Learning retinoscopy: A journey through problem space

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Key points

- The presence of cyclic performance hallmarks expertise in retinoscopy. The formation of sub-goals is an effective strategy to use when learning retinoscopy.

- Optometric education should place emphasis on understanding, rather than simply the performance of a practical skill.

- Meta-cognition is an important tool for developing understanding and clinical expertise.

Abstract

Purpose: Retinoscopy is a skill that requires the integration of procedural skill and declarative knowledge. Whilst the actual technique is simple, retinoscopy is a complex skill to acquire and is one that students often find challenging. This study compared the strategies that novices, third year students and experts use when performing retinoscopy, with the aim of identifying the key stages of learning, that may enlighten teaching practice.

Method: This study employed a protocol-based approach in which the verbal protocols and cognitive strategies of novices, students and experts were recorded and then subjected to "problem space" analysis.

Results: Clear differences existed when the retinoscopy of novices, students and experts was directly compared using a standardised simulated task. Experts were more accurate in performance and used defined strategies to reach the goal. The presence of these strategies significantly predicted the accuracy of the retinoscopy result.

Conclusion: This study highlights the importance of meta-cognitive strategies and the need for an adequate theoretical foundation in skill acquisition. The underpinning knowledge provides a pedagogic tool that specifies activities which are beneficial to learning a clinical skill.

Introduction

Retinoscopy is a task that requires procedural skill executed in conjunction with the direct application of declarative knowledge. It involves looking through an optical instrument (a retinoscope) and observing the movement of the reflected light within the patient's pupil. The technique is essentially a procedural problem in which the starting point is an unknown refractive error, and the solution is the production of an objective refraction. Whilst the actual technique is simple, retinoscopy is a complex skill to acquire, often taking several years of practice to attain competence. Evidence suggests that when retinoscopy is performed correctly by expert clinicians, the technique produces reliable outcomes.[1-3] Furthermore, retinoscopy has been shown to have the potential to quantify total astigmatism more accurately than other automated techniques.[4,5] There are several factors that can result in an inaccurate result.[6]

How does a clinician learn the technique of retinoscopy? Most learning commences with an element of trial and error.[7] For trainee ophthalmologists the technique is often taught during short workshop courses whilst undergraduate optometrists have it taught in laboratory sessions as part of their degree. Lecturers advocate practice on patients and model eyes using procedural instruction.[8] A broad range of literature exists regarding the procedure of how to perform retinoscopy and the applications and uses of the technique.[9] Far less emphasis has been placed on how student clinicians acquire this complex skill, or how their decision-making and observations are refined over time. Repetitive practice alone is not an effective way of learning a new skill and identifying and analysing errors has a greater benefit than simply observing the required technique.[10,11] Activities that incorporate meta-cognitive support have been shown to enhance learning.[12]

One approach to problem solving and acquiring the skill of a specific procedure was proposed by Newell and Simon in their classic theory of problem solving.[13] Newell and Simon characterise a given problem as a *"problem space".* The starting point is termed *"the initial state",* and the aim is to reach a *"goal state".* Reaching a solution consists of finding a pathway to the goal state. The pathway can be crossed using general purpose rules known as heuristics. Heuristic strategies reduce the length of the search and cognitive overload. *Means-ends analysis* is a well-known heuristic that divides a

problem space into a series of sub-goals, each of which moves nearer to the goal state.

