Received: 12 December 2023 | Accepted: 12 August 2024

DOI: 10.1111/opo.13383

OPO THE COLLEGE OF OPTOMETRISTS

ORIGINAL ARTICLE

Investigating the impact of OCT imaging of the crystalline lens on the accuracy and precision of cataract assessment

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Funding information
NIHR Biomedical Research Centre, Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology; College of Optometrists

Abstract

Purpose: To determine if supplementing standard clinical assessments with Optical Coherence Tomography (OCT) imaging of the crystalline lens improves the accuracy and precision of lens opacity assessment and associated clinical management decisions by optometrists.

Methods: Fifty optometrists registered in the UK or Éire undertook a clinical vignette study where participants graded lens opacities and made associated clinical management decisions based on the image(s)/information displayed. Three forms of vignettes were presented: (1) Slit-lamp (SL) images of the lens, (2) SL and OCT images and (3) SL, OCT and visual function measures. Vignettes were constructed using anonymised data from 50 patients with varying cataract severity, each vignette being presented twice in a randomised order (total vignette presentations = 300). The accuracy of opacity and management decisions were evaluated using descriptive statistics and non-parametric Bland–Altman analysis where assessments from experienced clinicians were the reference. The precision of assessments was examined for each vignette form using non-parametric Bland–Altman analysis.

Results: All ($n = 50$) participants completed the study, with 36 working in primary eyecare (primary eyecare) settings and 14 in hospital eyecare services (HES). Agreement was highest where vignettes contained all clinical data (i.e., SL, OCT and visual function data—grading: 51.0%, management: 50.5%), and systematically reduced with decreasing vignette content ($p < 0.001$). A larger number of vignettes containing imaging and visual function measures exhibited below reference (i.e., less conservative) grading compared with vignettes containing imaging data alone (all $p < 0.05$). HES-based optometrists were more likely to grade lens opacities lower than clinicians working in primary eyecare ($p < 0.001$). Good measurement precision was evident for all vignettes, with a mean bias close to zero and limits of agreement below one grading step for all conditions.

Conclusions: The addition of anterior segment OCT to SL images improved the accuracy of lens opacity grading. Structural assessment alone yielded more conservative decision making, which reversed once visual functional data was available.

KEYWORDS
cataract assessment, crystalline lens, OCT, optometrist, serial dependence

INTRODUCTION

Cataract is the opacification of the ocular crystalline lens.[1] This progressive condition can markedly affect visual function, in addition to the vision-related quality-of-life,[2] and is the primary cause of reversible visual impairment in low- and low-to-middle-income countries.[3] In Western Europe, cataract remains the second leading cause of reversible visual impairment,[4] and in the UK, cataract surgery is the most common elective surgery performed in the National Health Service (NHS) by ophthalmologists,[5] with over 450,000 operations undertaken in 2019.[6] With the ageing population and increase in life expectancy, the burden of cataract is likely to increase.[7] In a systematic review and meta-analysis regarding the prevalence of cataract globally and regionally, Hashemi et al.[8] reported a pooled prevalence of 17%, rising to 54% in those over 60 years of age.

The finding of cataract and onward referral for treatment is primarily undertaken by optometrists within primary care settings in the UK and Éire.[9,10] In making such decisions, clinicians typically use several discrete clinical assessments to determine the clinical status of the patient and decide upon their suitability for both onward referral to the hospital eye service (HES) and cataract surgery. This can include a combination of structural and functional visual assessments for the monitoring and management of cataract such as visual acuity, contrast sensitivity, slit-lamp assessment and crystalline lens imaging. In addition, vision-related quality-of-life questionnaires (e.g., CatQuest-9SF, Cat-PROM5[11]) and enquiries about the desire for surgical intervention can be used to determine an individual's suitability for referral. However, although these aspects of the clinical examination are considered in clinical decision making, it is unlikely that optometrists weigh them equally. Referral guidance criteria often have been based on visual acuity (VA) cut-offs, rather than reference to the extent of lens opacity. While this weighting of the functional impact of cataract is reasonable, additional information regarding the patient's symptoms, contrast sensitivity, glare disability and suitability for cataract surgery is ideally needed beyond just a VA measure to determine the need for intervention adequately. Accordingly, in the UK, the National Institute for Health and Care Excellence (NICE) developed a quality standard for cataract referral,[12] which asserts that adults should not be refused cataract surgery based solely on the VA criteria. Depending on the geographic area within the UK, there may be local referral criteria for optometrists to observe, which might include quality-of-life measures and/or the patient's desire for surgical intervention. Clinicians also need to consider whether lens extraction can benefit ocular health in cases such as those at risk of anterior angle closure.

There is significant variation in the NHS waiting list for cataract surgery across the UK and Éire, with some areas being up to 3 years.[13,14] NHS England data from March 2023 showed 630,000 people on the waiting list, representing 9% of all outpatient referrals.[15] This was exacerbated by the COVID-19 pandemic, but the relatively few ophthalmologists per capita meant that service provision capacity was already under stress.[16] For those patients with cataract, in order to avoid taking up unnecessary ophthalmology capacity, referral to secondary care should ideally yield listing for surgery, and this is often a measure of referral quality. However, a recent review of the referral accuracy of optometrists[17] noted that listing for cataract surgery occurred in 47%–81% of cases. The reasons for why these figures were not close to 100% were multifactorial, but a lack of patient symptoms has been reported as a possible reason, or alternatively that patients were not willing to undergo surgery.[17,18] However, in areas without specific cataract referral pathways, the constraints of a General Ophthalmic Service sight test means that optometrists may not have the capacity to add additional investigations that would refine cataract referrals.

While clinicians routinely assess the crystalline lens with a slit-lamp, it is unclear whether the introduction of advanced imaging technologies such as optical coherence tomography (OCT) will alter the role lens assessment plays in clinical decision making for referral by optometrists. OCT has increasingly been adopted in primary eye care, and newer models encompass anterior segment imaging, with specific modules for lens imaging. With appropriate clinician training, the use of OCT to supplement traditional clinical assessment has been demonstrated to improve the accuracy of optic nerve head and macula examinations by optometrists.[19] In a similar way, it may be hypothesised that supplementing traditional clinical assessment methods with OCT scans of the lens will improve the accuracy of assessing lens opacities. In addition, it is possible that the provision of OCT scans of the crystalline lens may serve to reduce both inter- and intra-observer variability. To date, no study has explicitly examined these hypotheses to determine whether the use of anterior segment OCT for cataract assessment alters clinical decision making. This

Key points

- This study highlights the value of anterior segment Optical Coherence Tomography imaging in addition to slit lamp imaging to improve the accuracy of cataract assessment.
- Visual function information appears to be weighted more highly by optometrists when making clinical decisions regarding cataract.
- Optometrists working in hospital settings were less conservative in grading lens opacities compared with those working in primary eye care.

clinical vignette study examined the effect of supplementing traditional clinical measures with OCT imaging of the crystalline lens for both the assessment of lens opacity and management decisions. The possible effect of exposure to clinical images with varying forms of cataract severity on subsequent gradings made by optometrists (serial dependency) was also investigated. Clinical vignettes were chosen for the study design as they are widely used to examine how clinicians manage disease across a range of medical conditions. Clinical vignettes have also been shown to simulate realistic patient interactions and offer the ability to manage the nature and range of severity of the selected cases for viewing.[20]

METHODS

Participants

Fifty optometrists registered with the General Optical Council (UK) or CORU (Éire) were recruited to take part in this study. Participants were required to be actively working in a clinical optometric setting and to have been qualified for at least 2 years at the time of the study. For each participant, the number of years of post-qualification, clinical experience, geographic region of practice and healthcare setting (e.g., hospital, primary care, etc.) were recorded.

