


Population eye health education using augmented reality and virtual reality: scalable tools during and beyond COVID-19

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INTRODUCTION

The COVID-19 outbreak has had a massive impact on healthcare systems, with over 12 million infected individuals as of 10 July 2020.¹ This has necessitated operational overhaul in ophthalmology and other clinical specialties in accordance with public health measures such as physical distancing and cancellation of non-urgent clinical services.² The downstream impact of these measures include the disruption of healthcare functions including preventive programmes such as eye screening, which serve a crucial role to detect disease at early stages before the onset of irreversible morbidity such as visual impairment (VI).

VI is already a growing problem even in developed countries.³ By 2020, estimates show that 230 million individuals will be affected by VI,⁴ and that 20 million across Asia are already severely affected to the point of blindness.⁵ Studies have attributed an increased risk of death to VI^{6,7} as well as significant socioeconomic costs comparable to diabetes.⁸ Glaucoma is a major contributor to this growing burden of VI,⁴ with a population prevalence of up to 5%.⁵ Individuals may not experience symptoms in the early stages or may wrongly attribute symptoms of eye diseases to normal ageing,⁹ which lead to delayed intervention and poor outcomes, earning glaucoma the moniker, ‘the silent thief of sight’.

Recent research has identified lack of awareness about eye diseases and the importance of eye screening as

Summary box

What is already known?

- ▶ Immersive technology such as augmented reality (AR) and/or virtual reality (VR) could be applied for health promotion in a scalable manner.

What are the new findings?

- ▶ This investigation highlights the potential role of immersive technology such as augmented reality (AR) and/or virtual reality (VR) for scalable health promotion.
- ▶ There were no safety issues encountered, and patients did not report any symptoms such as motion sickness with use of AR and/or VR.
- ▶ Patients had demonstrably improved understanding about glaucoma and the importance of eye screening after utilisation of these immersive tools for eye health.
- ▶ This can positively impact healthcare by improving patient understanding about the importance of screening if such solutions are made available when patients are waiting in primary care and/or ophthalmic clinic settings whereby busy practitioners may not have the bandwidth to discuss screening in detail.
- ▶ These can be made available in primary care and/or ophthalmic clinic waiting rooms, where busy practitioners may not have the bandwidth to discuss screening in detail.

a major contributing factor to VI.¹⁰ This applies even in developed nations like the UK which reported a ceiling of 85% in attendance for systematic

screening programmes, as well as Singapore whereby 72.1% of glaucoma⁹ and 83.3% of diabetic retinopathy¹¹ detected during opportunistic screening were previously undiagnosed. These issues will likely be compounded during the pandemic as patients hesitate to seek care for their symptoms. Reduced healthcare presentations of patients with acute coronary and neurological symptoms have already been observed, likely due to fear of exposure to COVID-19.¹²

This study aims to investigate the use of scalable immersive games for education about eye health to address the lack of awareness about ocular symptoms, eye disease and screening. Patient perceptions about eye health after completing conventional counselling and eye screening are described along with the effectiveness of immersive games to address the underlying lack of awareness that contributes to the growing burden of VI.⁵ Given the importance of incorporating patient-reported outcomes in the assessment of patient-led digital interventions,¹³ this pilot investigation examines patient acceptance of using immersive games as tools for population eye health education.

METHODS

Study design

This is a prospective interventional pre–poststudy. Consecutive willing patients were recruited from the specialist outpatient clinic of a tertiary referral eye centre in Singapore after completing eye screening and conventional counselling in accordance with existing processes and protocols (control). These are patients referred from primary care settings for opportunistic eye screening (no ocular symptoms with eye screening indicated based on age, family history or comorbidities such as diabetes mellitus). Participants who were not able to speak and read the English language were excluded as the solutions were built in English language.

