Influence of stereoscopic vision on task performance with an operating microscope

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PURPOSE: To determine the extent to which stereoscopic depth perception influences the performance of tasks executed under an operating microscope.

SETTING: Laboratory of Experimental Ophthalmology, University Medical Center Groningen, the Netherlands.

DESIGN: Experimental study.

METHODS: Medical students were assigned (on the basis of their stereoacuity) to a stereo-sufficient group (depth perception $\leq$240 seconds of arc [arcsec]) or stereo-deficient group ($\geq$480 arcsec). They performed a bead-stringing task (a mockup surgical test) under an operating microscope or a task on a cataract surgery simulator. The stereo-sufficient subjects also performed the bead-stringing task under artificial stereo-deficient conditions (binocular and monocular viewing).

RESULTS: The study comprised 77 medical students. The stereo-sufficient subjects performed both tasks faster than the stereo-deficient subjects and artificially stereo-deficient subjects ($P \leq$ .024). In addition, a within-group analysis established that the stereo-sufficient subjects were faster at the bead-stringing task with stereoscopic viewing than under artificial stereo-deficient conditions with binocular viewing ($P \leq$ .011).

CONCLUSIONS: Having stereovision resulted in better initial performance on certain tasks involving the use of an operating microscope or cataract surgery simulator. However, this study did not show that stereo deficiency necessarily results in an inability to perform such tasks properly. Hence, it was not evident that for admission to an ophthalmology residency program, stereovision should be judged more stringently than other traits.

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Achieving a minimum score on a standardized random-dot stereoscopy test has been part of the admission requirements for training in the specialty of ophthalmology in the Netherlands since 2001.[A] In other countries, however, ophthalmology training programs, as well as training programs for other medical specialties that also use stereoscopic operating microscopes, do not select applicants on the basis of stereoacuity.[1] Moreover, there is little to no evidence that performance with such a microscope would suffer from a lack of stereovision. This lack of evidence raises the question of whether the performance of young physicians using a surgical microscope would be influenced by a lack of stereovision.

Since 1921, microscopes have been used in medical operative practice.[2] The first surgical microscopes did not provide the same image quality as those of today, and many improvements followed. At present, operating microscopes are equipped with stereoscopic binoculars, which allow the perception of depth.[3] However, depth perception under an operating microscope is available only to surgeons who have sufficient stereovision. Between 1980 and 1995, difficulties in the surgical training of some ophthalmology residents were reported.[A] The difficulties concerned the residents' operative skills and were attributed to their lack of stereovision. Despite the absence of direct scientific

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evidence, it was presumed that a relationship existed between the lack of stereoacuity and moderate operative skills in using the stereoscopic microscope. This hypothesis resulted in stereoacuity requirements for training in the specialty of ophthalmology in the Netherlands. It has been reported that besides the Netherlands, only the Czech Republic has requirements regarding stereoacuity for ophthalmic surgeons.[1]

The aim of this study was to determine the extent to which stereoscopic depth perception influences the performance of tasks executed under an operating microscope. Therefore, an experiment with a mockup surgical test (bead-stringing task) and a cataract surgery simulator was designed.

SUBJECTS AND METHODS

Subjects

Students enrolled in the master of medicine program at University Medical Center Groningen were recruited to participate in the study. The study subjects included students who were participating in an internship in ophthalmology as well as students in other departments. The subjects had to state that they had normal function in both hands.

Ophthalmic Measurements

Corrected distance visual acuity (CDVA) was measured with the Freiburg Visual Acuity Test.[4] Because of the relationship between visual acuity and stereoacuity, only subjects with a CDVA of better than 20/20 were included.[5–7] Stereoacuity was assessed with the TNO Stereotest (Laméris Ootech BV).[8] On the basis of the stereotest results, subjects were divided into 2 groups. The first group of subjects had a stereoscopic depth perception of 240 seconds of arc (arcsec) or less (the stereo-sufficient group). This criterion was based on the prerequisites for the ophthalmology training program in the Netherlands. The second group of subjects was considered stereoblind; they had a stereoscopic depth perception of 480 arcsec or more or were unable to see any figures during the stereotest (the stereo-deficient group).