Most procedural problem solving can be analysed using the problem space approach. As expertise and skill develops, the strategies that an individual uses are refined into automated routines. The Anderson ACT-R model is a development of Fitt's associative phase of learning.[14,15] The model is based on production rules which explain how actions are consolidated into an automatised procedure through continued practice. These automated routines can initiate the task without retrieval of declarative knowledge. This both speeds up performance and frees retrieval processes to access other knowledge. Recent developments of ACT-R incorporate the notion of *"control tuning"* that draws on literature regarding the development of motor control.[16,17]

In respect of clinical skill, learning requires the integration and application of knowledge from several different domains such as recognition of visual patterns, execution of a detailed motor response and complex decision making.[17,18] Student optometrists and ophthalmologists are expected to acquire numerous complex skills. These practical motor skills require precise theoretical and clinical interpretation. This study investigates how optometry student clinicians learn the complex skill of retinoscopy. The aim is to identify which aspects of theory and practice are barriers to learning and understanding. Performance of clinicians with different levels of experience will be compared using a protocol-based approach. Protocol analysis is an established methodology used to study thought processes.[19] The verbal protocols of student and expert practitioners during retinoscopy will be used to identify any critical stages of the development of this clinical skill. In accordance with the problem space approach, it is predicted that expert practitioners will show a more defined route through the problem space and require fewer steps to reach a solution. Formally documenting the steps required to reach a solution will allow the identification of any critical strategies or indeed breakdowns in comprehension and performance. Once barriers to performance have been identified, strategies to overcome these can be incorporated into teaching and feedback.

Method

Participants

Thirty-six adult participants were recruited and allocated to one of three groups: novices, students, and experts according to experience and years of optometric practice. Novices were all first-year optometry students who had recently commenced their degree. Novices with little experience were included to provide a base line for trial and error with little strategy or knowledge foundation. The average experience for the novices was 3-months, SD 1.0; 6-hours of active training or practice on retinoscopy. Third-year optometry students were selected for the student group. These student practitioners have approximately two years of experience (average experience: 27 months, SD 0.2; 50 hours of active training or practice). The expert group consisted of practitioners who were fully registered with the General Optical Council and had been in regular practice for over 10 years (average experience was 15-years, SD 4.0, more than 10,000 hours of active training or practice).

Materials

Retinoscopy is known to vary in difficulty with different patients. Differences such as patient compliance, refractive error complexity, ocular pathology, and anatomical differences such as pupil size are all potential confounding variables. To address this, the presentation of the task was standardised by using an online retinoscopy simulator. The online retinoscopy simulator of the American Academy of Ophthalmology was used.[20] Refractive errors can be generated and the use of the retinoscope can be simulated to practice observing and decision making. The simulation was accessed using a web browser. On screen actions and auditory dialogue were recorded using screen capture software. Participants were asked to complete an objective refraction for an unknown prescription as quickly and accurately as possible.

Procedure

Participants were given a short demonstration of how to use the mouse to simulate the use of a retinoscope and how to use the online phoropter to change spherical power and cylindrical power and axis. An optical prescription was entered but covered so that it was not visible to the participant. All participants were given the same

prescription to determine. Participants were asked to narrate their rationale and decision making orally as they performed the task. Participants were also requested to verbalise their internal dialogue as per the studies by Ericson and Simon[19] where an example phrase was given, otherwise the participant used natural expression. For example, *"I can see a with movement, and so I will try using a plus lens", "I can't really say what the movement is like".* A maximum of ten minutes was allocated for the task. A short post-hoc debriefing was conducted where participants were asked to comment informally on their performance and understanding of the task.

Analysis

The average time to perform the task, number of steps taken, and the accuracy of the end point were recorded. The accuracy of the endpoint was graded out of a maximum of ten (evaluating the accuracy the power of sphere, cylinder, and axis). The grading scale is given in appendix 1.

Behavioural actions that were observed and associated with making a decision were quantified. The average number of sweeps per decision of the retinoscope and the number of times the practitioner adjusted the orientation of the streak was determined. The average number of lens changes and the nature of those changes were also categorised and recorded. Decision making was quantified by calculating the ratio of observations (i.e., observed motor actions), lens changes and cyclic strategies (indicative of bracketing). If the use of strategy is a hallmark of expertise in retinoscopy, then a significant relationship between cyclic behaviours such as bracketing and progression through the problem space would be expected which could be identified using correlation or regression analysis.