Participants completed a web-based interviewer-administered questionnaire (prequestionnaire) to assess their retention of information conveyed regarding eye screening and glaucoma after eye screening and conventional counselling. Questions and options in the questionnaire are randomly ordered by software program each time it is reopened by web link. Subsequently, participants used immersive games (intervention) on an HTC Vive virtual reality (VR) platform, thereafter willing participants also attempted the same on an augmented reality (AR) platform through a mobile phone application. All headsets and shared equipment were thoroughly sanitised with alcohol wipes after each use.

Participants then completed the same questionnaire a second time (postquestionnaire) to reassess their retention of information. Patient responses on both prequestionnaires/postquestionnaires were assessed using a 5-point latent construct for increasing level of understanding of 5 key messages—(Q1) What is

glaucoma? (Q2) Consequences of glaucoma? (Q3) Purpose of eye screening? (Q4) When is eye screening recommended? and (Q5) Consequences of peripheral vision loss? Wilcoxon signed-rank test was used to evaluate changes in participants' understanding and retention of information. Willing participants subsequently answered an optional survey about their willingness to use immersive games for understanding eye diseases and/or facilitating earlier detection of them.

Study intervention

Participants used immersive software (intervention) on an HTC Vive VR platform and dual external lighthouse sensors placed 1 m from the headset. The game was designed by the author DVG to increase recruitment of the peripheral visual field and simulate glaucoma, along with educational messages about eye health. Willing participants additionally attempted the same on an AR platform through a mobile phone application. Total gameplay time was a minimum of 5 min extending up to 10 min total in interested participants.

Immersive gameplay involved searching for their dragon avatar in a three-dimensional space around the participant while identifying hidden 'gems' to collect points. The game places participants in the shoes of a glaucoma patient with increasing difficulty from a gradually worsening annular visual field deficit and changes in lighting (glare/dimness) as the game progresses. This simulates functional difficulties encountered by some patients with Glaucoma in navigational tasks and searching for items. It is intended to help participants experience and appreciate how glaucoma may not be perceived if unilateral or in early stages, as well as the potential impact of severe glaucoma. Excerpts from the game are depicted in [figure 1](#) for illustration.

Statistical analysis

Descriptive statistical analysis was conducted using SPSS V.20 (IBM) with $p < 0.05$ considered significant. Associations between categorical variables were analysed using χ^2 test where expected counts within all categories were more than 5, otherwise Fisher's exact test was used instead. Associations between ordinal variables were analysed using independent samples t-test.

RESULTS

Twenty patients were recruited with a mean age of 33.2 ± 15.9 (range 17–68). Most participants had no systemic (19/20, 95%) or ocular (17/20, 85%) past medical problems. Systemic problems include diabetes and hypertension in one participant. Ocular medical problems included glaucoma suspect in one participant, allergic conjunctivitis in one participant and amblyopia in one participant. Sixteen participants (80%) used the VR platform while four participants (20%) used both the VR and AR platforms. Background information of