Bead-Stringing Task (Mockup Surgical Test)

For this task, an operating microscope (OPMI 6-SFC, Carl Zeiss Meditec AG) was used. Subjects had to string small beads (rocailles, size 15/0) onto a 6-0 nylon suture (Ethilon) with a forceps and a needle holder. The beads (25 black and 25 white) were provided in a tray under the microscope. They had to be strung onto the suture to create a chain of alternating black and white beads. Because not all the beads would fit on the needle, subjects had to slip the beads from the needle to the suture thread after each set of 5 beads. The task was completed once 20 beads were on the thread.

For this task, 3 viewing conditions were established as follows: with a stereoscopic viewer, with a binocular viewer without stereoscopic vision, and with a monocular viewer. These viewing conditions were created on the operating microscope with 2 sets of oculars; that is, a set with stereoscopic view and a set without stereoscopic view. Under the monocular viewing condition, subjects selected an ocular (from the set without stereoscopic view) to be covered. The stereo-sufficient group had to perform the task 5 times in a row under 1 of the viewing conditions followed by 5 times in a row under another viewing condition, thus resulting in 10 runs per subject. The 3 different viewing conditions were used in 4 combinations to create 4 testing categories (Table 1). Stereo-sufficient subjects were assigned to 1 of these categories using stratified randomization (categories SS1 through SS4). The 2 stratification factors in this study were category and sex. Subjects in the stereo-deficient group had to perform the task 5 times in the stereoscopic viewing condition only (category SD1).

Table 1. Overview of conditions in the bead-stringing and cataract surgery simulator tasks.

Task/Group/Category	Subjects (n)	Viewing Condition 1	Viewing Condition 2
Bead-stringing task			
Stereo-sufficient			
SS1	9	Stereo	Binocular
SS2*	9	Binocular	Stereo
SS3	8	Monocular	Binocular
SS4	7	Binocular	Monocular
Stereo-deficient			
SD1	7	Stereo	—
Cataract surgery simulator task			
Stereo-sufficient			
SS5	28	Stereo	—
Stereo-deficient			
SD2	9	Stereo	—

*The group categorized as SS2 (binocular viewing condition) is also termed the artificial SD group.

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Drs. Nibourg and Wanders performed this study as part of the curriculum for the master of medicine program at the University of Groningen. The University of Groningen had no role in the design, conduct, analysis, or publication of this research. Students from the University of Groningen participated in this study, and Remco Renken provided helpful comments during the design of the experiments.

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Simulator Task

For this task, the Eyesi surgical cataract surgery simulator and software (version 2.7, VRmagic Holding AG) were used. The simulator consisted of a model head connected to a microscope, which provided a virtual stereoscopic view of an eye lying under the operating microscope. The subjects (categories SS5 and SD2) had to execute the first level of the cataract forceps training 5 times. For this task, subjects had to grasp small cubes that were floating in the anterior chamber and drag them into a frame situated in the middle of the anterior chamber. When all the blocks had been placed within the circle, the task was completed. The time needed to execute the task was recorded.

Outcome Parameters

Execution of the bead-stringing task was recorded with a digital camera attached to the microscope. For each separate run, the test time was determined from the recording by measuring the interval between the actual start and stop times. Errors made during execution of the task were scored as 1 point. Errors included beads running away, beads falling from the needle, and the needle falling from the needle holder.

To evaluate performance across the different viewing conditions, 2 outcome parameters were used. The first outcome parameter was the median test time of the last 3 attempts of each series. (To eliminate possible effects of learning during the initial attempts, only the last 3 attempts were considered.) Furthermore, the test time just before switching oculars was compared with that directly after switching viewing conditions (ie, the test time of run 5 [the last run under the first viewing condition] was compared with the test time of run 6 [the first run under the second viewing condition]).

During the simulator task, completion times of the 5 executions by each subject were recorded. The 5 completion times were used to determine each subject's median test time.