Results

The mean performance measures (SD in parenthesis) are summarised in the table below:

	Novice Practitioners	**Student Practitioners**	**Expert Practitioners**	**p <**
Time and Accuracy				
Total time to reach endpoint (minutes)	**9.04 (1.0)**	**3.09 (1.3)**	**4.48 (0.9)**	0.001
Accuracy of endpoint	**25% (0.8)**	**69% (1.0)**	**87% (1.3)**	0.001
Observations				
Total observations	**43.6 (2.7)**	**13.0 (4.2)**	**6.6 (1.1)**	0.001
Number of sweeps	36.0 (4.9)	5.3 (2.3)	4.1 (1.4)	
Change of streak orientation	7.6 (0.4)	3.4 (1.6)	2.5 (0.7)	
Actions				
Total number of steps	**35.2 (8.5)**	**8.8 (3.4)**	**5.6 (1.8)**	0.001
Change of SPH*power	28.4 (11.4)	5.25 (1.7)	3.5 (2.1)	
Change of CYL**power	7.8 (5.6)	3.75 (2.8)	2.1 (1.4)	
Change of CYL axis	4.5 (2.7)	2.2 (1.2)	2.2 (1.1)	
Decision Making				
Cycles (bracketing)	**0.5 (0.9)**	**0.3 (0.4)**	**2.8 (0.7)**	0.001
Ratio: Observations to lens changes	1.5 (0.3)	1.4 (1.2)	0.7 (0.3)	0.001
Fresh start***	0.7 (0.8)	0.2 (0.6)	0.8 (0.2)	
Final checks for neutrality****	0.2 (0.5)	1.1 (0.5)	1.6 (0.3)	

Table 1: Mean Performance Indicators

*SPH = sphere power, **CYL = cylinder power/cylinder axis.

Actions refer to motor movements that could be directly observed (such as a lens change). Observations refer to viewing a reflex in conjunction with the movement of the retinoscope.

***Fresh start: Abandoning the attempt and starting again from scratch

****Final checks for neutrality: Once the potential solution is reached, performing a cross check of neutrality, for both meridians prior to concluding.

Analysis of speed/accuracy

The time to reach the end point was significantly different between the participant groups ($F(2,33) = 107.9$, $p < 0.001$). The end point accuracy was also significantly different between the participant groups ($F(2,33) = 230.86$, $p < 0.001$). Post hoc comparisons conducted with Fisher LSD found all comparisons to be significantly different (all p's < 0.001).

Student practitioners obtained a solution more quickly than both the novices and the expert group. This appeared to be a speed vs. accuracy trade-off, as although faster than the experts, the students' end points were less accurate. Successful outcome was determined as an accuracy of 70%, and an endpoint was reached within the set time. None of the novices attained this accuracy (mean 25%, SD =0.8). Students performed close to this mean performance accuracy (mean 69%, SD =1.0). Expert practitioners attained the required accuracy well within the time limit (mean 87%, SD =1.3).

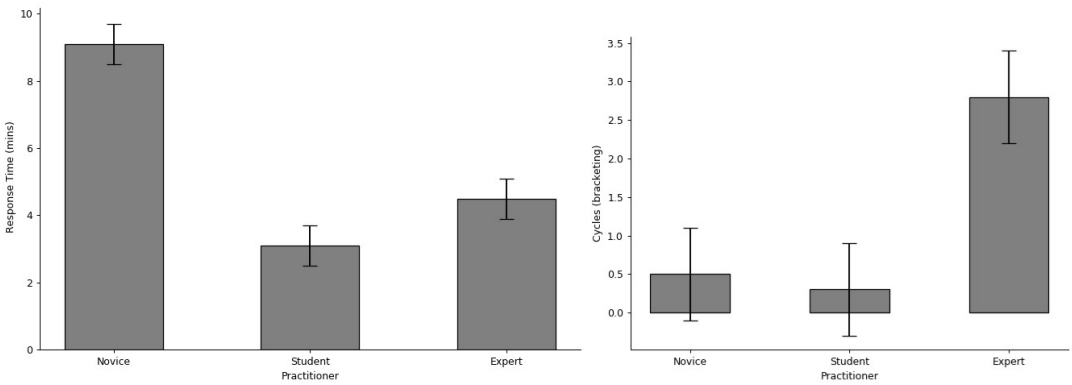

Figure 1: Retinoscopy of Novice, Student, and Expert practitioners. Total time and number of processing cycles (bracketing). Error bars illustrate 95% confidence intervals.