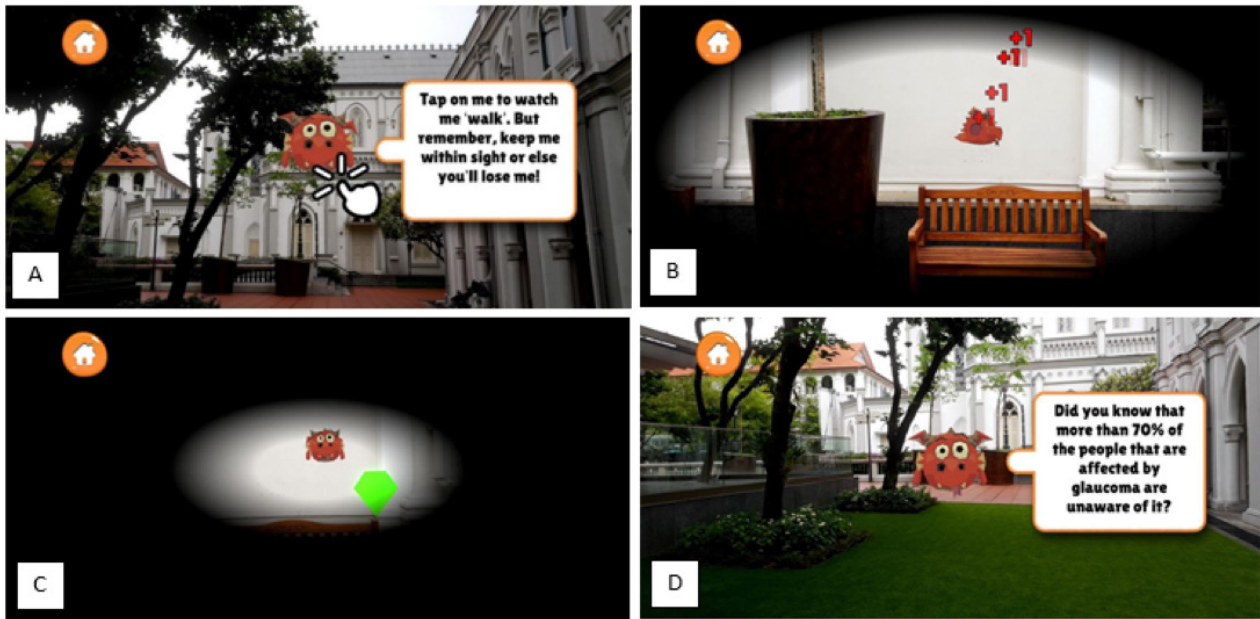


Figure 1 Immersive serious games for eye health education. Users are engaged in an immersive game that is easy to understand (A). They gain points for keeping the avatar within their visual field as it darts around in a three-dimensional space around the user (B). It incorporates progressive visual field deficits in game play (B) requiring the user to find gems (C) to recover their vision and continue playing, along with embedded educational messages (D) at key junctures.

participating patients is detailed in [table 1](#). None of the participants reported symptoms of visual disturbance, motion sickness or giddiness after using the game(s),

Gender	Male	6 (30%)
	Female	14 (70%)
Age (mean±SD, range)	33.2±15.9	(range 17–68)
Race	Chinese	15 (75%)
	Malay	2 (10%)
	Indian	1 (5%)
	Others	2 (10%)
Highest education level	Secondary school	6 (30%)
	Diploma	9 (45%)
	Degree	4 (20%)
	Masters/PhD	1 (5%)
Employment status	Student	3 (15%)
	Home maker	1 (5%)
	Self-employed	1 (5%)
	Blue collar (manual work)	2 (10%)
Previous ocular history	White collar (professional)	13 (65%)
	Yes	3 (15%)
Systemic medical history	None	17 (85%)
	Yes	1 (5%)
Solutions used	None	19 (95%)
	Virtual reality (VR) solution	16 (80%)
	VR and augmented reality	4 (20%)

and there were no safety issues such as falls encountered in the course of this study.

After using the immersive solutions, participants had statistically significant improvement in their understanding of the pathophysiology of glaucoma (Q1, $p=0.004$), effects of glaucoma (Q2, $p=0.001$), purpose of eye screening (Q3, $p=0.001$), recommended frequency of eye screening (Q4, $p=0.023$) and impact of peripheral vision loss (Q5, $p=0.012$). These are detailed in [table 2](#) and visualised in Sankey plot form in [figure 2](#). On the optional user acceptance survey, 86.7% ($n=13/15$) of patients indicated willingness to use VR and/or AR to understand eye diseases. One patient was undecided and one patient was unwilling. 35.7% ($n=5/14$) were interested to use VR and/or AR to understand eye diseases even if they had to pay for access to these health education tools, while two patients were undecided and seven patients were unwilling to use these tools if they had to pay for access. One-hundred per cent of patients ($n=13/13$) indicated that they would be more interested in health education if it were to be incorporated in immersive games such as these.

