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Evaluating students' cognitive processes and eye movements when assessing a clinical image

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Research Article

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Title Page

Full Project Title: "Evaluating students' cognitive processes and eye movements when assessing a clinical image"

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Abstract:

Purpose:

Developing healthcare students' cognitive and metacognitive processes to levels approaching those of experienced healthcare practitioners during clinical assessments remains an educational challenge. Integrating gaze tracking within a cognitive apprenticeship model may support this development by externalising expert visual search strategies, enabling students to critically evaluate their own. To evaluate this approach, this study investigated whether undergraduate optometry students demonstrate systematic visual search patterns when examining optic nerve head (ONH) images, and whether a cognitive apprenticeship-based educational intervention could shift students' gaze strategies towards those of an expert and improve clinical recording completeness and accuracy.

Methods:

A prospective intervention study was conducted with Deakin University Master of Optometry pre-clinical students (n=168) from the 2021 and 2023 cohorts. Gaze-tracking technology was used to examine students' visual search patterns when analysing high-resolution digital ONH images. Changes in visual search patterns, clinical recording completeness and recording accuracy were evaluated before and after an educational intervention.

Results:

Prior to the educational intervention, a mean of 19.9% of students demonstrated a structured ONH assessment consistent with the expert approach, increasing significantly to 74.3% following the intervention ($p < 0.001$). Clinical recording completeness and accuracy also improved significantly across most clinical signs post-intervention ($p < 0.001$). However, despite these improvements,

accuracy remained low among the pre-clinical students, with mean scores below 50% when compared with graduating standards.

Conclusion:

Embedding gaze tracking within a cognitive apprenticeship framework may provide quantifiable insight into students' cognitive processing while supporting the development of more expert-like clinical decision-making. Shaping students' visual search patterns during pre-clinical training to closely reflect those of experienced practitioners could strengthen clinical skill development before clinical placement and entry into practice. However, further work is needed to improve the quality and accuracy of students' clinical recording, a core competency essential for safe and effective patient care.

Keywords:

Gaze-tracker, cognitive apprenticeship model, clinical images, clinical decision-making, optic nerve head, FORGE guidelines

Key Points:

- Gaze-tracking technology represents a valuable pedagogical tool by providing objective, quantifiable insight into students' cognitive processing during clinical tasks.
- Gaze tracking, combined with a cognitive apprenticeship-based educational intervention, improves pre-clinical optometry students' systematic approach to optic nerve head assessment, supporting their progression towards expert-level performance.
- A cognitive apprenticeship-based educational intervention significantly improves students' clinical recording completeness and accuracy through improved interpretation of key clinical findings.

Introduction:

Health practitioners are increasingly required to accurately and efficiently interpret complex imaging data to support clinical reasoning and diagnostic decision-making, skills that are fundamental to the delivery of safe and effective patient care. The ability to systematically evaluate and accurately interpret such data is a recognised hallmark of expert clinical performance and is generally developed through the accumulation of clinical experience over time [1]. For many healthcare students, the development and consolidation of these competencies occur during clinical placements involving direct patient care. However, ideally, a strong foundation in these skills should be established during the pre-clinical stages of training, defined as the formative period of education before students commence clinical placements and direct patient care [2].

Objectively assessing clinical reasoning in healthcare students remains a significant challenge [3] , particularly when evaluating their interpretation of diagnostic outputs, such as clinical images. While factual knowledge and information recall are relatively straightforward to assess, these measures provide limited insight into students' capacity to critically analyse information, synthesise evidence and formulate diagnostic conclusions. Addressing this challenge requires a deeper understanding of the cognitive processes underpinning clinical reasoning, as well as a shift beyond traditional knowledge-based assessment to incorporate authentic and innovative learning activities and assessment strategies that evaluate students' clinical reasoning processes in contexts that reflect the complexities healthcare professionals face in clinical practice.

Cognitive apprenticeship is increasingly recognised as an effective pedagogical approach for cultivating higher-order cognitive skills in healthcare students [4]. Central to this model is the explicit demonstration of the cognitive processes and reasoning strategies of experienced healthcare practitioners, enabling students to observe, understand and progressively integrate these

approaches into their own practice, thereby strengthening their clinical reasoning, problem-solving and decision-making abilities, towards an expert level of performance [5, 6].

Integrating gaze tracking into this pedagogical framework could further strengthen this learning by externalising aspects of expert cognition that are otherwise difficult to observe directly. By capturing practitioners' visual search patterns, gaze tracking provides insight into how experts direct their visual attention when assessing and interpreting clinical information, offering students a visual representation of the cognitive strategies that underly expert clinical performance and facilitate metacognitive awareness.

While gaze-tracking technology has been adopted internationally to support the teaching and assessment of clinical skill acquisition in medical education [7-10], research in this area remains limited in Australia, particularly within eye care disciplines. To the best of our knowledge, there has been no research on the visual interpretative processes of Australian optometry students, especially within the pre-clinic environment. Two Australian studies, involving ophthalmologists and orthoptists, demonstrated that gaze patterns for ophthalmology glaucoma specialists and glaucoma specialist orthoptists differed from those of ophthalmology trainees and orthoptist novices, respectively, when assessing the optic nerve head (ONH). More specifically, specialists tended to employ a structured and efficient visual search strategy, while also utilising more time in clinically relevant areas, which supported superior clinical decision-making and higher diagnostic accuracy than that observed among trainees and novices [11, 12].