Statistical Analyses

Statistical analyses were performed with Statistical Package for the Social Sciences software (version 20, International Business Machines Corp.). Four comparisons for the bead-stringing task and 1 comparison for the simulator task were performed. Table 2 shows the compared groups, outcome parameters, and statistical tests used in the analyses. For all tests, P values less than 0.05 were considered statistically significant.

RESULTS

Of the 77 study subjects, 40 were recruited for the bead-stringing task and 37 for the simulator task. The subjects had a mean age of 23.2 years (range 20 to 28 years), and 30 (39.0%) were men. Their CDVA ranged between 20/17 and 20/11, with a mean of 20/13. The stereo-sufficient group had a mean score of 33 arcsec on the TNO Stereotest (range 15 to 120 arcsec). In the stereo-deficient group, 2 subjects were able to detect a figure at 480 arcsec, whereas the others were unable to see any figures of the stereotest. Causes for stereoblindness were amblyopia and strabismus.

First, performance of the bead-stringing task by the stereo-sufficient subjects (SS1, condition 1 only) was compared with that by the stereo-deficient (SD1) subjects. For this comparison, test time was shown as a function of test number (Figure 1). A gradual decrease in time required to complete the test was noted in both groups of subjects: $F(4,52) = 2.90$ and $P = .031$. Nevertheless, the stereo-deficient subjects remained slower than the stereo-sufficient group: $F(4,52) = 16.1$ and $P < .001$.

Next, the performance of the stereo-deficient subjects (SD1) was compared with that of the subjects

Table 2. Overview of statistical analyses performed by task and group.*

Task/Figure	Comparison	Outcome Parameters	Statistical Test
Bead-stringing task			
Figure 1	Viewing condition 1: SS1 vs SD1	Test time	Repeated-measures analysis of variance
Figure 2	Viewing condition 1: SS1 vs SS2 vs SD1	Median test times	Kruskal-Wallis test with Wilcoxon rank-sum post hoc analysis and Holm-Bonferroni correction
Figure 3	Within-group analysis: viewing condition 1 vs 2 (SS1, SS2, SS3, SS4)	Median test times; switch of conditions	Wilcoxon rank-sum test
Figure 4	Correlation test time and errors (SS1, SS2, SS3, SS4, SD1) and correlation SS1–SS4 vs correlation SD1	Test time; errors	Spearman correlation coefficient and Fisher z-transformation
Cataract surgery simulator task			
Figure 5	SS5 vs SD2	Median test times	Wilcoxon rank-sum test

*For both tasks, the compared groups and outcome parameters are given. The figures corresponding to the data are also indicated.

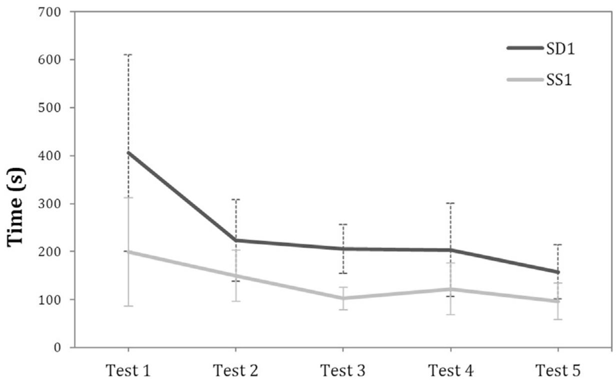

Figure 1. Comparison of test times on the first 5 runs of the bead-stringing task by the stereo-sufficient subjects (SS1; n = 9) and stereo-deficient subjects (SD1; n = 7) Group means (±standard deviation) are shown.