DISCUSSION

High rates of VI have been described in countries with advanced healthcare systems.³ These are consistent with reports in Singapore, whereby one-fifth of locals between age 40 and 80 suffer from VI.⁸ The global burden of VI is contributed by lack of awareness about eye diseases leading to insufficient uptake of eye

Table 2 Interview responses

	Prequestionnaire	Postquestionnaire	P value
What is Glaucoma (mean±SD)	2.8±1.2	3.5±1.1	0.004
I don't know	4 (20%)	1 (5%)	
A disease	4 (20%)	3 (15%)	
An eye disease	5 (25%)	4 (20%)	
An eye disease due to raised eye pressure	6 (30%)	10 (50%)	
An eye disease of optic nerve damage caused by raised eye pressure	1 (5%)	2 (10%)	
What are consequences of glaucoma (mean±SD)	2.2±1.3	3.5±1.4	0.001
I don't know	7 (35%)	3 (15%)	
Blindness	8 (40%)	2 (10%)	
Preventable blindness	1 (5%)	3 (15%)	
Visual field loss	2 (10%)	6 (30%)	
Peripheral visual field loss	2 (10%)	6 (30%)	
What is the purpose of eye screening (mean±SD)	2.3±1.1	3.2±0.9	0.001
I don't know	6 (30%)	0 (0%)	
Eye check-up	6 (30%)	6 (30%)	
Eye check to diagnose disease	5 (25%)	4 (20%)	
Eye check for early detection of disease	3 (15%)	10 (0%)	
Eye check for early detection of disease for better outcomes/ less invasive treatment	0 (0%)	0 (0%)	
When is eye screening recommended (mean±SD)	2.7±1.2	3.2±1.0	0.023
I don't know	4 (20%)	1 (5%)	
Eye check that is optional/ ad hoc	5 (25%)	3 (15%)	
Eye check that is regular	4 (20%)	8 (40%)	
Eye check at age 40 and regular after	7 (35%)	7 (35%)	
Eye check at age 40 and regular after, when symptomatic, or when have hypertension, diabetes mellitus or family history of eye disease	0 (0%)	1 (5%)	
What are consequences of peripheral vision loss (mean±SD)	2.4±0.9	3.2±1.2	0.012
I don't know	4 (20%)	2 (10%)	
Blindness	6 (30%)	3 (15%)	
Difficulty with some tasks	8 (40%)	7 (35%)	
Initially undetectable, later difficulty with some tasks	2 (10%)	5 (25%)	
Initially undetectable, later progressive difficulty with some tasks or loss of independence	0 (0%)	3 (15%)	

screening and late detection.^{4 9 10} When eye diseases are detected late, individuals may already have irreversible VI⁴ and the condition(s) may have progressed beyond stages amenable to medications, necessitating invasive interventions with associated risks.¹⁰ To our knowledge, this is the first report of immersive games applied to enhance eye health awareness, whereby existing literature primarily describes other technologies with respect to digital health promotion regarding any particular topic,¹⁴ along with isolated applications of immersive games in Ophthalmology for the training of doctors.¹⁵

This solution is limited in terms of the forms of VI simulated, whereby not all patients with glaucoma experience annular field loss. Also, some forms of glaucomatous visual field deficits such as blur patches and skip lesions of visual field defects are not included.¹⁶ Nonetheless, the solution was designed with the primary intention to highlight the lack of VI in early stages, symptoms that should prompt early ophthalmology review, and the potential severe VI with uncontrolled glaucoma. Future iterations of

the solution can incorporate additional forms of VI attributed to Glaucoma to provide a holistic appreciation of glaucoma. Strengths of the solution are its scalability and engaging nature that captures the attention of the public and helps transcend cultural barriers to understanding traditional education materials that are purely text based.