Therapeutically endorsed optometrists in Australia are qualified to diagnose and manage several ocular diseases, including glaucoma; therefore, it is imperative that educational institutions intentionally develop visual search strategies in their graduating optometrists that approximate those of eye specialists. To support this objective, the optometry curriculum at Deakin University teaches second-year undergraduate optometry students in their pre-clinical years to use the 'Five

Rules to Assessing an Optic Nerve Head' method, developed by the Focusing Ophthalmology on Reframing Glaucoma Evaluation (FORGE) study [13]. The five rules encompass:

1. Evaluation of ONH size
2. Evaluation of the neuroretinal rim size and shape
3. Assessing for the presence of retinal or optic disc haemorrhages
4. Evaluation of the retinal nerve fibre layer
5. Assessing for the presence of peripapillary atrophy

To simplify these five rules, students are taught the mnemonic 'Simple Rules Have No Problems' with:

S = (S)ize of the optic nerve

R = appearance of the neuroretinal (R)im

H = presence of optic nerve head (H)aemorrhages

N = (N)erve fibre layer

P = (P)eripapillary atrophy

A limitation of this approach is its inability to objectively assess the metacognitive processes underlying students' performance of these clinical tasks. Although students report using the FORGE guidelines to guide their assessment of the ONH, educators are unable to determine whether this reflects simple recall of the mnemonic or genuine cognitive engagement with the underlying principles. To address this limitation, a learning activity was developed for students enrolled in the Deakin University Master of Optometry program that combined gaze tracking with an educational intervention based on the principles of the cognitive apprenticeship model.

The aim of this study was to determine whether undergraduate optometry students use a systematic search pattern when viewing clinically relevant areas of an ONH image, and whether an

educational intervention, explicitly demonstrating expert eye movement patterns, can influence and improve students' gaze pattern strategies and clinical recording.

Methods:

Participant recruitment

Master of Optometry students from the 2021 and 2023 cohorts were recruited during a clinical learning activity while attending placement in Deakin University's optometry pre-clinic. Eighty-five students were enrolled in 2021, and eighty-three in 2023.

Study Design

This study used a prospective intervention design. High-resolution ONH digital images, sourced from a clinical practice, were supplied by one of the researchers. The research team, all of whom are registered optometrists in Australia, independently and unanimously agreed that the two images, taken from different eyes, displayed glaucomatous pathology and were suitable for inclusion in the gaze tracker learning activity.

The activity was initially piloted with optometric educators within the Optometry program at Deakin University School of Medicine to confirm general understandability. These individuals were not included in the participant pool. Following the pilot test, no additional changes were made to the gaze tracker activity as it achieved good face validity based on oral feedback from the pilot group.

All students completed this learning activity individually during a routine pre-clinical placement. The activity required approximately 10 minutes to complete and was conducted over two rounds: a pre-intervention round and a post-intervention round. A different ONH image was presented in each round to minimise familiarity. In both 2021 and 2023, the pre-intervention round took place during March and April, followed by the post-intervention round in August and September. Prior to the

post-intervention round, students viewed a four-and-a-half-minute narrated instructional video demonstrating the eye movement patterns associated with ONH assessment, with reference to the FORGE guidelines. The gaze patterns presented in the instructional video were those of one of the researchers, an Australian registered optometrist with expertise in glaucoma. At the completion of the task in both rounds, individual feedback was given, and consent was sought to use these data for the study. Further description of the consent process is provided below.

Gaze Tracker Set Up

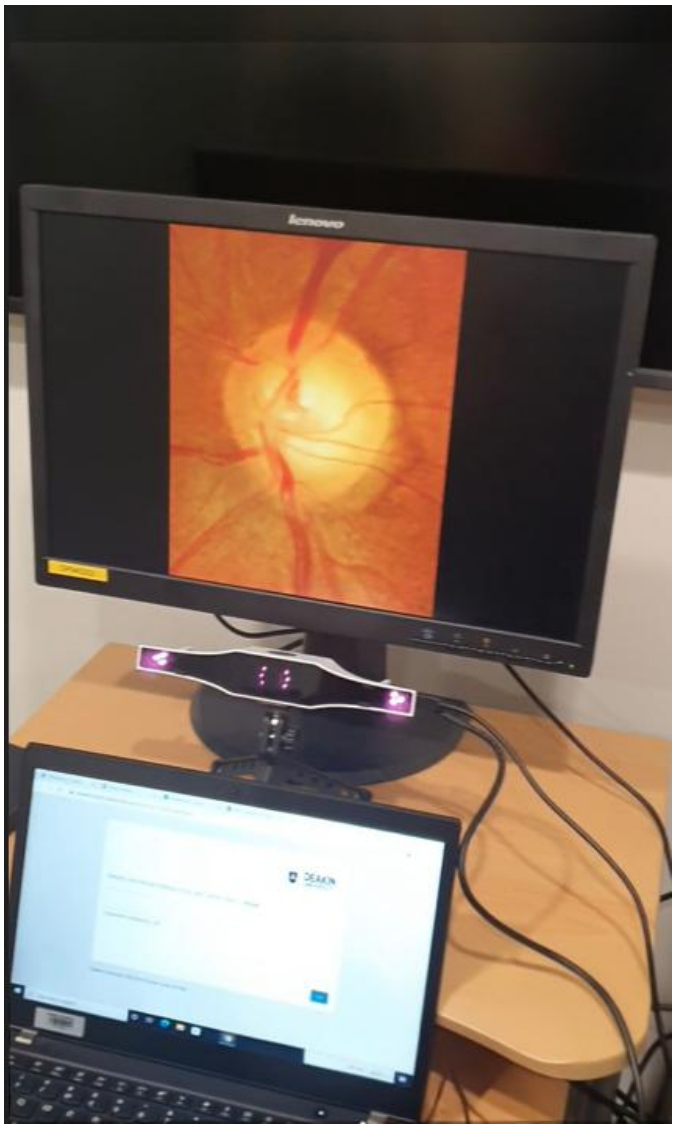
To assess students' gaze behaviours, a Gazepoint™ GP3 HD 150 Hz eye tracker (Gazepoint, Vancouver, BC, Canada) was used. This device tracks pupil-centred corneal reflections using near-infrared light and has an accuracy of 2° of visual angle, verified by our laboratory [14]. It also has a advertised sampling rate of 150 Hz and can accommodate head movements of up to ±15 cm in depth and 25 cm horizontally and 11 cm vertically.