Analysis of observations/actions

Significant differences existed in the number of observations made by practitioners ($F(2,33) = 51.25$, $p < 0.001$). The number of steps (lens changes) was also considered using ANOVA ($F(2,33) = 28.21$, $p < 0.001$). The definition of what was classified as an observation is provided in Table 1. In both instances, post hoc testing (Fisher LSD) indicated that all the comparisons of means were significantly different (all p's <0.001).

Analysis of clinical decision making

Several differences were found in the way practitioners performed. Significant differences were found in the way practitioners organised their decision making in cycles ($F(2,33) = 16.31$, $p < 0.001$). Post hoc comparisons on the number of cycles illustrated how the different groups of practitioners used bracketing strategies to perform the task. Novice vs. Experts and Students vs. Experts were significantly different in the use of bracketing strategy. In contrast, the bracketing strategies used by both Novices and Students were not significantly different (Novice vs. students: mean diff 0.2, crit diff 0.606, p =0.41; Novice vs. Experts: mean diff -1.33, crit diff 0.606, p =0.001; Student vs Experts: mean diff 1.58, crit diff 0.606, p =0.001).

The ratio between observations and steps was also of interest, as this provided a significant index of decision making, i.e., actions initiated through observation. Significant differences in decision making were found ($F(2,33) = 4.39$, $p < 0.001$). Post hoc comparisons were conducted with Fisher LSD and showed that Novice vs. Experts and Students vs. Experts were significantly different in their decision making. In contrast, the bracketing strategies used by both Novices and Students were not significantly different (Novice vs. Experts: mean diff 0.53, crit diff 0.52, p =0.05; Student vs. Experts: mean diff 0.71, crit diff 0.518, p =0.007; Novice vs. Students: mean diff -0.21, crit diff 0.52, p =0.42).

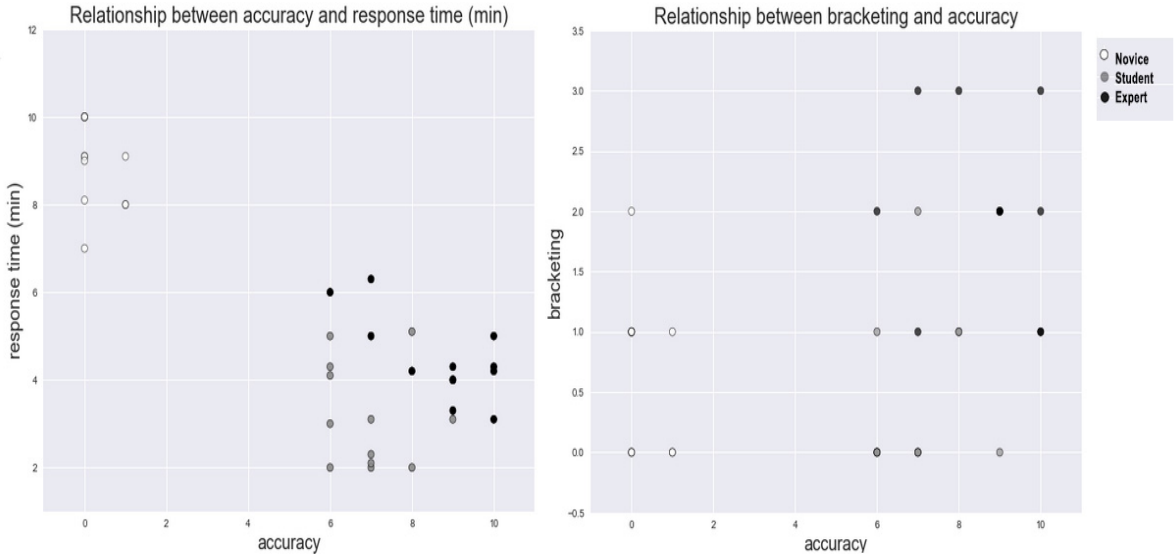

Figure 2: The relationship between response time (min) bracketing steps and accuracy for the different practitioner groups