This study received ethical approval from National Research Ethics Service HRA committee, Health Care Research Wales (HCRW) (IRAS 293722) and the Ulster University Biomedical Sciences Research Ethics Committee. The research protocol adhered to the tenets of the Declaration of Helsinki with informed consent being collected for each participant.

Clinical vignettes

Clinical vignettes were developed from anonymised data sets of 50 individuals collated during previous research studies where participants with varying severity of lens opacity were recruited. These individuals had their pupils dilated using 1% tropicamide hydrochloride as part of the research studies. In all instances, imaging and visual function data were available and subjects provided informed consent to use anonymised data for secondary research purposes. The cases selected for the vignettes were mild-to-moderate cataract, typical of what would be seen in routine optometric practice. The study authors used the LOCS-III grading system[21] to classify the selected slit-lamp images and included images with LOCS-III nuclear opacity grades 1–4. Vertical optic sections of the crystalline lens and en-face lens transilluminated slit-lamp images were presented either alone or in combination with an anterior segment OCT image of the lens and/or visual function measures. Three forms of vignette were presented: (1) slit-lamp images alone (SL), (2) slit-lamp images with corresponding OCT lens sections (SL + OCT) and (3) imaging data (slit-lamp images with OCT lens sections) plus corresponding visual function measures and the age of the patient (ALL). Figure 1 illustrates an example of (ALL) with the slide presenting both imaging modalities and visual function data. Two phases were used with visual function only added into the second phase to ensure clinicians did not base their decision solely on the visual function measures. Slit lamp images were captured with either a Haag-Streit BQ-900 (haag-streit.com/en) or Nikon FS 3 (healthcare.nikon.com/en/index.html) instrument, with ISO 6400 and 1/60s shutter speed, and consistent slit width and illumination angle for slit-lamp images. All candidate

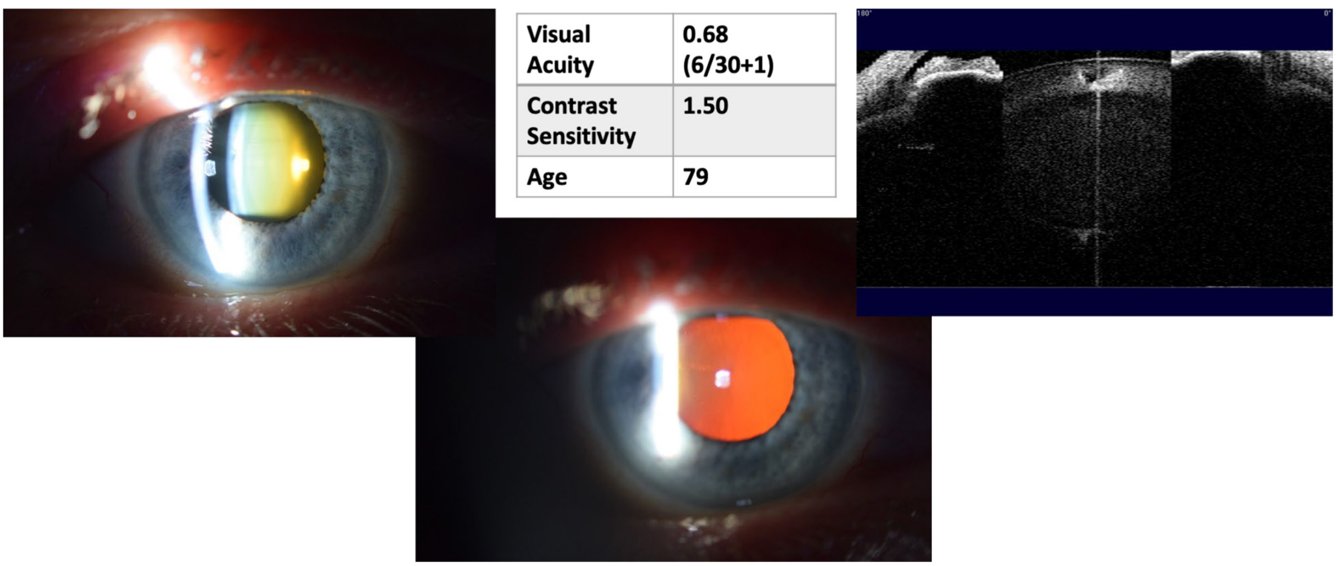

FIGURE 1 Vignette presentation illustrating the ALL imaging condition (Condition 3), with slit lamp images (top left and lower), optical coherence tomography (OCT) lens section (top right) and corresponding visual function measures (upper middle), showing visual acuity in logMAR with Snellen equivalent, log Contrast Sensitivity and age in years.

TABLE 1 Grading criteria provided to participants for analysing the clinical vignette cases.

	Opacity assessment	Clinical management
Stage 0	No opacity	Not clinically significant; review in 24 months
Stage 1	Mild opacities, not clinically significant	Early changes; review 12–24 months
Stage 2	Moderate opacities, clinically significant	Moderate changes; review 6–12 months
Stage 3	Severe opacities, clinically significant	Clinically significant; referral recommended
Stage 4	Very severe opacities, clinically significant	Clinically significant, referral required

images were examined by two experienced observers (co-investigators NB and JAL) to ensure the focus and image orientation were optimal prior to inclusion, and that visual function and OCT images were available. OCT images were averaged single-line scans captured along an axis identical to the lens sections (90° meridian, vertical lens section) using a Visante OCT (Carl Zeiss Meditec, zeiss.com/meditec/en/home.htmlss) or a binocular OCT prototype (Envision Diagnostics, linkedin.com/company/envision-diagnostics-inc/). For all scans, care was taken to ensure that the output was free from distortion and was captured perpendicular to the ocular surface so that an interference pattern was observed. Corresponding visual function measures for selected vignettes included best-corrected high-contrast visual acuity (VA) measured with a crowded logMAR VA chart (precision-vision.com/) and (with approximate Snellen equivalent values) contrast sensitivity (log CS) measured using a Pelli-Robson chart (precision-vision.com/). VA and CS ranged between −0.20 and 0.78 logMAR and 1.05–1.95 log CS, respectively.

Grading criteria were created for the participants to apply to the clinical vignettes (see Table 1). These were developed by the study team after discussion with clinical colleagues. They included two key aspects of assessment: evaluation of the significance/severity of the cataract and the clinical management decision. These were broken down into five stages, from "no opacity" to "very severe" and "not clinically significant" to "clinically significant". This grading system was necessary given that the application of LOCS-III grading[21] requires a lightbox (something not possible given the nature of the study) and the LOCS-III system did not include provision for the grading of OCT images and/or visual function data

Experimental procedure

Clinical vignettes were presented in two phases during an online videoconference call lasting approximately 1 h between the researcher and each individual optometrist. Prior to commencing data collection, participants gave consent to take part in the study and it was ensured that the images could be seen clearly on the device being used (laptop or tablet computer). A short practice session was provided for all observers to ensure the task being undertaken was understood, to familiarise them with the two vignettes being presented and the grading criteria to be used (for both cataract opacity assessment and clinical management decision, see Table 1). Participants had visual reference to the options for opacity grading and clinical management decisions throughout each data collection session. They were free to choose different gradings for the opacity assessment and clinical decision-making selections.

Vignettes were presented in two phases. For phase 1, participants were presented with the first two conditions in a randomly interleaved fashion, that is, (SL) slit lamp images either alone ($n = 50$) or (SL + OCT) in combination with corresponding OCT lens sections ($n = 50$). Then, these conditions were re-randomised and presented again to evaluate intra-observer variability. The total number of vignettes presented in phase 1 was 200. In phase 2, (ALL) vignettes were presented, i.e., slit-lamp images, OCT lens sections and visual function measures (VA and CS) (50 vignettes). These were presented twice in random order (total number of vignettes presented in phase 2 = 100). Hence, participants viewed a total of 300 vignettes. In all cases, participants were asked to assess the severity of the opacity and to give their clinical management decision based solely upon the clinical information presented in each vignette; with these being reported verbally to the researcher. There was no time limit for participants to respond to each vignette, but they were unable to go back to earlier slides to change their answers.