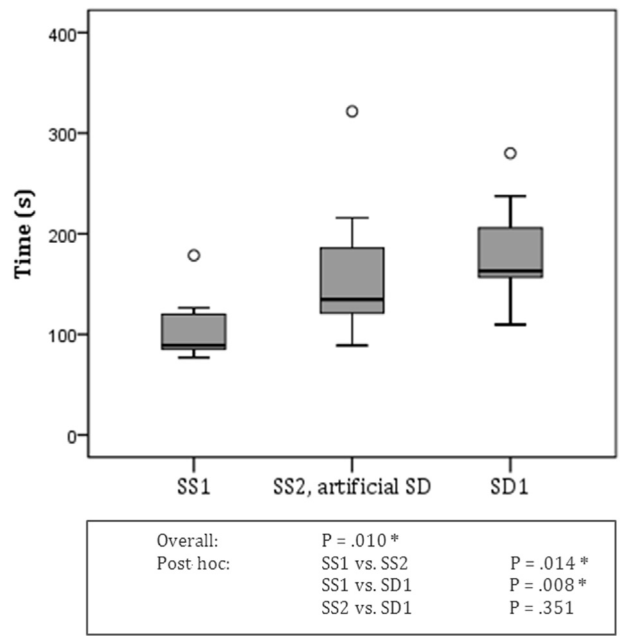

Figure 2. Performance in the first 5 runs of the bead-stringing task by the stereo-sufficient (SS1; n = 9), artificially stereo-deficient (SS2; n = 9), and stereo-deficient (SD1; n = 7) subjects. Comparisons of the median test times are shown. Outliers are indicated with an open circle (* = statistically significant [$P < .05$]).

rendered artificially stereo-deficient (group SS2, condition 1 only). For completeness, data for the stereo-sufficient subjects (SS1, condition 1 only) were also included. Because the data for this analysis were not normally distributed, mean test times could not be used. Therefore, the median test times of the last 3 attempts of the first 5 runs during the bead-stringing task were determined for each subject. The results are shown in Figure 2 and Figure s1 from the supplemental material (available at http://jcrsjournal.org), which show that the subjects with stereovision performed better than those in the other 2 groups ($P \leq .014$). Furthermore, no differences between the artificially stereo-deficient and actually stereo-deficient groups were found ($P = .351$).

To evaluate microsurgical performance on the bead-stringing task across the different viewing conditions without having to account for intersubject variability, a within-group analysis was performed. Because the data for the within-group analysis were not normally distributed, the median test times under both viewing conditions were used once again. The graphs in Figure 3 plot the median test times and the test times at the switch of viewing conditions for the 4 different groups of stereo-sufficient subjects used in the bead-stringing task (groups SS1 through SS4, see Table 1). For the subjects in test category SS1, the switch from stereoscopic to binocular viewing resulted in a statistically significant increase in test time ($P = .008$). For the subjects in test category SS2, the median test times were shorter under the stereoscopic condition than under the binocular condition ($P = .008$). The median test times of the subjects in category SS3 were shorter under the binocular condition than under the monocular condition ($P = .025$). With regard to the subjects in category SS4, no differences between their test times under binocular and monocular conditions were found ($P \geq .128$). In addition, the results of the slowest and fastest test times in the 4 groups of stereo-sufficient subjects are shown in Figure s2 from the supplemental material (available at http://jcrsjournal.org).

The possible existence of differences in accuracy of performance between the stereo-sufficient (SS1 through SS4) and stereo-deficient (SD1) subjects was also examined. In Figure 4, test time is plotted as a function of the number of errors. The overall correlation is displayed by a dotted line, which indicates an association between more errors and a longer test time ($r_s = .27, P < .001$). This correlation was stronger for the stereo-deficient subjects (SD1: $r_s = .42, P < .001$) than for the stereo-sufficient subjects (SS1 through SS4: $r_s = .22, P < .001$). However, the difference between the correlations of these groups was not statistically significant ($z_{difference} = -1.92, P = .055$).

Finally, performance of the simulator task by the stereo-sufficient (SS5) subjects was compared with that by the stereo-deficient (SD2) subjects. Figure 5 shows that the median test times did not differ between the groups ($P = .073$). However, the trend in the results suggests faster performance by the stereo-sufficient subjects. Furthermore, the slowest test times (supplemental material and Figure s3, available at http://jcrsjournal.org) of the stereo-deficient (SD2) subjects were statistically significantly longer than those of the stereo-sufficient (SS5) subjects ($P = .015$).