Further analysis was performed by converting successful outcome (successful/not successful) and the presence of bracketing strategies to categorical variables (present/absent). A Chi squared analysis was found to be significant indicating that that there was a significant occurrence of bracketing for successful outcomes (X^2 = 3.95, n=36, df =1, p< 0.05). Regression analysis indicated that the use of cyclic strategies significantly predicted the accuracy of outcome (R=0.369, R^2=0.136, F(3,32) = 5.36, p=0.02; ß=1.47 t=2.32. p =0.02). The interaction of bracketing by participant group provided a significant predictor of end point accuracy for the Novices and the Expert groups, but not the Student group (R=0.77, R^2=0.60, F(3,32) = 16.10, p=0.001; cycles Experts: ß=1.73, t=3.89. p =0.0005; cycles Students ß=1.79, t=1.70. p =0.09 NS cycles Novices ß=-3.64, t=-3.85. p =0.005).

Discussion

Clear differences for performance existed when the retinoscopy performed by novices, students and experts was directly compared. Theoretically, reaching a solution involved a successful, strategic route through the problem space and the application of a specific production rule.[13,14] Means-ends analysis is a common strategy used for problem solving.[17] This procedure requires the formation of sub-goals (such as initially determining the two principal power meridians before neutralising the spherical

power). If attaining each sub-goal occurs the strategy will traverse the problem-space.[17] The current study shows that allocation of sub-goals is crucial to performing the clinical skill of retinoscopy.

Novices attempted to use a direct route through the problem space by trying to solve the task by observation of many different lens powers which is indicative of a simple strategy of trial and error.[10] Note that the novices had received theoretical background on the technique and received approximately 6 hours of practical training. Nevertheless, there was little evidence of the use of sub-goals. This may indicate that a shift in clinical teaching to flipped teaching (where practical skills are taught before the theory) may not be the most effective pedagogy. The ratio between observations and lens changes indicated that a clear strategy was not being used by the novices; rather there was a weak strategy accompanied with a large degree of trial and error. This resulted in low accuracy and extended response times. Few of the novices managed to complete the task within the 10-minute time constraint. Practice alone was not enough to elicit good clinical technique.

In contrast, the 3rd year students generally performed the task more quickly, in fact, they were quicker than the experts, but at the expense of accuracy. At this point in training students are encouraged to improve their speed in performing retinoscopy. The current data indicate that this has indeed been part of the learning focus. This observation is also consistent with models of learning which have shown that once basic competence has been attained the acquisition of skill becomes focused upon speed.[14,16,17] Strategy was starting to be adopted by the third year of study. For example, they would work on neutralising one power at a time, or identify the principal powers, and axis before starting to neutralise the powers. However, the accuracy measures indicate that this had not attained the same level of skill as the expert practitioners. The tendency to not perform a fresh start nor perform a final check of neutrality may indicate that the novices and students were either confident of their result, or indeed were unaware of the meta-cognitive processes driving their performance.[10]

It was no surprise to find experts were more accurate in their performance.[14] The use of sub-goals was apparent in the performance of experts. Experts used around three

sub-goals (cycles) to reach the final solution. In contrast to the other two groups, experts also tended to perform a final check of neutrality. Anderson suggests that over time procedural skill develops and becomes automated into a production rule. Once formed, production rules operate outside of conscious control. An example of a production rule used when performing retinoscopy would be to identify power meridians and then neutralise the most plus of the powers.