Data analysis

The accuracy of grading and clinical management decisions made by participants were evaluated through comparison with reference standard assessments. Reference standard values for cataract severity grading and associated management decisions were developed following the grading of each vignette by two clinicians (who practice in the UK and Éire, respectively), experienced in cataract assessment and using the same grading scheme as the study participants (Table 1). The two graders are co-investigators (NB and JAL) and were masked to each other's grading results. Where any discrepancies in cataract severity or management grading occurred ($n = 2$ images) a third experienced clinician (PJM) was invited to adjudicate to achieve consensus grading. Grading accuracy was reported as a % of the total, with differences in grading being stratified according to whether the participant scoring was higher or lower than the reference gradings. For example, where an observer's grading was higher than the reference grading, this indicated a more conservative decision (i.e., that the participant determined this was more severe/significant than the reference standard). Conversely, when a participant's grading was lower than the reference grating, this indicated a less conservative decision (i.e., the observer did not regard this as severe/significant compared with the reference standard). Given the reported regional differences in cataract referral pathways and waiting times,[13–15] the effect of geographic working location (UK vs. Éire) on grading agreement was also assessed. The effects of primary practice location (primary care or HES) and the length of time from initial professional qualification on the accuracy of grading and management decisions were also examined. For the purposes of this analysis, the second grading undertaken by each participant for each vignette was used in order to account for possible learning effects.

Considering the categorical nature of the grading conventions used here (and by extension the non-parametric nature of differences in grading between repeated presentations of the same vignettes within each vignette form), non-parametric method-of-limits analysis[22,23] was used to examine grading repeatability for each vignette form. In short, this method of analysis calculated the proportion (%) of the sample of measurement differences (method 1–2) that fell outside the 5% and 95% centiles of the distribution. The same analysis was used to examine the inter- (for individual vignettes) and intra-observer measurement variability (across all vignettes). In each case, the presence of proportional bias was examined using Kendal's correlation.

An exploratory analysis to examine the effect of serial dependence on cataract grading and management decisions was also undertaken. This analysis considered the grading reported by each observer for the previous three slides (on an individual basis) and any effect this had on the accuracy of grading or management decisions made (compared to the reference) for individual vignette presentations. To determine if serial dependence varied significantly across the range of possible cataract opacity severities and clinical management decisions (Table 1), hierarchical multinomial logistic regression analysis was used. In each case, the predictor variables considered were previous image grading or management decisions, in addition to the point in the sequence that the given image was considered (i.e., immediately preceding the current vignette [−1], or presented two [−2] or three steps [−3] prior to the current vignette). Given that the SL and SL + OCT vignettes were considered in the same run (phase 1), only these vignettes were included in this analysis.

For all tests, $p < 0.05$ was considered statistically significant. Holm-Bonferroni correction was also applied to p-values where multiple tests of the same hypothesis were undertaken.

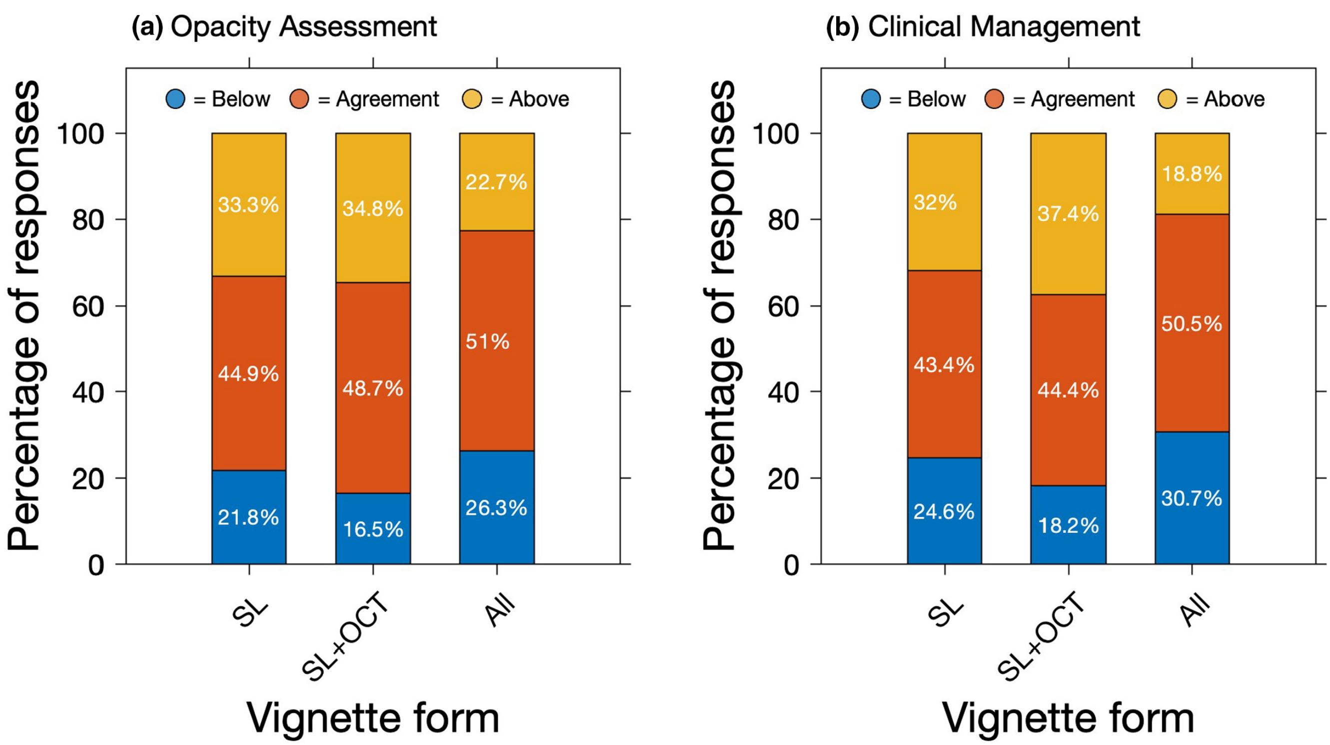

FIGURE 2 Stacked bar charts illustrating agreement (orange) for: (a) opacity grading and (b) clinical management decisions made by participants compared with the reference standard for each vignette form presented (SL: Slit-lamp data only; SL + OCT: Slit-lamp plus optical coherence tomography data; ALL: Slit-lamp, optical coherence tomography and visual function measurements). Where there was disagreement, the proportion of participants that graded higher (yellow) (i.e., more conservative) and lower (blue) (i.e., less conservative) than the reference standard is also included.

RESULTS

Data collection was successful for all 50 optometrists who participated in this study, with 24 and 26 working in the UK and Éire, respectively. Years post-initial qualification ranged from 2 to 32 years (median 6.5 years), with 36 reporting their main role as working in primary eyecare (primary eyecare) settings and 14 in the HES. For the latter case, the majority (10/14) were in the UK region.

Accuracy of grading and clinical management decisions

The proportion of vignettes for which agreement with the reference standard for opacity grading and clinical management decisions was observed is reported in Figure 2. Agreement, in addition to the nature of any disagreements made, varied with the content of the vignettes presented. Specifically, agreement was highest when ALL clinical data (Condition 3), i.e., slit lamp, OCT and visual function data, were presented (Figure 2), (grading: 51.0%, management: 50.5%); this systematically reduced with vignette content (condition (2): SL + OCT – grading: 48.7%, management: 44.4%; condition (1): SL alone – grading: 44.9%, management: 43.4%). Further, grading and management errors varied with the vignette content. Specifically, there was an increase in the number of vignettes which participants graded below the reference (i.e., less conservatively) when imaging data was supplemented with visual function measures, in comparison with imaging data alone. In order to determine whether deviations in participant responses changed with vignette content, Friedman tests were undertaken. Considering cataract opacity grading, a statistically significant difference in response was observed across vignette forms (chi squared, (2) = 24.66, $p < 0.001$), with post-hoc testing revealing significant differences between both the SL + OCT ($p < 0.001$) and SL ($p = 0.02$) vignettes in comparison with the ALL clinical information condition. Similarly, differences in clinical management decisions with vignette form were significant (chi squared, (2) = 60.5, $p < 0.001$), with post-hoc testing revealing significant differences between all vignette forms (all $p < 0.05$).