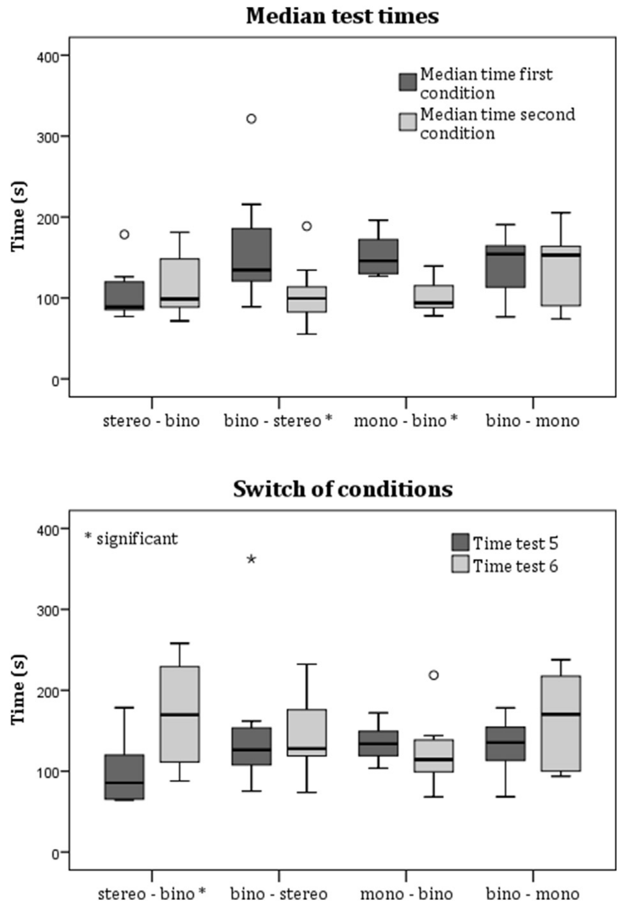

Figure 3. Outcomes of the within-group analysis of data from the bead-stringing task under artificial conditions. The 4 testing categories of stereo-sufficient subjects are displayed as follows: stereoscopic (stereo)–binocular (bino) (SS1; n = 9), bino-stereo (SS2; n = 9), monocular (mono)–bino (SS3; n = 8), and bino–mono (SS4; n = 7). Outliers are indicated with an open circle and extreme outliers with a star (* = statistically significant [$P < .05$]).

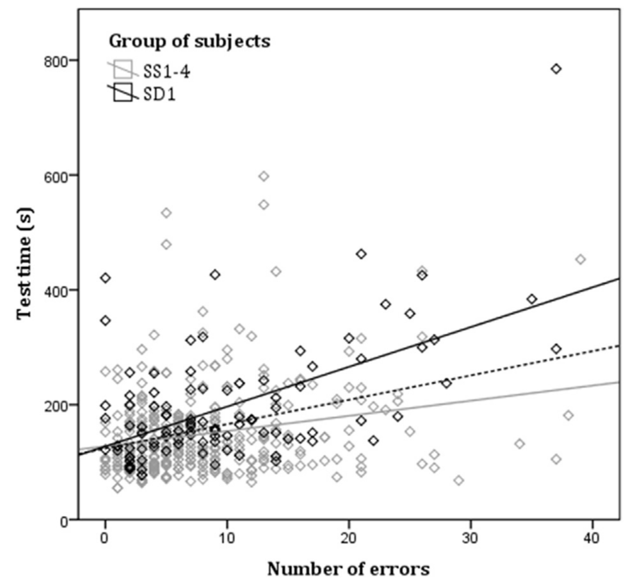

Figure 4. Correlation between test time and number of errors on the bead-stringing task. For each subject, the score for each test is shown, thus providing 10 squares per subject. Errors were scored as 1 point per error. The dotted line indicates the correlation between the accuracy of performance and test times for both groups together. The black line indicates the correlation for the stereo-deficient subjects (SD1; n = 7), and the gray line indicates the correlation for the stereo-sufficient subjects (SS1-4; n = 33).