Images were presented on a 23" Lenovo®, (North Carolina, USA) monitor with a screen resolution of 1280 x 1024 pixels. Students were seated at a distance of 60 cm ± 10 cm from the display, in line with manufacturer recommendations for the eye tracker, under ambient room lighting. The gaze tracking software included a distance indicator to allow for adjustments if the student was not positioned at the optimal viewing distance. Pupil visibility of both eyes was verified to ensure there was accurate detection by the gaze tracker. A standard five-point calibration using the Gazepoint™ software was performed before each student started the task. This required each student to follow a moving dot on the screen with their eyes only. Once all five calibration points were successfully calibrated, students were instructed to continue maintaining a steady head position while following the on-screen instructions once the task commenced. The initial instruction screen directed each student to examine an image of an ONH and record their clinical findings on a separate laptop using the survey-based platform Qualtrics XM (Qualtrics LLC, Washington, USA). Students were given 90

196 seconds to examine and analyse the image, during which their eye movements were recorded.

197 Students were given unlimited time to record their clinical findings (Fig 1).

198 **Fig. 1**



199

200 Instrument setup with monitor, gaze tracker and laptop computer displaying the Qualtrics survey to
201 collect student responses.

202

203 Data collection was carried out by the same four researchers; however, only one researcher and one

204 student were present in the room during each session.

205 For the 2021 cohort, the gaze tracker's automated unique response identifier (ID) generator was

206 used to de-identify student data. For the 2023 cohort, the de-identification process was modified to

207 use student numbers as the ID, which were de-identified prior to statistical analysis.

Gaze Tracker-Enabled Neuroretinal Rim Evaluation

Four researchers analysed each student's gaze tracker video to determine whether their ONH assessment followed a systematic sequence based on the inferior, superior, nasal and temporal (ISNT) pattern (Fig 2). For each video, the presence or absence of the ISNT pattern was recorded in an Excel spreadsheet using a binary coding system, with **0** indicating that the student did not follow the ISNT pattern and **1** indicating that the ISNT pattern was followed.

Fig. 2



Eye movement tracking image. The upper number within each circle indicates the chronological order of gaze position, while the lower number represents the duration of fixation. The circle size is proportional to fixation duration at each location. The student's eyes have been redacted from the upper left corner of the figure to maintain anonymity.

Accuracy and Completeness of Clinical Recordings:

Students' clinical recordings were exported from Qualtrics XM into a Microsoft Excel (Version 2310, 2023, Microsoft, Washington, USA) spreadsheet and independently analysed and assessed by two researchers using a rubric developed collaboratively by all research members. Any discrepancies in scoring were subsequently discussed until a consensus was reached.

The rubric consisted of two parts. Part A assessed the completeness of students' clinical recordings using the 'Simple Rules Have No Problems' mnemonic, which required documentation of nine clinical signs including optic disc size, status of neuroretinal rim (NRR), ISNT rule, cup-to disc ratio (CDR), visibility of lamina cribrosa (LC), status of blood vessels from a glaucoma perspective (BVS - e.g. baring of circumlinear vessels), presence of a Drance haemorrhage (Haem), status of the retinal nerve fibre layer (NFL), and peripapillary atrophy status (PPA). Part B assessed the accuracy of each student's recorded clinical findings.

For part A, one mark was allocated for each of the nine clinical signs recorded, and zero marks if not documented. Similarly, for Part B, one mark was allocated for each correctly recorded clinical sign and zero marks for inaccurate recordings. A maximum score of 9 marks was achievable for both Part A and B. It should be noted that the marking rubric was aligned with entry-to-practice (graduation) standards, whereas the students being assessed were still in the pre-clinical phase of their training. As such, there was an expectation that student scores using this rubric could be relatively low. The rationale for benchmarking the assessment against graduation standards was to provide students insight into their current level of development relative to the level expected for independent clinical practice. For further analysis, the Excel data from the Gaze Tracker Videos and Qualtrics XM results were transferred to IBM SPSS Statistics for Windows (Version 26.0, IBM Corp., Armonk, NY).

Statistical Analysis:

Descriptive statistics, chi-square (χ^2) tests, and independent samples t-tests were conducted on the SPSS datasets. A significance threshold of $p = 0.05$ was applied to all statistical analyses.

As no statistically significant differences were identified between the 2021 and 2023 cohorts in pre- or post-intervention clinical recording completeness, the datasets from both cohorts were pooled for analysis. Although no significant differences were observed in pre-intervention clinical recording accuracy between the cohorts, a statistically significant difference was identified in post-intervention

accuracy. Therefore, clinical recording accuracy data for the 2021 and 2023 cohorts were analysed separately.