Kendall's correlation was used to examine the relationship of clinical experience (years post-initial qualification) with the observed differences in clinical decisions

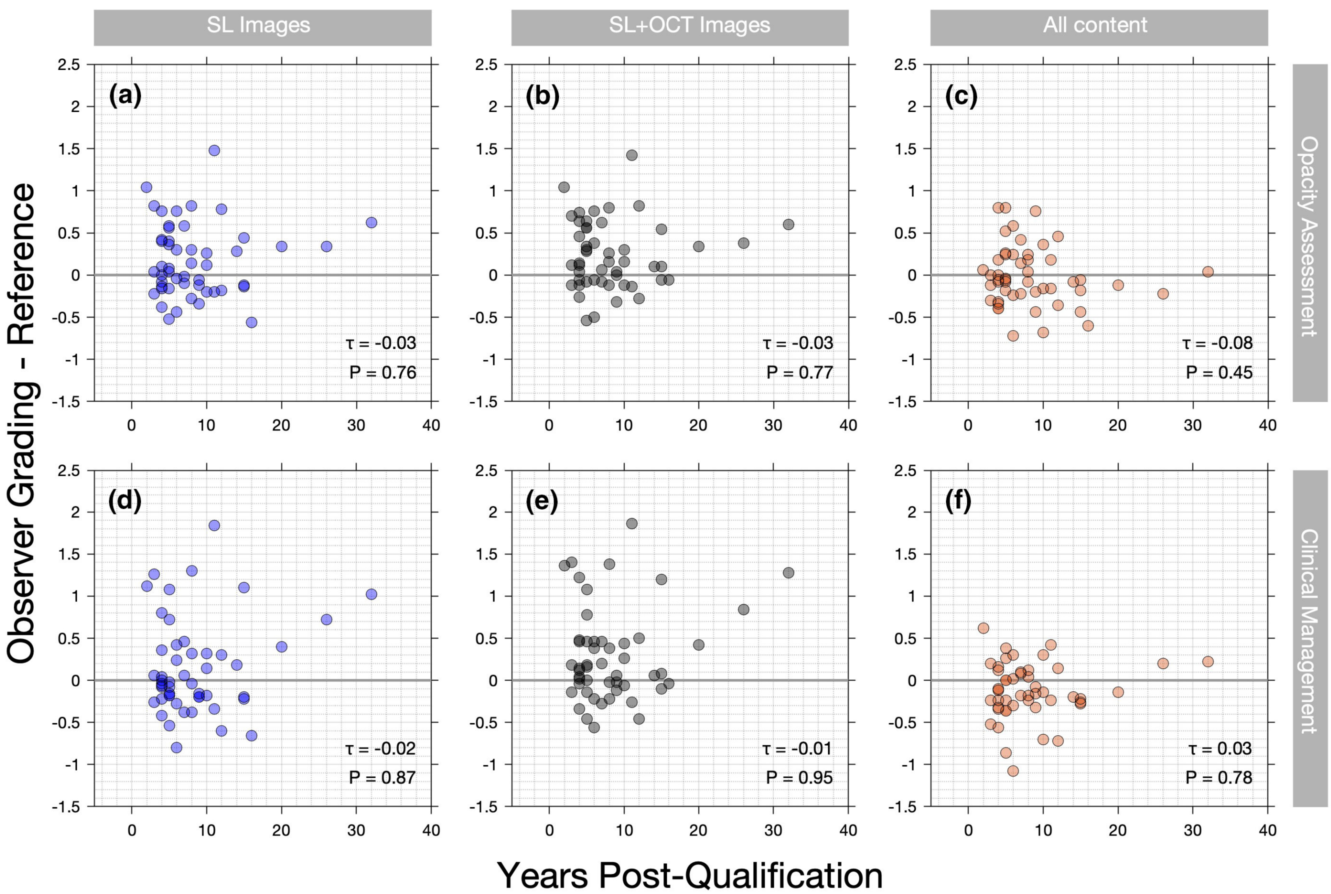

FIGURE 3 Scatter plots showing the relationship between the mean observed differences in opacity grading (a–c) and clinical management decisions (d–f) for each observer relative to the reference standard and years post-qualification for each vignette form (SL: Slit-lamp data only; SL + OCT: Slit-lamp plus optical coherence tomography data; ALL: Slit-lamp, optical coherence tomography and visual function measurements). Included for reference are Kendall's correlation values and the agreement line (grey) where no difference with reference standard was observed.

with respect to the reference standard (mean for each observer). While no statistically significant relationship was observed (all $p > 0.05$), scatter plots (Figure 3) indicated a trend towards differing grading errors with vignette content. Specifically, the proportion of data points below the line of agreement (horizontal grey line),