DISCUSSION

The ability to combine detailed visual information with fine manual dexterity is considered very important for performing ophthalmic microsurgery. In this study we found a performance benefit of stereoscopic depth perception for tasks executed under an operating microscope and a cataract surgery simulator. The stereo-sufficient subjects performed both tasks faster than the stereo-deficient subjects or artificially stereo-deficient subjects. Additionally, the stereo-sufficient subjects were faster at executing a bead-stringing task under stereoscopic viewing than were subjects who could not make use of their stereovision (ie, those who were rendered artificially stereo-deficient). Therefore, we conclude that stereovision is advantageous for performing certain tasks under an operating microscope and in a cataract surgery simulator.

Both tasks were also performed by stereo-deficient subjects. We had expected that subjects with a long-term deficiency in stereopsis would have somehow adapted to this situation and developed compensatory strategies. Contrary to our expectation, we found no differences in performance on the bead-stringing task between the artificially stereo-deficient subjects and the actually stereo-deficient subjects. A trend in the results even suggests a slightly faster performance by the artificially stereo-deficient subjects.

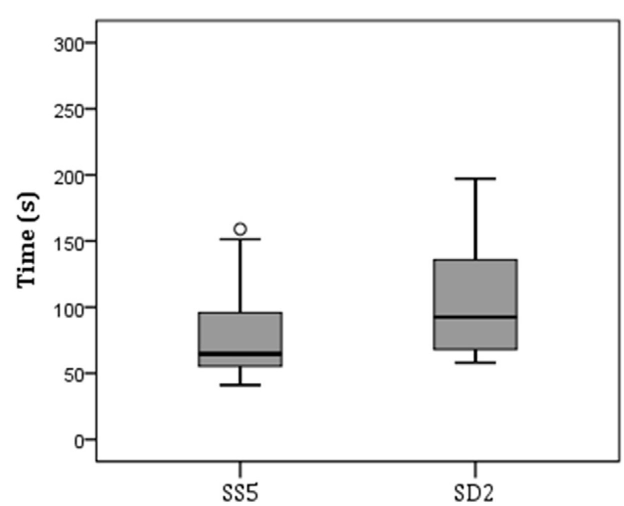

Figure 5. Median test times from the simulator task for the stereo-sufficient subjects (SS5; n = 28) and stereo-deficient subjects (SD2; n = 9). Outliers are indicated with an open circle.

Furthermore, we found no differences between stereo-deficient and stereo-sufficient subjects from the standpoint of the correlation between their test time and number of errors on the bead-stringing task. The overall correlation showed that more errors are associated with a longer test time, and in the case of the stereo-deficient deficient subjects, this correlation was somewhat stronger but not statistically significantly different from that in the case of the stereo-sufficient subjects. This finding indicates that stereo-deficient subjects show similar learning curves and that stereo deficiency would not necessarily result in an inability to perform surgical tasks properly. The resemblance in learning curves can also be seen in Figure 1, which shows that the stereo-sufficient subjects performed the task significantly faster. However, the learning curves in both groups (the stereo-sufficient and stereo-deficient subjects) appear similar, which suggests that after prolonged practice, test times for stereo-sufficient and stereo-deficient subjects could become equal. Because we tested only initial performance and did not repeat the tasks after prolonged practice, it is possible that stereo-deficient subjects could eventually achieve performance equal to that of stereo-sufficient subjects.

To our knowledge, this is the first study to compare within-subject microsurgical performance by stereo-sufficient and artificially stereo-deficient subjects with intact stereopsis. Such a within-subject design allowed us to compare the influence of stereopsis on the performance of a microsurgical task without having to also account for intersubject variability. A limitation of our study is that we investigated performance on only 1 mockup suturing task (bead-stringing) under a microscope and only 1 simulator task, whereas many more skills are required in ophthalmic surgery. Nevertheless, our finding that stereoscopy does affect execution of the tasks examined suggests that it may also contribute to the overall performance of a surgeon. However, we have to consider the possibility that after prolonged practice, stereo-deficient subjects could still achieve sufficient surgical skills.