Results:

Participants

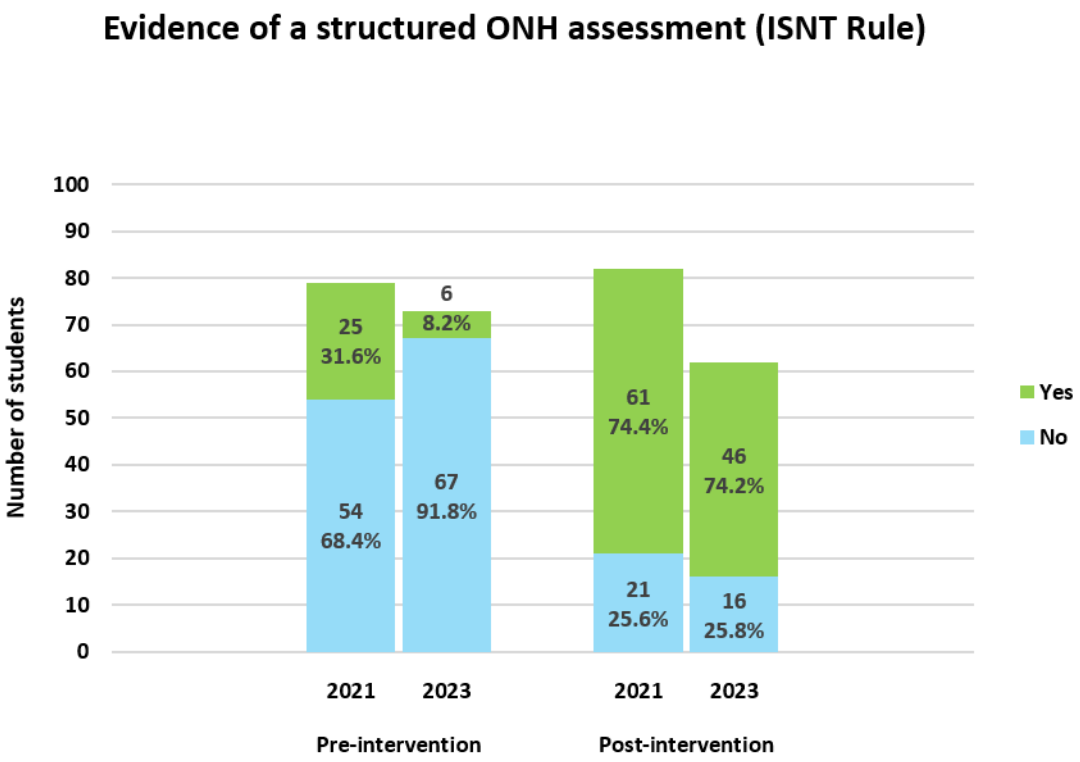
In 2021, n=82 of 85 eligible students consented for their data to be used across both rounds of data collection. In 2023, n=78 of 83 eligible students consented to participate in round one, and n=63 of 83 in round two. The lower participation rate in the second round was primarily due to unplanned student absences. To account for this variation in sample sizes across the rounds, graphical data is presented as normalised percentages, with raw numbers displayed on each bar.

Gaze Tracker-Enabled Optic Nerve Head Evaluation

Nine gaze-tracking video files could not be analysed due to file access issues, including three from round 1 of 2021, five from round 1 of 2023, and one from round 2 of 2023.

Prior to the educational intervention, the proportion of students demonstrating a systematic visual search strategy when assessing an ONH image was low, with the ISNT pattern observed in 31.6% (n=25/79) of the 2021 cohort and 8.2% (n=6/73) of the 2023 cohort (overall mean, 19.9%). Post-intervention, a statistically significant improvement was observed ($p < 0.001$), with 74.4% (n=61/82) of students in 2021 and 74.2% (n=46/62) in 2023 following the ISNT approach (overall mean of 74.3%) (Fig 3).

Fig. 3



Bar chart showing number of students demonstrating evidence of a structured ONH assessment pre- and post- educational intervention.

Completeness of Clinical Recordings

The mean clinical recording completeness score was 4.26 ± 1.13 (out of a possible 9) pre-intervention, significantly improving to 5.38 ± 1.15 post-intervention ($p < 0.001$) (Table 1).