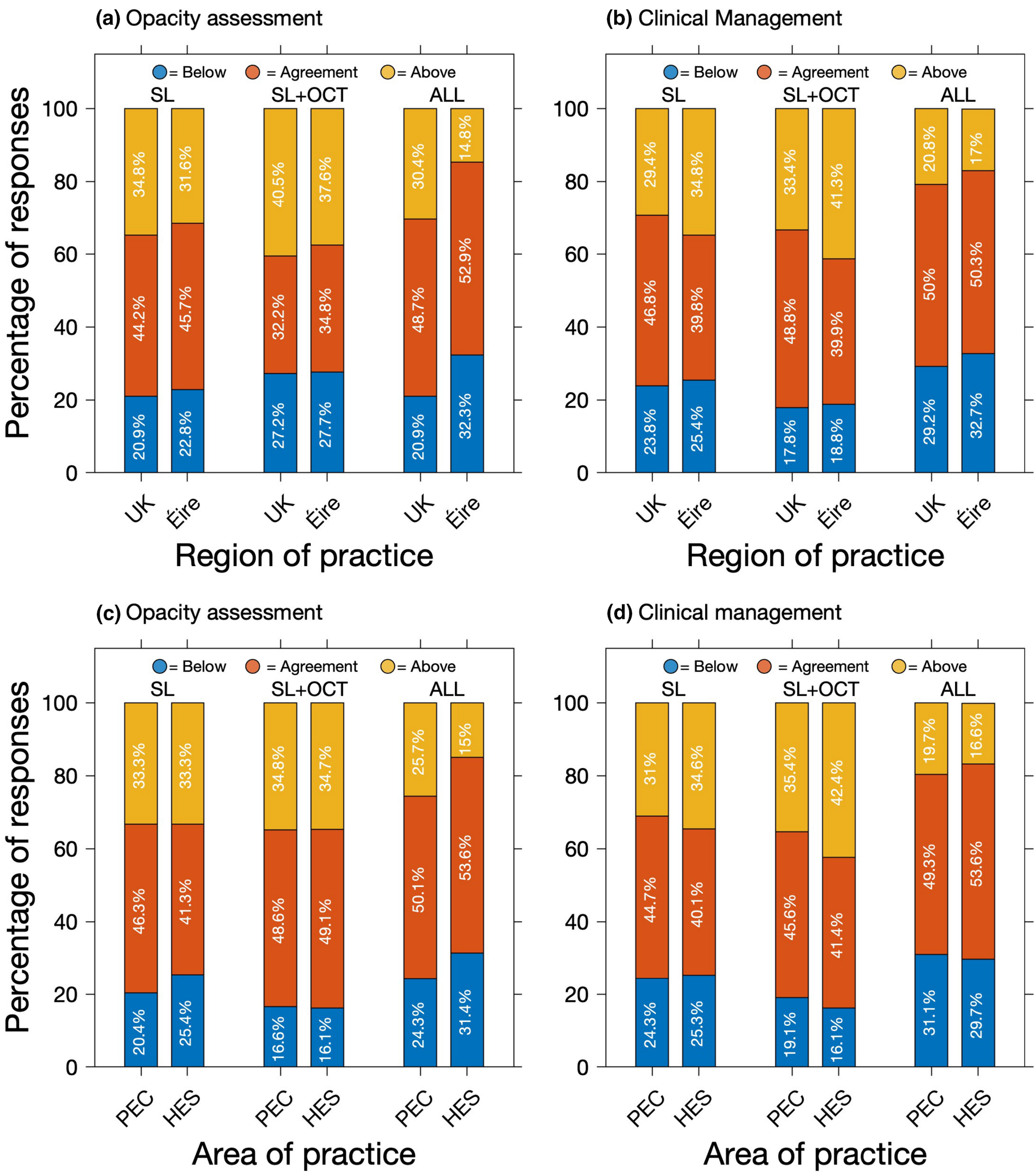

FIGURE 4 Stacked bar charts showing the agreement in observer opacity gradings (a,c) and clinical management decisions (b,d) compared with the reference standard values for different regions of practice (UK and Éire, a,b) and areas of practice (primary care [PEC] and hospital eye service [HES], c,d). Data are presented for each vignette form (SL: Slit-lamp data only; SL + OCT: Slit-lamp plus optical coherence tomography data; ALL: Slit-lamp, optical coherence tomography and visual function measurements).

where the observer would have been less conservative with grading, is greater for the vignettes containing imaging and function data (Figure 3c,f) compared with the imaging data alone (SL and SL + OCT vignettes) for both opacity grading (Figure 3a,b) and management decisions (Figure 3d,e).

The effect of practice location (UK [$n = 14$] vs Éire [$n = 36$]) and form of clinical practice (primary care vs. HES) on participant performance was also investigated. Regarding practice location, decisions made by participants in each group exhibited trends that mirrored that of the whole data set (i.e., an improvement in the proportion of vignettes showing agreement with the reference standard where all clinical information was provided [post-hoc comparisons between the SL + OCT and SL vignettes with the ALL clinical information condition were all $p < 0.05$ for both opacity and management decisions]; Figure 4a,b). For the opacity grading task, the extent of under-grading increased to a greater extent when visual function was added to vignette content in those who practised in Éire versus the UK (Wilcoxon signed rank: SL vs. ALL, $p < 0.001$; SL vs. SL + OCT, $p = 0.84$; SL + OCT vs. ALL, $p < 0.001$). When considering the mode of practice (primary eye care versus HES), a significant trend towards increased agreement with the reference standard was also observed for both opacity assessment and management decisions for vignettes contained imaging and function data (post-hoc comparisons between the SL + OCT and SL vignettes with the ALL clinical information vignette were all $p < 0.05$, Figure 4c,d). Those in HES settings ($n = 14$) were more likely to grade lens opacities lower than clinicians in primary eyecare settings ($n = 36$, Figure 4c) when all content was available ($p < 0.001$).

The effect of cataract severity grading on both opacity assessment and management decisions was also investigated (Figure 5). It may be seen that for all vignette forms the decisions became less conservative (i.e., lower grading than reference) where reference grading was higher. Examining the SL-only vignettes, an increase in the proportion of presentations where agreement with the reference was observed may be seen for both the opacity assessment (reference grade 1: 43%, reference grade 4: 56%; $p < 0.001$) and management decisions (reference grade 1: 43%, reference grade 4: 60%; $p < 0.001$) as reference grading increased. Statistical analysis indicated a shift towards under-grading opacity and less conservative management decisions when the reference opacity level was higher for the SL only vignette form (Kruskal–Wallis, both $p < 0.001$). Post-hoc pairwise analysis revealed significant differences between opacity and management decisions for stage one opacities and all other opacity levels (Mann Whitney U-test, all $p < 0.05$). For the SL + OCT vignettes and those where all clinical information was available, there was also a marked shift towards lower grading relative to reference where the reference opacity was more severe (Kruskal–Wallis, all $p < 0.001$). For those vignette forms, statistically significant differences in opacity assessments (SL + OCT: $p < 0.001$, All: $p < 0.001$) and management decisions (SL + OCT: $p < 0.001$, All: $p = 0.02$) were observed between

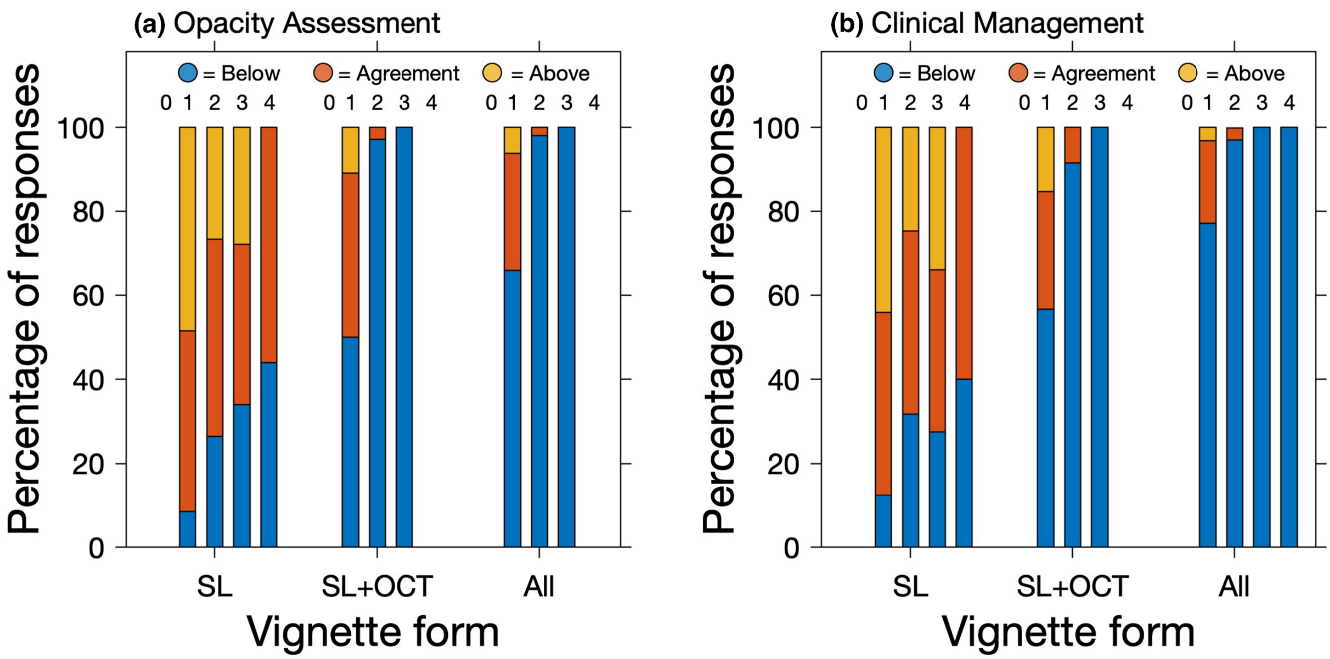

FIGURE 5 Accuracy of (a) opacity assessment and (b) clinical management decisions stratified according to the reference grading (stage 0–4, where stage 0 is no opacity/no management and stage 4 is dense cataract/referral necessary). Where no stacked bar chart is included no reference grading at that level was present. Data are presented for all vignette forms (SL: Slit-lamp data only; SL + OCT: Slit-lamp plus optical coherence tomography data; ALL: Slit-lamp, optical coherence tomography and visual function measurements).

those images for which a reference opacity grading of one and three was allocated.