Limitations of the study design include a small cohort size with lack of randomised, parallel group analysis and validated questionnaire. Future studies should incorporate these considerations with longitudinal assessment to determine the real-world effectiveness of immersive games in comparison with conventional eye screening and counselling, as opposed to the incremental benefit of participants receiving both sequentially. Relevant validated questionnaires include the National Eye Health Education Programme (NEHEP) glaucoma questionnaire. Strengths of this study include being the first to report on the effectiveness of immersive games for population eye health education. These results suggest potential utility of gamified education in this manner with no safety issues encountered. This

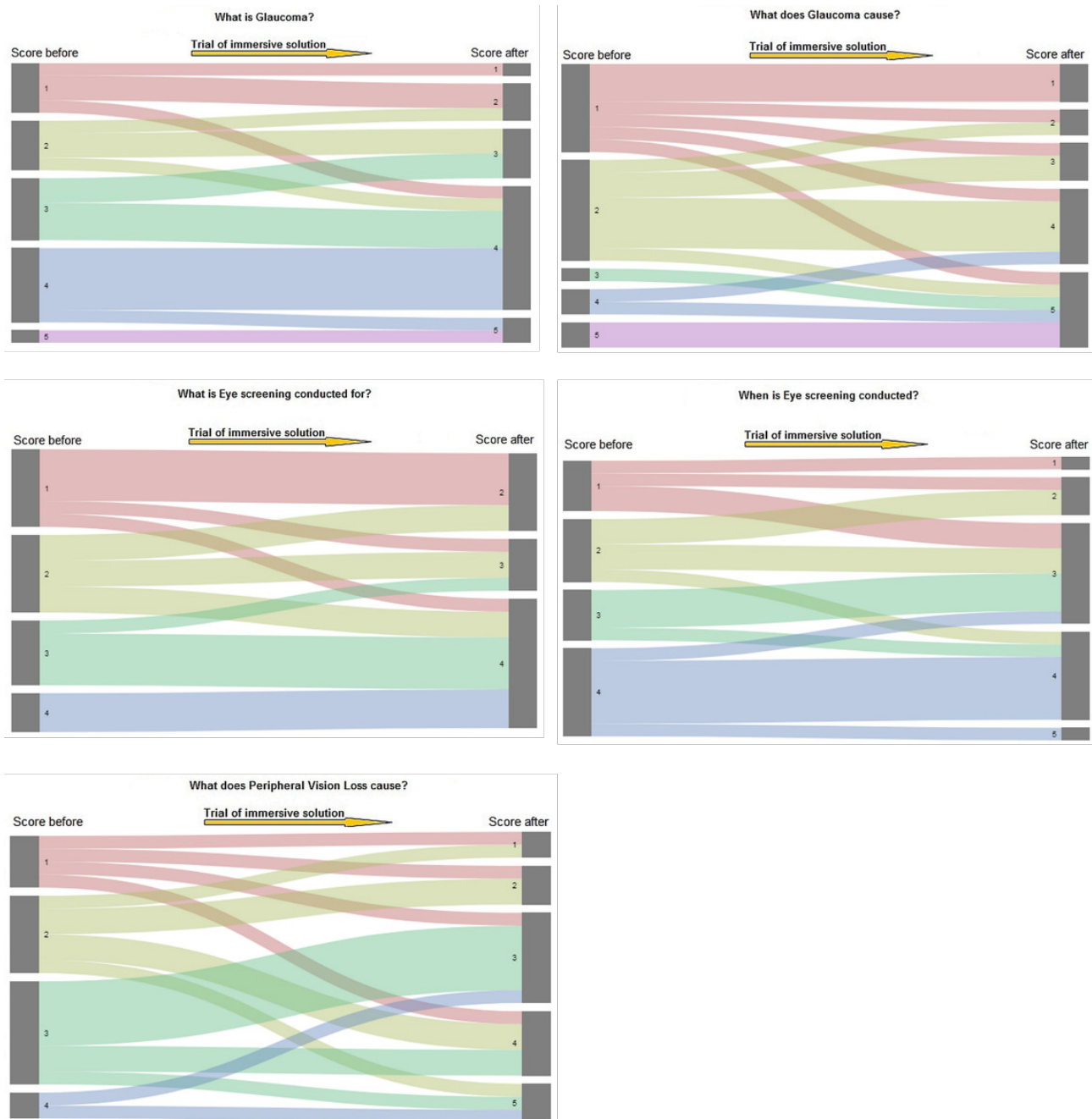


Figure 2 Sankey plot diagrams for survey results.

paves the way for larger and longitudinal studies to definitively examine the impact of such novel interventions on behavioural change and adherence to eye screening and/or follow-up assessment of ocular symptoms or eye disease.