The use of a production rule would account for the difference in speed and accuracy that the experts displayed. Certainly, the experts reputed that they found it quite difficult to verbalise their decisions and this may be an indicator that the process had indeed become automatised into a production rule. The categorical analysis of successful outcomes indicated that decision making was the hallmark of expert performance. The regression analysis supported this interpretation and indicated that the presence of cyclic strategy was a significant predictor for the accuracy of outcome. Efficient skill acquisition requires a clear strategy and understanding the steps involved to reach a solution.[17,18,19]

Ohlsonn (2004)[21] has suggested that what is unclear in the Newell and Simon approach is 'How do people generate a problem space when confronted with a new task?' For the novices, the structure of the retinoscopy task would not be clear, until adequate practice had formed a representation of the problem space. Some amount of trial and error together with a foundation would be required to form the basis for the problem space itself. Whatever strategies are used, problems may require a foundation of conceptual knowledge to reach a solution.[22] Indeed, when the novices were asked about their underlying knowledge of visual optics, they did not understand the concept of sphero-cylinder prescription. This highlights the importance of an adequate theoretical foundation being present *before* commencing the teaching of practical skill. This is an important factor for consideration in a profession where there is a drive for a reduction in theory and a push for vocational style training.

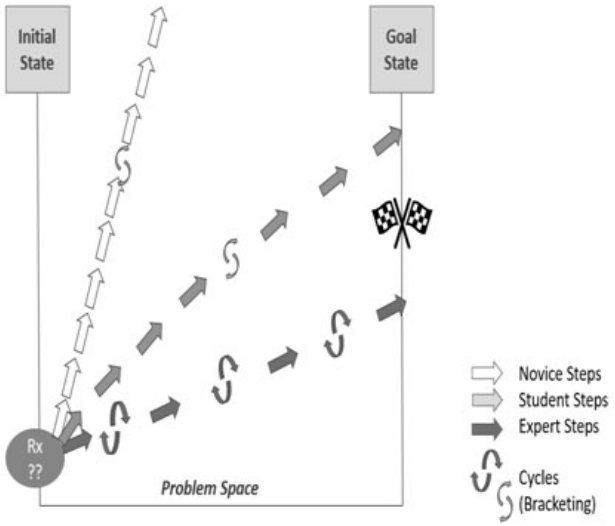

Figure 3: Routes through the retinoscopy problem space. The performance of novices is little more than trial and error. In contrast, students demonstrate some degree of strategy. Expertise is characterised with clear cyclic strategy that proceeds towards the goal state.

The current study employs problem space analysis as a pedagogic tool, using protocol as a method to elicit self reflection and awareness of the learners' own meta-cognitive strategy. [23,24.] The teaching of any practical skill requires instruction of practical technique, however, it is clear that practice and technique alone will not necessarily evoke understanding. The current study demonstrates that experts in the technique are aware of the actions and the consequences of action. It would therefore be beneficial to promote meta-cognitive awareness from an early point in training when the technique is introduced, rather than the current learning by trial and error.

When the experts were asked to comment on the use of the simulation, it was clear that they conducted the procedure in a similar way as they would on a real patient. Students may find the simulation easier than working on a real patient due to factors such as working distance, position etc. Simulation does not replace experience of work on real patients, who will have different refractive errors, may have ocular pathology, or show poor compliance. Nor does the simulation evoke techniques such

as the use of the collar or a change in working distance. However, this was not the aim as these techniques require an understanding of visual optics.