Precision of grading and management decisions

Modified Bland–Altman analysis revealed that the median bias between repeated grading episodes was close to zero for all vignette forms for both the opacity and management grading tasks (Figure 6). Minimal effect of image grading level (i.e., no proportional bias) was seen across the majority of tasks except for opacity grading when all content was available (Figure 6c). In this condition, there was a trend towards a more negative bias between repeated grading episodes ($\tau = -0.24$, $p = 0.02$). It may also be seen in Figure 6 that the vertical extent of the limits of agreement (LOA) were relatively constant and <1 (range: 0.30–0.44). Grading precision was also independent of clinical experience (all $p > 0.05$, see Figure 7 for individual p-values).

Serial dependence of opacity grading and management decisions

The effect of prior responses on both opacity gradings and management decisions can be seen in Figure 8. Hierarchical multinomial logistic regression analysis revealed the responses given to previous vignettes influenced the nature of any errors made by participants on subsequent images. First, considering the image grading task, observers who made a grading error were more likely to make these in a conservative direction (+1 compared to reference grading) when the grading applied to previous images in the sequence was higher (Figure 8a, OR 1.05, $p = 0.01$). Similarly, for management decisions, observers who made errors were also more likely to make these in a more conservative direction (+1 compared to reference) when the grading applied to previous images was higher (Figure 8b, OR 1.05, $p = 0.04$). For both opacity assessment and management decisions, there was no statistically significant effect of vignette position (–1 to –3 images in sequence) on any serial dependence effects observed (opacity: $p = 0.99$; management: $p = 0.97$).

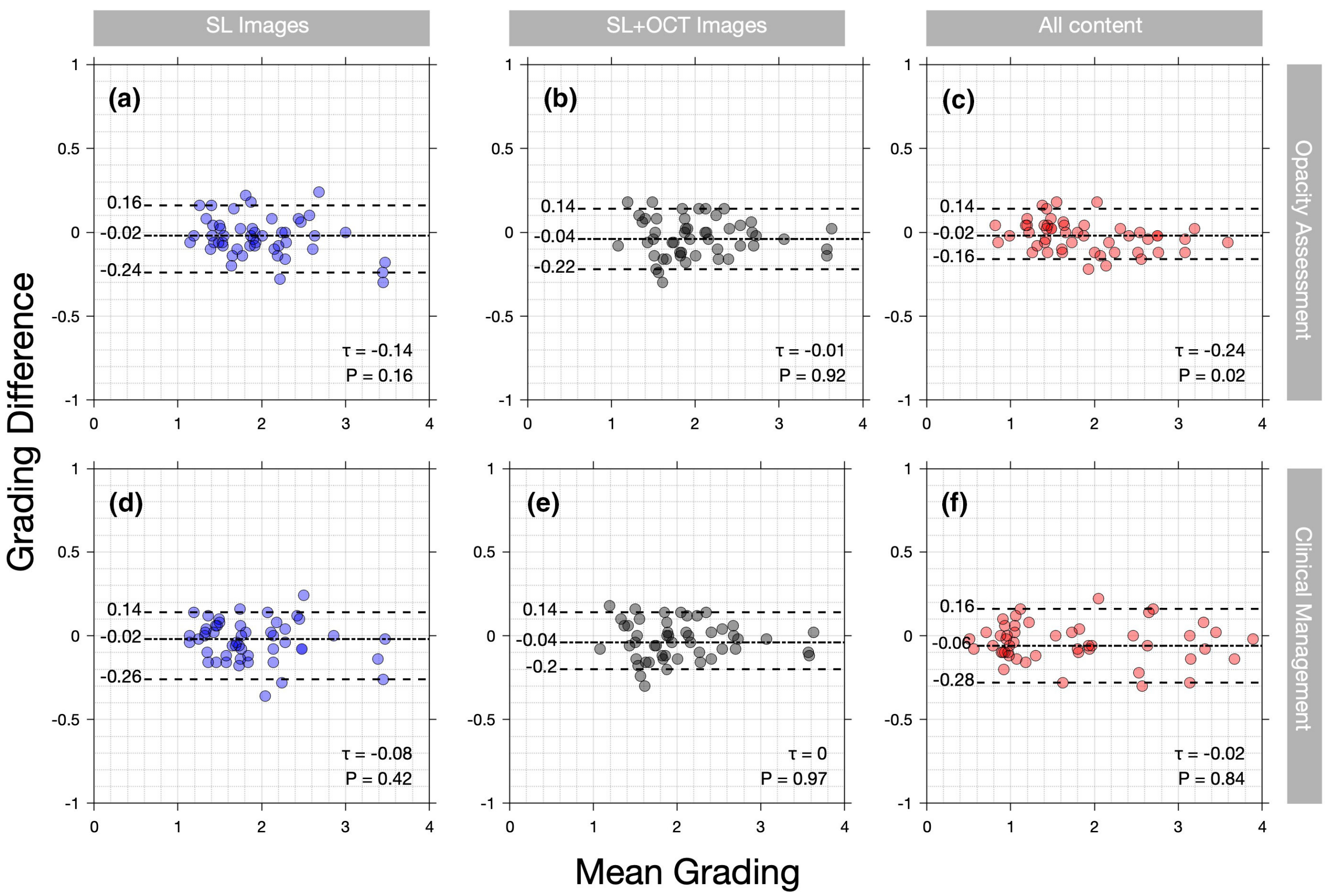

FIGURE 6 Bland–Altman plots examining test–retest repeatability of opacity grading (a-c) and clinical management decisions (d-f) made with each vignette form as a function of cataract severity or management decision suggested (stage 0–4, where stage 0 is no opacity/no management and stage 4 is dense cataract/referral necessary). In each plot, a single summary value is used for each vignette, this being the mean across all participants. Given the non-parametric nature of the data, a median bias line (the solid line), in addition to the limits-of-agreement encompassing 90% of the data points (dashed lines), is included. Data are presented for all vignette forms (SL: Slit-lamp data only; SL + OCT: Slit-lamp plus optical coherence tomography data; ALL: Slit-lamp, optical coherence tomography and visual function measurements).