CONCLUSION

The results of this investigation indicate that gamified VR and AR solutions may be effective for population eye health education. These results are published at this crucial time during the pandemic given the need for scalable remote health promotion to educate patients about key symptoms that should prompt clinical review, even in the context of the ongoing pandemic.

Future research can incorporate prospective enrolment and sample size calculation to definitely determine the clinical efficacy of health promotion with these solutions.

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Patient consent for publication Not required.

Ethics approval Ethical approval was received (NHG DSRB Red: 2018/00194) from the Institutional Review Board (IRB) of Tan Tock Seng Hospital, Singapore. All study procedures were conducted in accordance with the Tenets of the Declaration of Helsinki.

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REFERENCES

- World Health Organisation (WHO). Coronavirus disease (COVID-2019) situation reports. Available: <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/> [Accessed 1 Mar 2020].
- Olivia Li J-P, Shantha J, Wong TY, *et al.* Preparedness among ophthalmologists: during and beyond the COVID-19 pandemic. *Ophthalmology* 2020;127:569–72.
- Chan T, Friedman DS, Bradley C, *et al.* Estimates of incidence and prevalence of visual impairment, low vision, and blindness in the United States. *JAMA Ophthalmol* 2018;136:12–19.
- Bourne RRA, Flaxman SR, Braithwaite T, *et al.* Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. *Lancet Glob Health* 2017;5:e888–97.
- Wong TY, Loon S-C, Saw S-M. The epidemiology of age related eye diseases in Asia. *Br J Ophthalmol* 2006;90:506–11.
- Siantar RG, Cheng C-Y, Gemmy Cheung CM, *et al.* Impact of visual impairment and eye diseases on mortality: the Singapore Malay eye study (SiMES). *Sci Rep* 2015;5:16304.
- Ng SK, Kahawita S, Andrew NH, *et al.* Association of visual impairment and all-cause 10-year mortality among Indigenous Australian individuals within central Australia: the central Australian ocular health study. *JAMA Ophthalmol* 2018;136:534–7.
- Wang X, Lamoureux E, Zheng Y, *et al.* Health burden associated with visual impairment in Singapore: the Singapore epidemiology of eye disease study. *Ophthalmology* 2014;121:1837–42.
- Chua J, Baskaran M, Ong PG, *et al.* Prevalence, risk factors, and visual features of undiagnosed glaucoma: the Singapore epidemiology of eye diseases study. *JAMA Ophthalmol* 2015;133:938–46.
- Vujosevic S, Aldington SJ, Silva P, *et al.* Screening for diabetic retinopathy: new perspectives and challenges. *Lancet Diabetes Endocrinol* 2020;8:337–47.
- Huang OS, Tay WT, Ong PG, *et al.* Prevalence and determinants of undiagnosed diabetic retinopathy and vision-threatening retinopathy in a multiethnic Asian cohort: the Singapore epidemiology of eye diseases (seed) study. *Br J Ophthalmol* 2015;99:1614–21.
- Rosenbaum L. The Untold Toll — The Pandemic's Effects on Patients without Covid-19. *New Engl J Med* 2020.
- Gunasekeran DV. Technology and chronic disease management. *Lancet Diabetes Endocrinol* 2018;6:91.
- Li LW, Chew AMK, Gunasekeran DV. Digital health for patients with chronic pain during the COVID-19 pandemic. *Br J Anaesth* 2020;125:657–60.
- Borgersen NJ, Skou Thomsen AS, Konge L, *et al.* Virtual reality-based proficiency test in direct ophthalmoscopy. *Acta Ophthalmol* 2018;96:e259–61.
- Crabb DP. A view on glaucoma--are we seeing it clearly? *Eye* 2016;30:304–13.