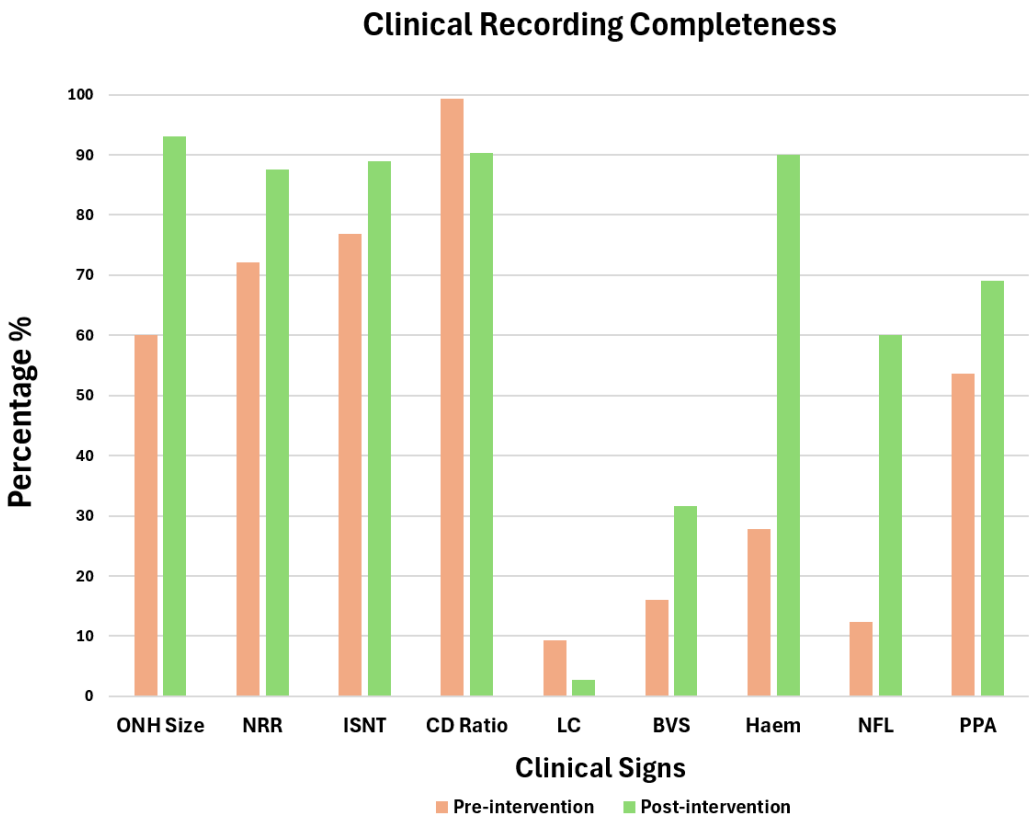
Table 1: Mean Clinical Recording Completeness Scores

Cohort Year	Pre-Intervention Mean Completeness Score ± SD (max score=9)	Post-Intervention Mean Completeness Score ± SD (max score=9)	p Value
2021 & 2023 (Pooled)	4.26 ± 1.13	5.38 ± 1.15	p<0.001

Standard Deviation (SD), p<0.05

The largest improvement in clinical recording completeness was observed in the documentation of the NFL, with recording rates increasing from 12.5% (20/160) pre-intervention to 60.0% (87/145) post-intervention. The second-largest improvement was noted in the recording of ONH size, with a 33% increase in the proportion of students documenting this clinical sign following the educational intervention. CDR documentation remained consistently high (>90%) across both data collection rounds. Conversely, recording of lamina cribrosa visibility and glaucomatous retinal blood vessel changes, including baring of circumlinear vessels or vessel bayonetting, was limited both pre- and post-intervention. Similarly, recording the presence or absence of a Drance haemorrhage remained comparatively low across both rounds (Fig 4).

Fig. 4



Bar chart showing percentage of students' clinical recording completeness pre- and post-educational intervention (2021 and 2023 data pooled)

Accuracy of Clinical Recordings

Mean pre-intervention clinical recording accuracy scores were comparable between the 2021 and 2023 cohorts (2.44 and 2.55 out of 9, respectively). Following the educational intervention, both cohorts demonstrated a statistically significant improvement in clinical recording accuracy ($p < 0.001$) (Table 2).

Table 2: Mean Clinical Recording Accuracy Scores

Cohort Year	Pre-Intervention Mean Accuracy Score ± SD (max score=9)	Post-Intervention Mean Accuracy Score ± SD (max score=9)	p Value
2021	2.44±1.34	3.23±1.41	p<0.001
2023	2.55±1.21	4.24±1.66	p<0.001

Standard Deviation (SD), $p<0.05$

In the 2021 cohort, clinical recording accuracy improved following the educational intervention for 7 of the 9 clinical signs assessed. The largest improvement was observed in ONH size documentation, with recording accuracy increasing by 28.1%, from 51.2% (n = 42/82) pre-intervention to 79.3% (n = 65/82) post-intervention. The second largest improvement was seen in PPA documentation, which increased by 25.7% (Fig 5).

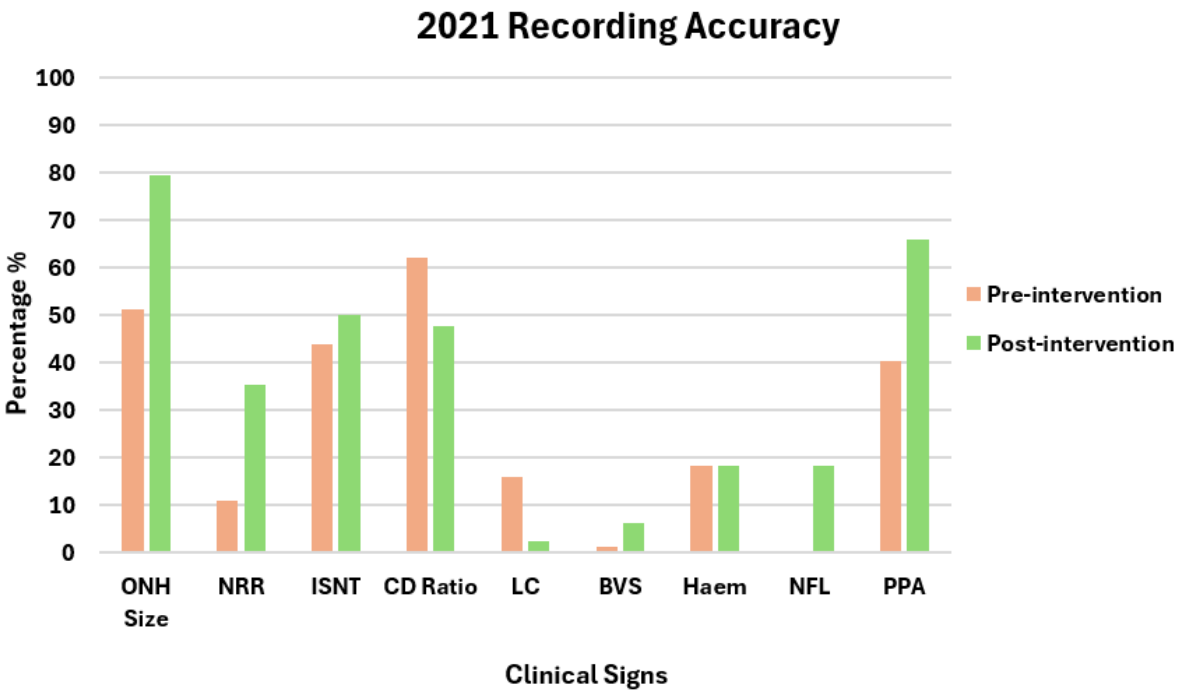
The 2023 cohort showed improvements in recording accuracy across all nine clinical signs, with greater gains than those observed in the 2021 cohort. NFL documentation showed the largest improvement, increasing from 0% (n=0/78) to 42.9% (n=27/63) post-intervention. A similar improvement was observed in the NRR documentation, with recording accuracy increasing by 41.2%, from 12.8% (n=10/78) pre-intervention to 54% (n=34/63) post-intervention (Fig 6).