A frequent observation in the novice group was that they repeatedly moved the retinoscope but didn't make any action. This is evident from the number of observations. When asked during the debriefing, novices often stated that they didn't recognise the reflex that they were observing. Clearly the simulation has utility in preparing the novices for what to expect when working on a real patient. Furthermore, simulation allows the learner to develop the foundational knowledge and strategy before working on more complex 'real' patients. Activities that incorporate meta-cognitive support have been shown to enhance learning and from a cognitive perspective, the formation of a sub-goal also helps to reduce the load on working memory[12]. Moreover, sub-goals are not just beneficial in terms of processing speed. Sub-goal formation has been shown to have benefits in terms of motivation and task completion, especially where the goal of a task may be uncertain.[25]

Activities that evoke metacognition, are beneficial in several other ways. Firstly, they initiate self assessment and reflection. This allows the learner to identify what they already know and more importantly what they do not understand.[26] Being aware of one's performance allows the learner to monitor their progress and revise their procedure accordingly.

Rather than giving students extended periods of practice, initially we feel that developing a meta-cognitive awareness of the procedure, from an early point would be highly beneficial. One way to achieve this would be to encourage students to set themselves a sub goal and for them to subsequently attain this goal before proceeding further. In terms of retinoscopy, an initial goal may simply be to determine the principal power meridians, before selecting lenses or attempting to neutralise any powers. The use of a strategy that works, would not only lead to a repeat of that behaviour, but act as a signpost to assess if the actions were not yielding a result that was expected. Being aware of the consequences of action would also help to elicit a deep conceptual understanding of the process.[27,28]

We have demonstrated that successfully performing retinoscopy requires a strategic pathway through the problem space. This demonstrates the importance of meta-cognition which should be the focus of clinical training. By the third year of study the students had acquired the basic procedure for conducting retinoscopy but accuracy was an attribute that was still developing. Given the importance of performing retinoscopy in certain populations[29] this study highlights the importance of pedagogy in optometric education.

Training in the UK currently includes a pre-registration period that is completed after a satisfactory degree has been obtained. The pre-registration period is the time when knowledge from procedural and theoretical knowledge is fully integrated into effective practice. This period of practice fulfils the need for exposure to more real patients under the safety of appropriate supervision. The role of the supervisor at this point should focus on raising the pre-registration practitioners' awareness of their own meta-cognitive strategy. This ensures that pre-registration practitioners attain the required level of decision-making skill. This is an important consideration, at a time when the training of optometrists in the U.K. is under review. There is limited time or opportunity for such coaching in a busy optical practice, and this reveals the importance of effective pedagogy early within the educational setting.

Adopting meta-cognitive strategy into optometric pedagogy will ensure that clinical teaching practice is effective, and that skills that are learnt are based around solving clinical scenarios rather than simply performing a procedure by rote. Further work will be able to demonstrate the use of meta-cognitive strategy in optometric education.

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List of Figures and Tables

Table 1: Mean Performance Indicators*SPH = sphere power, **CYL = cylinder power/cylinder axis. Actions refer to motor movements that could be directly observed (such as a lens change). Observations refer to viewing a reflex in conjunction with the movement of the retinoscope. ***Fresh start: Abandoning the attempt and starting again from scratch****Final checks for neutrality: Once the potential solution is reached, performing a cross check of neutrality, for both meridians prior to concluding.

Figure 1: Retinoscopy of Novice, Student, and Expert practitioners. Total time and number of processing cycles (bracketing). Error bars illustrate 95% confidence intervals.

Figure 2: The relationship between response time (min) bracketing steps and accuracy for the different practitioner groups

Figure 3: Routes through the retinoscopy problem space. The performance of novices is little more than trial and error. In contrast, students demonstrate some degree of strategy. Expertise is characterised with clear cyclic strategy that proceeds towards the goal state.

Appendix 1

Grading of Accuracy

Marks were awarded for accuracy and a total accuracy rating calculated

(One mark per statement that applies, up to a maximum of 10).

Sphere power within 1.00 Dioptre = 2

Sphere power within 0.50 Dioptre = 1

Sphere power within 0.25 Dioptre = 1

Cylinder power within 1.00 Dioptre = 2

Cylinder power within 0.50 Dioptre = 1

Cylinder power within 0.25 Dioptre = 1

Cylinder axis within 15 degrees = 1

Cylinder axis within 5 Degrees = 1