optom Vis Sci. Author manuscript; available in PMC 2018 April 01.

Table 4

Multivariate logistic regression analysis models for cataract (LOCS III scores ≥ 2) in participants, Rotorua, New Zealand.

	Odds ratio (95% Confidence interval)	
	Nuclear Opacity	**Nuclear Color**
H_2S exposure quartile		
Q1	1.00	1.00
Q2	0.92 (0.69, 1.23)	1.16 (0.86, 1.55)
Q3	1.08 (0.83, 1.42)	1.08 (0.81, 1.43)
Q4	0.82 (0.62, 1.10)	1.04 (0.78, 1.40)
Age (years)		
18–29	1.00	1.00
30–39	1.49 (0.88, 2.50)	1.84 (0.99, 3.42)
40–49	2.79 (1.72, 4.51)	5.28 (2.96, 9.42)
50–59	5.85 (3.64, 9.38)	17.7 (9.98, 31.5)
60–65	10.3 (6.22, 17.0)	48.9 (26.6, 90.1)
Ethnicity		
European	1.00	1.00
Maori	0.56 (0.41, 0.76)	0.81 (0.61, 1.08)
Other	1.59 (0.99, 2.58)	2.23 (1.34, 3.73)
Gender		
Female	1.00	1.00
Male	0.75 (0.61, 0.92)	0.77 (0.63, 0.95)
Eye		
Right	1.00	1.00
Left	0.65 (0.58, 0.72)	0.30 (0.26, 0.34)