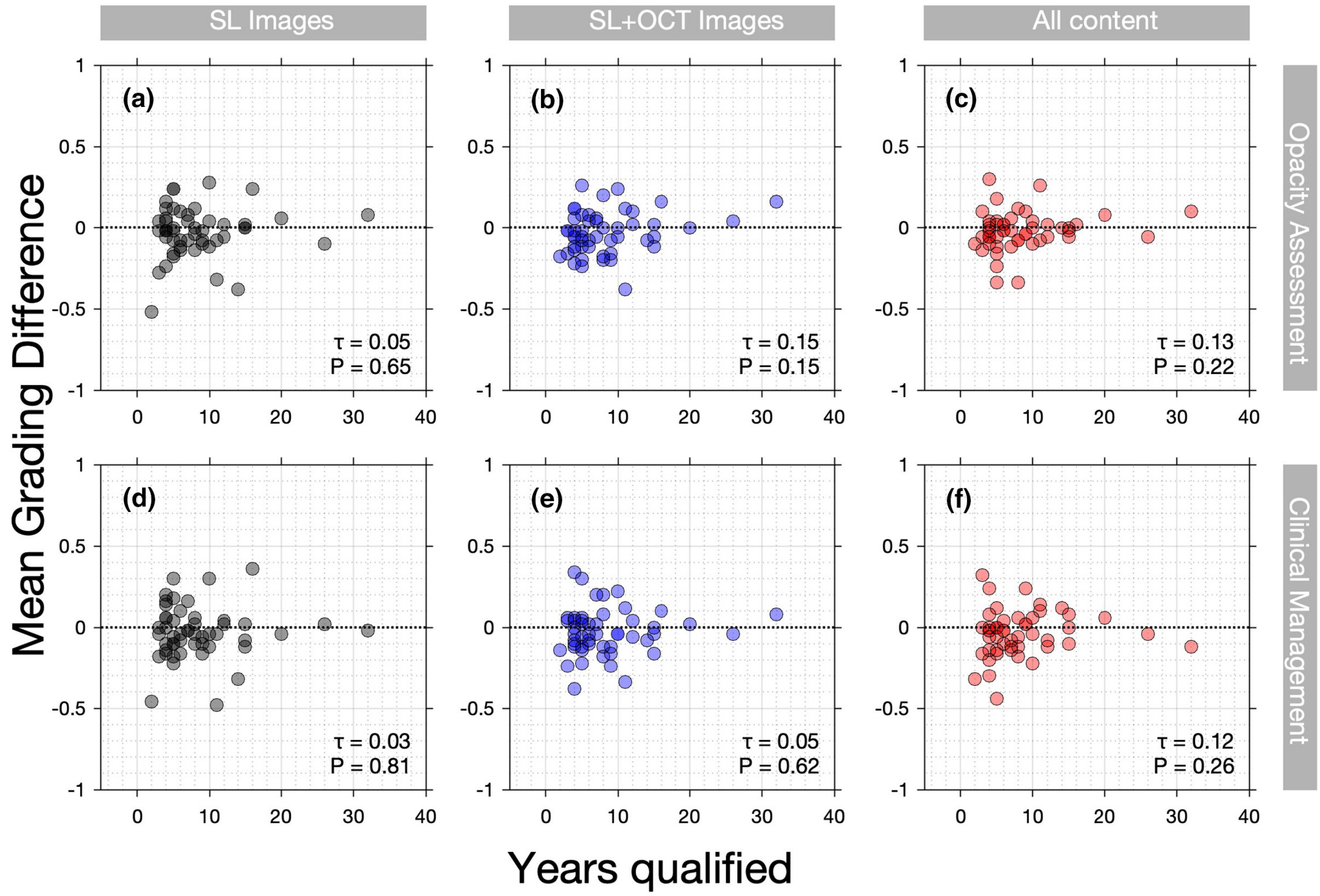

FIGURE 7 Scatterplots showing grading precision (mean difference in repeated grading across all images for each observer) for opacity grading (a–c) and clinical management decisions (d–f) for each vignette form as a function of years since qualification. Data are presented for all vignette forms (SL: Slit-lamp data only; SL + OCT: Slit-lamp plus optical coherence tomography data; ALL: Slit-lamp, optical coherence tomography and visual function measurements).

DISCUSSION

Effective pathways for cataract detection and treatment are vital to maximise healthcare resources and patient's quality of life. In the UK and Éire, the main referral route for cataract treatment is via primary care optometrists.[24] Developments in imaging technology and quality-of-life measures mean that there are additional validated tools to support clinical decision making, but there is scant information regarding how optometrists use and interpret such data. Jindal et al.[19] reported improvement in glaucoma referrals with the use of additional information from OCT imaging. Given that there are still a proportion of referrals from primary care which do not lead to listing for cataract surgery,[17] it would be valuable to create novel stratification methods to ensure effective deployment of secondary care ophthalmic service provision, and to utilise optometrists effectively in primary care through cataract pathways.

This study found that optometrists showed best agreement with the reference grading when all slit lamp, OCT and visual function data were available. For the purposes of evaluating the benefit of inclusion of anterior segment OCT in cataract assessment, it appears that the addition of these images improves the opacity grading assessment in particular. While grading agreement progressively improved across conditions with more information, it is interesting that the inclusion of OCT as well as slit lamp images (SL + OCT) yielded more conservative decisions (over-grading); a trend which reversed for (ALL) when visual function measures were also available (see Figure 2). This is perhaps due to the fact that the vignette examples were of mild-to-moderate cataracts, and in those cases where VA or CS measures did not show substantive reduction, this influenced participants to under-grade. Knowledge of VA is often considered the key metric for evaluation of the impact of cataract, and these findings support the notion that inclusion of VA overrides structural opacity grading alone. It is possible that without further information from patients about their quality of vision, including lifestyle factors or their VA in prior years, the need for intervention is under-estimated.

The behaviours of the participants with regard to their years qualified, mode of practice or geographic location yielded interesting results. In terms of years of experience, there was no significant association with grading decisions, demonstrating that years of experience did not influence

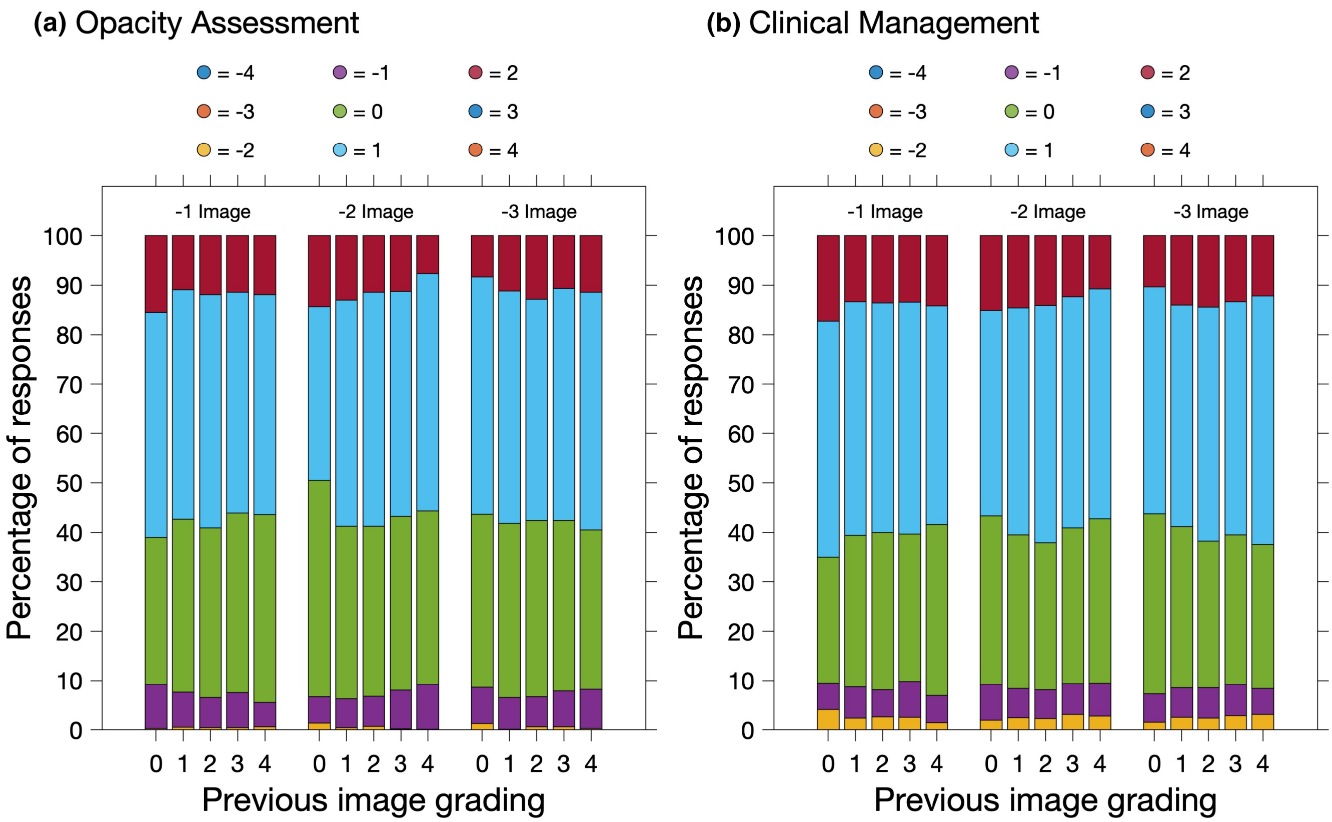

FIGURE 8 Stacked bar charts showing the effect of serial dependence on vignette image grading (a) and management decisions (b). Agreement with reference (green segments) as well as grading/management differences compared to the reference (see key) is presented for conditions where the previous vignette image grading (a) and management decision (b) were stage 0 (no lens opacity/no referral) through to stage −4 (dense lens opacity/referral necessary). Serial dependence effects are presented for the immediately preceding vignette (−1 image), in addition to those presented two (−2 image) and three steps (−3) previously in the random sequence for each observer.

the accuracy of cataract assessment. One of the inclusion criteria was that participants had to have been working for at least 2 years, and so they may have had sufficient exposure and experience by this time. Regarding the location of work, participants working in Éire were more likely to under-grade both opacity assessment and clinical management, compared to UK practitioners, when all clinical information was presented. This may be reflective of different referral practices in the two countries.