Among the small proportion of students who documented clinical observations relating to LC and blood vessel appearance, the educational intervention resulted in less than a 10% improvement in

recording accuracy across both cohorts. In fact, the 2021 cohort demonstrated a decline in recording accuracy for these clinical signs following the intervention.

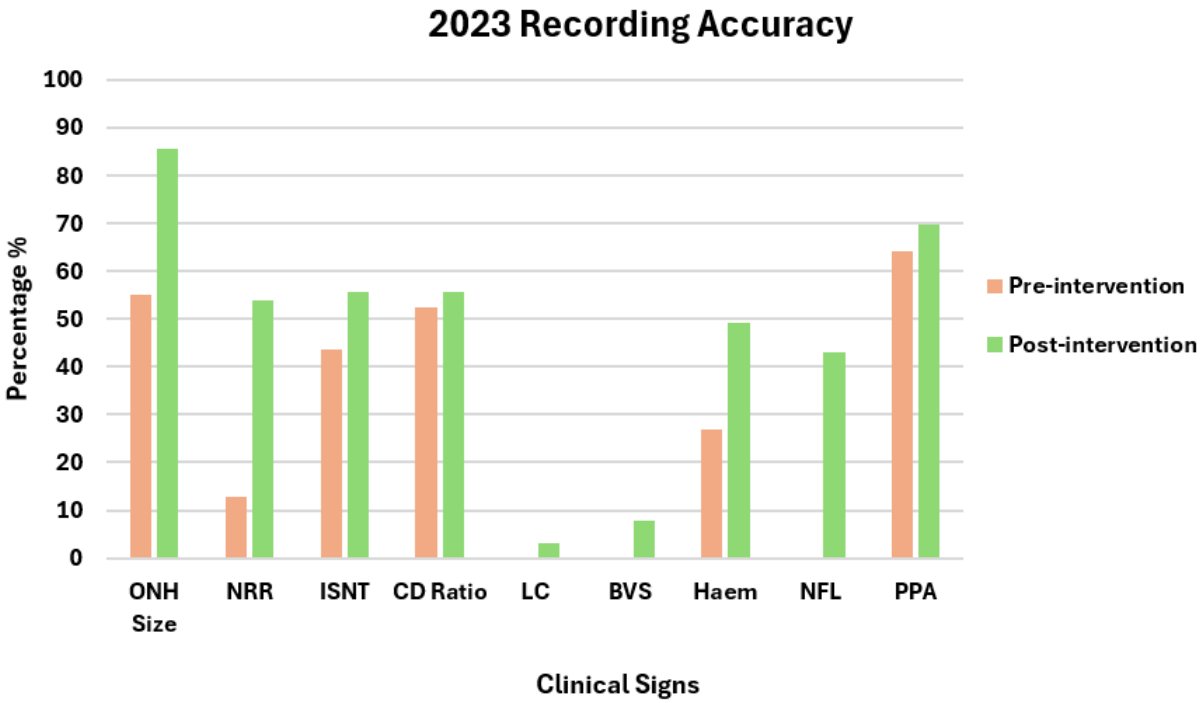
Across both cohorts, ONH size was the most accurately documented clinical sign post-intervention, with recording accuracy reaching 79.3% (65/82) in 2021 and 85.7% (54/63) in 2023. Although more than 90% of students documented CDR information both pre- and post-intervention, accurate recording of this clinical sign was only achieved by approximately half of students (Fig 5 and 6).

Fig. 5



Bar chart showing percentage of students' clinical recording accuracy pre- and post-educational intervention (2021)

Fig. 6



Bar chart showing percentage of students' clinical recording accuracy pre- and post-educational intervention (2023)

Discussion:

Novice healthcare practitioners and students often demonstrate less rapid, intuitive, and accurate clinical reasoning than typically observed in expert healthcare practitioners [15]. Consistent with the current literature, our findings suggest that integrating contemporary gaze-tracking technology with a cognitive apprenticeship-based educational intervention can improve students' clinical skills and strengthen existing knowledge frameworks, particularly within the pre-clinic environment. As such, this approach represents a promising pedagogical strategy for developing specific clinical competencies and supporting healthcare students' progression towards expert-level performance.