Reduced stereovision has previously been associated with poorer performance on bead-stringing tasks without the use of a microscope.[9,10] The role of stereovision in performance of microsurgery with a microscope was first examined by Grober et al.[11] Their subjects, all of whom were surgical residents with normal stereoscopic vision, performed a suturing task under normal and monocular conditions. No relationship between the presence of stereovision and microsurgical performance was found. Perhaps the global rating scale used to assess microsurgical performance was not sensitive enough to uncover differences in performance.[12]

Previous studies did identify an advantage of stereoscopic vision for tasks performed under a cataract surgery simulator. Sachdeva and Traboulsi[13] found that subjects with a lifelong deficiency or absence of stereovision performed consistently worse than controls with normal stereoacuity. As in our study, the subjects had no previous surgical experience. In the simulator study of Selvander and Åsman,[14] the subjects were medical students who performed 3 different tasks. Performance was compared among subjects with different levels of stereoacuity. Although the number of subjects with reduced stereoacuity was relatively small (with 3 subjects at 480 arcsec and 5 subjects at >480 arcsec), stereoacuity was correlated with performance on 2 of the 3 simulator tasks. This correlation is in line with our finding that stereoscopic vision is advantageous for performance of tasks on a cataract surgery simulator.

Training involving the use of a cataract surgery simulator is increasingly being implemented in ophthalmology residency programs.[15,16] The importance of simulator training is supported by a study in which such training was found to improve the surgical skills of ophthalmology residents.[16] Because stereoscopic vision provides a performance advantage during use of a cataract surgery simulator, training outcomes may give some indication of the stereoacuity-dependent surgical competence of the residents. Moreover, because the ability to combine detailed visual information with fine manual dexterity is considered very important for ophthalmology residents, surgery simulators might be envisaged as playing a role in screening residents for admission to ophthalmology resident programs. Further work is required to determine the relationship between initial performance on a simulator as a resident and subsequent performance as a cataract surgeon.

The question of whether stereoacuity requirements for ophthalmology resident programs can be justified was recently discussed.[1,B] No studies that can provide a direct answer are available. A large retrospective survey on the surgical competency of ophthalmology residents found that 9% had problems developing surgical skills of sufficient quality as judged by their program directors.[17] In only 3% of these residents were (unspecified) visual problems present as well. The residents with surgical skill problems more often had problems such as poor hand–eye coordination (24%), poor intraoperative judgment (22%), tremor (14%), questionable behavior (11%), and inappropriate reaction to stress in the operating room (10%).

To summarize, the relevance of screening for stereovision for admission to ophthalmology resident programs is not proven, and many additional factors may influence surgical performance. This study shows that stereoscopic depth perception is beneficial for the initial performance of tasks executed under an operating microscope and on a cataract surgery simulator.

Therefore, it is likely that stereovision is also advantageous when learning to perform or actually using surgical skills. Importantly, our study does not show that stereo deficiency would necessarily result in an inability to perform such tasks properly. Hence, in our view, in light of all the possible issues that may hamper the acquisition of surgical skills by ophthalmology residents, it is not evident that stereovision should be judged more stringently than other traits.

WHAT WAS KNOWN

- The ability to combine detailed visual information with fine manual dexterity is considered very important for performing ophthalmic microsurgery.
- In some countries (eg, the Netherlands), achievement of a minimum score on a stereoscopy test is part of the requirements for training in the specialty of ophthalmology because a lack of stereovision is thought to have a negative impact on surgical performance during use of an operating microscope. However, the relevance of screening for stereovision for admission to ophthalmology residency programs has not been demonstrated.

WHAT THIS PAPER ADDS

- Stereovision improved the initial performance of tasks involving use of an operating microscope and cataract surgery simulator. Therefore, it appears likely that stereovision is also advantageous when learning to perform or when actually using surgical skills.
- This study did not show that stereo deficiency would necessarily result in an inability to perform surgical tasks properly. Hence, it is not evident that for admission to an ophthalmology residency program, stereovision should be judged more stringently than other traits.

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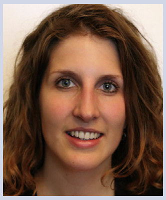

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