While grading agreement was similar when comparing HES and primary eyecare optometrists, those who worked in HES settings were more likely to undergrade lens opacity relative to clinicians who worked in primary eyecare settings where vignettes contained both imaging and function data (Figure 4c). Given that those in the HES may see more substantive later-stage cataracts routinely, they may have under-estimated the severity of the condition.

There was good agreement (precision) for repeated gradings, with a mean bias close to zero and relatively narrow 95% LOA that were below one grading step. The potential for the precision of grading decisions to be influenced by the severity of the clinical vignette was also examined, as well as the years of experience of the participant. The only condition which revealed any proportional bias trend was when all clinical information was available (ALL) for assessment, with a negative association indicating that for more severe cataracts, participants tended to overgrade on the second occasion they viewed these cases. However, no proportional bias was found regarding the same condition for clinical management decisions.

This analysis of serial dependency, while exploratory, indicates that the content of the previous vignette influenced both the opacity assessment and clinical decisions made. Serial dependence as a concept has been investigated widely in the basic psychophysical literature. It has been shown that past experience influences the perception of current stimuli.[25,26] Further, serial dependence exhibits spatial and temporal tuning whereby the effect is strongest when similar image features are examined, and a small temporal delay is present between successive image presentations.[25] A serial dependence effect has also been demonstrated previously for image analysis tasks. Manassi et al.[27] simulated a medical image visual search task, and found that shape classification was markedly affected by recent experience. Interestingly they reported serial dependence to occur for images presented in the previous 12 s. A similar effect was also reported for the assessment of images of dermatological lesions.[28] The present work demonstrates the potentially detrimental impact of serial dependence on clinical decision making, and therefore knowledge of this is essential so that its effects can be minimised. However, the magnitude of this serial dependence effect was small, and so its influence on clinical outcomes in real-world practice, where increased heterogeneity in clinical data and assessment is likely, requires further research.

This study had several strengths, with a large sample size yielding rich and detailed information about decision making for cataract assessment, as well as equal numbers of participants across two neighbouring countries with similar training and education for optometrists. Further, the vignette presentations were repeated to capture data on the precision of grading assessments. However, there was an unequal proportion of HES and primary eyecare practitioners in each area and an uneven distribution of years of qualified experience, with the majority having ≥15 years of training.

Overall, optometrists appear to weigh clinical information (slit lamp vs. OCT vs. imaging and function) differently for cataract assessment and management, with the best agreement being seen when visual function information was included with slit lamp and OCT images. While participants had brief training session for viewing and interpretation of anterior-segment OCT images, many optometrists were not routinely employing this method, and future studies could employ gaze tracking to understand better which elements of the vignette case the observers spent most of their time evaluating. Another aspect of image presentation that was not considered in this work was the influence of decision support systems which, when combined with imaging outputs, aid clinical interpretation. Previous work has demonstrated the utility of lens opacity segmentation from OCT B-scans[29]; this potentially could alter clinical decision making if applied to the images presented in this study. A further consideration is that in practice, slit-lamp examination is a dynamic assessment where optometrists can view the crystalline lens at different magnifications, orientations and levels of brightness. This increased information obtained during the clinical slit-lamp assessment might decrease the utility of additional findings from OCT in clinical practice, compared with the benefits demonstrated in the current study. Furthermore, additional work is required to determine if any benefits from OCT cataract assessment in practice surpass the additional costs, both in terms of equipment expense and consultation time. Nevertheless, the current findings highlight the potential benefits of using anterior segment OCT for improving the precision of cataract assessment.

CONCLUSIONS

This study found that optometrist's precision of grading improved when more clinical information was given, and that OCT imaging compared with the slit-lamp alone increased the proportion of accurate grading assessments. However, structural assessment alone yielded more conservative decision making, which reversed when visual functional data was available. As we seek to stratify and improve cataract referral pathways, inclusion of anterior segment OCT may improve the precision of cataract grading.

AUTHOR CONTRIBUTIONS

Niamh Burke: Conceptualization (supporting); data curation (lead); formal analysis (equal); investigation (lead); methodology (lead); project administration (lead); resources (supporting); validation (supporting); visualization (equal); writing – original draft (lead); writing – review and editing (equal). **Pádraig J. Mulholland:** Conceptualization (lead); data curation (supporting); formal analysis (equal); funding acquisition (supporting); investigation (supporting); methodology (supporting); project administration (supporting); resources (supporting); supervision (supporting); validation (supporting); visualization (supporting); writing – review and editing (equal). **Pearse A. Keane:** Conceptualization (supporting); formal analysis (supporting); funding acquisition (supporting); investigation (supporting); methodology (supporting); project administration (supporting); resources (supporting); supervision (supporting); validation (supporting); visualization (supporting); writing – review and editing (supporting). **Julie-Anne Little:** Conceptualization (supporting); data curation (supporting); funding acquisition (lead); investigation (supporting); methodology (supporting); project administration (lead); resources (supporting); supervision (lead); validation (supporting); visualization (supporting); writing – review and editing (equal).

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the participants that took part in the study. They would also like to thank Dr Aman Mahil for supplying the analysis code which was used here. The study was supported by a PhD studentship from the College of Optometrists (NB) and in part by the National Institute for Health & Care Research (NIHR) Biomedical Research Centre based at Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology (PJM, PAK). Dr Keane is supported by a Moorfields Eye Charity Career Development Award (R190028A) and a UK Research & Innovation Future Leaders Fellowship (MR/T019050/1).

FUNDING INFORMATION

Supported by a PhD studentship from the College of Optometrists (NB) and in part by the National Institute for Health and Care Research (NIHR) Biomedical Research Centre based at Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology (PJM, PAK). The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health.

CONFLICT OF INTEREST STATEMENT

Dr Keane has acted as a consultant for Roche, Novartis, Boehringer-Ingleheim, Adecco and Bitfount and is an equity owner in Big Picture Medical. He has received speaker fees from Novartis, Gyroscope, Bayer, Thea, Boehringer-Ingleheim, Apellis, Abbvie, Alimera, Roche, Genentech, Specsavers, Heidelberg Engineering, Topcon and Santen. He has received travel support from Bayer, Topcon and Roche. He has attended advisory boards for Boehringer-Ingleheim, RetinAI, Novartis, Apellis, Abbvie and Roche. Dr Mulholland has received research support from Heidelberg Engineering Gmbh.

DATA AVAILABILITY STATEMENT

The corresponding author (NB) can be contacted in relation to data queries.

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How to cite this article: Burke N, Mulholland PJ, Keane PA, Little J-A. Investigating the impact of OCT imaging of the crystalline lens on the accuracy and precision of cataract assessment. *Ophthalmic Physiol Opt*. 2024;00:1–13. https://doi.org/10.1111/opo.13383