A key challenge for healthcare educators is finding a way to accurately and efficiently evaluate the cognitive and metacognitive processes underlying students' performance of clinical assessments. Gaze-tracking technology offers a means of addressing this challenge by providing real-time objective insight into how students visually analyse and interpret complex clinical tasks. In this study,

gaze-tracking technology revealed that many pre-clinical optometry students were not applying the FORGE guidelines when assessing an ONH image; instead, they demonstrated random and unstructured visual search patterns. Although this finding was not unexpected, given similar observations have been reported among ophthalmology trainees and novice glaucoma-specialised orthoptists [11, 12, 16], it highlighted the need for targeted educational strategies to support students in developing systematic and efficient visual search behaviours consistent with those demonstrated by experienced glaucoma practitioners.

To address this need, a cognitive apprenticeship-based educational intervention was implemented, incorporating explicit modelling of the visual search strategy of an optometrist with subspecialty expertise in glaucoma. Following the intervention, a statistically significant improvement in students' ISNT search patterns was observed, with, on average, 74.3% of students demonstrating gaze behaviours comparable to those of the expert optometrist, compared with 19.9% prior to the intervention. These findings suggest that knowledge of the FORGE guidelines alone may be insufficient in establishing a systematic approach to assessing the ONH. Combining these guidelines with explicit modelling of expert visual search strategies may therefore provide a more effective pedagogical approach to developing structured ONH assessment skills.

Eye-tracking technology has been used to improve the clinical performance of novice practitioners across a range of healthcare disciplines, including but not limited to ophthalmology, radiology, cardiology, and pathology [9, 16-20]. In ophthalmology, Shirley et al. [16] reported improvements in the visual search behaviours of both consultant and trainee ophthalmologists following an educational intervention that modelled a structured approach to diabetic retinopathy assessment. Similarly, Jarodzka et al. [21] found that clinical reasoning in medical students diagnosing infant epileptic seizures improved after viewing expert eye-tracking recordings accompanied by explanations of the expert's clinical reasoning and diagnostic process. In radiology, Litchfield et al.

[17] demonstrated that observing expert radiologists' eye movement patterns was associated with improved X-ray interpretation performance among novice radiographers.

Collectively, these findings support the use of a cognitive apprenticeship model, particularly when combined with gaze-tracking technology, as an effective educational approach for improving clinical performance among novice healthcare practitioners and students. By making expert visual search strategies and associated cognitive processes visible, this approach may help learners develop more systematic, efficient and clinically appropriate strategies when assessing complex clinical information.

While clinical skill competency and diagnostic decision-making are core learning outcomes for healthcare students, accurate and comprehensive clinical record-keeping is an equally essential professional competency that supports safe, high-quality patient care [22]. This is particularly important in multidisciplinary settings where effective communication and continuity of care depend on the accurate documentation and exchange of clinical information between healthcare providers. Several studies have reported that medical students' record-keeping is often sub-optimal, but can improve with consistent and meaningful feedback [23-25]. Our study focused on two areas of students' clinical recording: a) completeness and b) accuracy. Regarding completeness, all nine clinical signs specified in the assessment rubric were documented by students in both the pre- and post-intervention assessments. Following the educational intervention, documentation frequency increased across six of the nine categories, except for LC, CDR and BVS. The decline in LC documentation may be partly explained by the fact that it was not explicitly referenced in the educational intervention, nor is it covered by the mnemonic 'Simple Rules Have No Problems'. However, this does not readily account for the decrease in the documentation of CDR or blood vessel appearance, as both clinical features were directly covered in the intervention. One possible explanation is cognitive overload, whereby the introduction of the mnemonic and associated information may have increased the cognitive demands placed on the students. In attempting to

recall and apply the mnemonic, students may have inadvertently overlooked or omitted some clinical signs from their clinical recordings. Additionally, during the period between the pre- and post-intervention assessments, students continued to be taught that CDR is less clinically informative than the size and quality of the NRR. The reduced documentation of CDR may therefore reflect an appropriate shift in students' focus towards clinically more relevant characteristics when assessing the ONH.

Despite this slight decrease, it remained a predominant aspect of students' clinical recording, with at least 90% recording this sign in both pre- and post-intervention assessments. This finding is consistent with O'Neill et al [12] who reported that ophthalmology residents similarly concentrate on the central optic cup, whereas ophthalmology glaucoma subspecialists spend more time in areas of interest, such as the NRR and adjacent NFL of the ONH, regions more likely to demonstrate glaucomatous pathology.

The increased number of students recording ONH size, NRR (ISNT rule), and NFL characteristics, following the intervention, represented a positive outcome. This aligns with the Deakin optometry curriculum, which emphasises the importance of these clinical signs in evaluating glaucoma risk, rather than relying heavily on CDR observation.

Clinical recording accuracy also improved significantly following the intervention, with the greatest gains, again, primarily observed in the recording of the ONH size, NFL and NRR characteristics. While there is limited literature with which to compare our findings regarding the relationship between visual search patterns and clinical recording accuracy, Shirley et al. [16], who investigated pre- and post-intervention accuracy in the identification and grading of clinical findings from diabetic retinal images between ophthalmologists and trainee ophthalmologists, found no significant correlation between the two groups, despite the ophthalmologist group achieving a higher mean accuracy score overall. However, these findings may not be directly comparable to our study, as Shirley et al. [16] used a different scoring methodology, in which point deductions were applied for

missed or incorrect findings, whereas our study used a rubric-based system that did not penalise inaccurate recordings, which may partly account for the observed differences.

Despite significant improvements in students' recording accuracy, overall performance was below the expected graduation-level standard in both pre- and post-intervention assessments, with mean accuracy scores below 50%. Accurate interpretation of clinical findings relies on a systematic and targeted evaluation of clinically relevant features [11, 12, 26], and the absence of such an approach may have contributed to the lower recording accuracy observed in some students. These findings should, however, be interpreted in the context of the students' stage of clinical training. Although the assessment rubric was aligned with graduation-level standards, students were still in the pre-clinical phase of their training and had further clinical experience, including a six-month clinical placement program, to complete. The use of graduation-level criteria was intended to provide students with a benchmark against which to contextualise their current performance relative to the standards required for independent clinical practice.

Students' perceptions of the impact of this learning activity on their clinical development were not evaluated in the present study; however, research conducted across several Australian universities using a similar educational approach has investigated this aspect of student learning [27]. O'Meara et al. [27] reported that 90% (35/39) of nursing and paramedicine students from Monash, La Trobe and the University of Queensland rated the integration of eye-tracking with post-educational feedback videos, incorporating expert-led debriefing, as highly effective in improving both knowledge and clinical skill development. Our findings, together with those of O'Meara et al [27], highlight the value of post-educational feedback strategies, particularly those that make experts' cognitive processes explicit, in positively transforming the student learning experience and addressing deficits in clinical performance.

This research supports the use of gaze-tracking and cognitive apprenticeship approaches to develop students' visual search strategies and enhance their clinical diagnostic capabilities. Given the potential benefits demonstrated in this study, these approaches should be considered for sustained integration into the curriculum. Embedding opportunities for educators to discuss and provide feedback on students' eye movement patterns following clinical skills activities may facilitate the ongoing refinement and consolidation of systematic visual search strategies before students' transition to clinical placement.

Limitations:

The most significant limitation of this study was the demand on staff resources. Although a feedback-rich, one-on-one environment can meaningfully support student development, the time required to prepare and deliver the practical component to individual students was considerable, making it challenging to sustain as a year-round learning activity. A further limitation was the time interval between the pre- and post-intervention assessments. During this period, students continued to develop their ONH assessment and clinical recording skills through routine teaching and feedback. Consequently, improvements observed in the post-intervention assessment may not be attributable solely to the educational intervention. In addition, clinical recording completeness and accuracy were assessed only immediately following the intervention. As a result, the study was unable to determine whether the knowledge and skills acquired through the intervention were retained over time.

Future Research:

Future research is warranted to further investigate the relationship between visual attention and clinical decision-making, as eye-tracking data alone are insufficient to fully elucidate the cognitive

processes underlying students' clinical reasoning. Specifically, eye-tracking cannot establish the rationale for fixations on specific areas of interest (AOIs) or determine whether the visual information acquired during these fixations was accurately interpreted. Integrating think-aloud protocols with eye-tracking methodology may help address this limitation by capturing students' cognitive processes either concurrently with task performance or retrospectively following task completion. Additionally, analysis of AOIs, including fixation frequency and dwell time, may provide additional quantitative measures of visual attention and offer further insight into students' engagement with relevant versus irrelevant clinical signs.

Further research could also investigate the educational value of embedding eye-tracking activities longitudinally within the optometry curriculum, rather than as a single intervention. Providing students with individualised feedback on their gaze patterns following task completion may encourage reflection on their visual search strategies and increase awareness of how they allocate attention during clinical assessment. Repeated opportunities to review and discuss their own gaze behaviour with educators may further support the development of metacognitive awareness and more deliberate visual search strategies over time. Evaluating the impact of such an approach across multiple stages of clinical training would help determine whether sustained integration of gaze tracking into the curriculum provides educational benefits beyond those observed following a single learning intervention.

Conclusion:

Independently, gaze-tracking technology represents a valuable pedagogical tool by providing objective, quantifiable insight into students' cognitive processing during clinical tasks. This facilitates the identification of deficiencies in visual search strategies and enables the delivery of precise, targeted feedback from educators. When embedded within a cognitive apprenticeship framework,

gaze-tracking may further enhance clinical decision-making by scaffolding students' progression from novice toward more expert-like performance. These insights carry important implications for healthcare education. If students' eye-movement patterns can be systematically shaped during their formative training to more closely resemble those of experienced healthcare practitioners, there is considerable potential to strengthen clinical skill development before clinical placements and entry into the workforce. However, while improvements in visual search behaviour are valuable, further work is also required to simultaneously enhance the quality and accuracy of students' clinical recording, a core professional competency essential for safe and effective patient care.

Declarations:

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Author contribution statement:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Natalie Ann Watt, Nicholas Hockley, Heather Rosalind Mary Connor, Amanda Grace Douglass and James Andrew Armitage. The first draft of the manuscript was written by Natalie Ann Watt, and all authors commented and made edits on subsequent versions of the manuscript. All authors read and approved the final manuscript.

Data availability statement:

The data from this study are not openly available due to reasons of sensitivity.

Ethics declarations

Competing interests

The authors declare no competing interests.

Ethics approval

This study adhered to the tenets of the Declaration of Helsinki. Ethics approval was granted by Deakin University's Faculty of Health Human Ethics Advisory Group (HEAG_H 245_2020).

Consent to publish declaration

Not applicable.

Consent to participate

At the completion of the optic nerve head activity, students were provided with an online Plain Language Statement and given the option to consent or decline for their data to be used in this research study.

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