



# Training Effects of Visual Stroboscopic Impairment on Surgical Performance: A Randomized-Controlled Trial

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**OBJECTIVE:** There have been numerous advances to accelerate and improve quality and dexterous proficiency of surgical training to meet the growing US demand of graduating surgeons. The authors aimed to investigate the learning effects of such limited visual input on the surgical proficiency in untrained novice surgeons.

**DESIGN:** A prospective randomized-controlled study was created with 11 participants in the study and 11 in the control group.

**SETTING:** An inanimate surgical simulation lab of a tertiary academic institution (Houston Methodist Hospital, Houston, Texas).

**PARTICIPANTS:** Adult medical students in the experimental group were wearing stroboscopic eyewear while performing the same tasks as students in the control group with normal vision. For 5 weeks, the

subjects were scored during 3 standardized surgical tasks from the American College of Surgeons and the Association of Program Directors in Surgery Resident Skills Curriculum: knot tying, simple interrupted sutures, and a running stitch. Pretrial, we employed the State-Trait Anxiety Inventory and post-trial, the NASA Task Load Index.

**RESULTS:** The demographic characteristics of our study participants were uniformly distributed between the 2 cohorts: each group had 7 males and 4 females. Average ages were 23.6 and 24.2 years ( $p = 0.471$ ). The anxiety was low during all 5 sessions and indifferent between both groups. At the end of the study, no changes were observed in the stroboscopic group for the knot-tying task ( $p = 0.619$ ). However, for the simple interrupted and the running stitch, the students with stroboscopic glasses performed significantly better ( $p = 0.001$  and  $p = 0.024$ , respectively). The stroboscopic students also had significantly lower NASA workload scores ( $p = 0.001$ ).

**CONCLUSIONS:** Regular training with stroboscopic glasses that limit visual input has a significant positive effect on the technical skills of novice surgical trainees with regards to more complex tasks such as multiple simple interrupted suturing or running suture. Intermittently impaired vision is beneficial in the early education of students and surgical residents. (*J Surg Ed* 76:560–567. © 2018 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

**KEY WORDS:** Stroboscopic, 3D vision, Performance, Skills, Education, Residents

**LEVEL OF EVIDENCE:** I: Randomized-controlled trial

**COMPETENCIES:** Practice-Based Learning and Improvement, Patient Care, Interpersonal and Communication Skills

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**Ethical considerations:** The work described in this manuscript was approved by our institutional review board (protocol number Pro00017727: "Utility of Stroboscopic visual training to improve surgical skills").

**Study registration:** Not applicable, not a health-related clinical trial by ICMJE/WHO definition: <http://www.icmje.org/about-icmje/faqs/clinical-trials-registration/>.

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## INTRODUCTION

Surgical training has dramatically changed during the recent years with the hope to achieve better theoretical education but also greater dexterous skill in operative or invasive procedures. Multiple national consensuses have introduced standardized curricula that have been implemented and adhered to by the surgical residency programs. For instance, the joint endeavor of the American College of Surgeons and the Association of Program Directors in Surgery (ACS/APDS) is a skills curriculum for residents to train their operative skills and evaluate them across the United States.<sup>1</sup> Similar advancements include modules, such as the Fundamentals of Endoscopic Surgery, the Fundamentals of Laparoscopic Surgery, or the Fundamentals of Robotic Surgery.<sup>2-4</sup> In general, all current trends go toward greater simulation—a young surgeon today is anticipated to have sophisticated skills when going to the operating room. The major goals are to maintain high patient safety with resident involvement,<sup>5</sup> improve surgical outcomes, and reduce time and cost within the operating suite.<sup>6,7</sup>

Sports science research has shown us how intermittent visual impairment can have a positive impact on people performing various demanding tasks. Human subjects have the capability to adapt to their limited stimuli and, over a period of time, to operate in that restricted environment.<sup>8</sup> Stroboscopic eyewear has been a common tool in literature to test these theories in various scenarios. Appelbaum et al. reported on improved short-term memory after practicing with stroboscopic glasses.<sup>9</sup> Further studies reported favorable outcomes with anticipatory timing,<sup>10</sup> ball catching,<sup>11</sup> baseball batting,<sup>12</sup> and ice hockey skills.<sup>13</sup> The exact mechanism for the positive influence of stroboscopic vision on anticipatory human responses has not been established yet. Supporters of perceptual training in athletes argue that limited visual input teaches players how to predict a ball's movement in the air and how to subsequently improve their reaction.<sup>12</sup>

In the surgical field, reaction times to moving or flying objects are naturally not as crucial of a parameter as they are in professional sports. Here, decreased 3-dimensional vision and a moderate increase in stress levels may be the main factors accelerating the operative training process. The benefit of this stroboscopic device for surgical teaching

has not been previously reported. The authors, therefore, designed a prospective randomized-controlled trial to investigate the effect of intermittent vision training on the proficiency of unexperienced medical students performing basic surgical tasks from the ACS/APDS curriculum.<sup>1</sup>

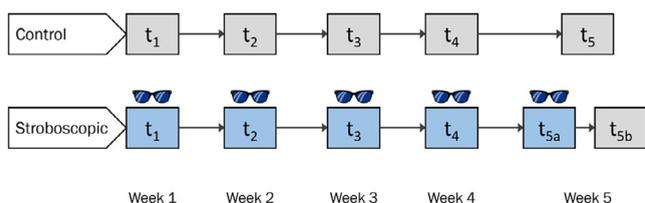
## METHODS

### Study Design and Participants

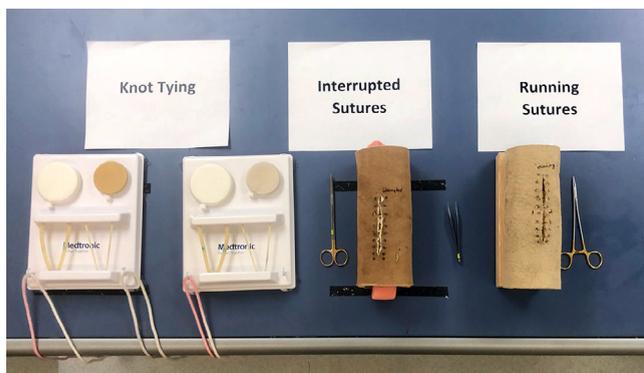
After institutional board review approval at our hospital, the dean's offices and surgical student societies of the 3 major medical schools in Houston, Texas were contacted for voluntary participants for our study. All enrolled adult medical students, years 1 through 4, with no prior surgical experience were eligible for inclusion. Exclusion criterion was previous participation in a suturing or formal surgical training course. After enrollment, the students were randomized into a control group that would perform all surgical tasks without the eyewear or an experimental group that would perform the same tasks while wearing Senaptec Strobe stroboscopic glasses (SENAPTEC, Beaverton, Oregon). These glasses have lenses that are set to flicker bilaterally at a medium frequency, level 4 out of 8 (about 120 Hz) and alternate between transparent and opaque. The frequency setting was mainly based on reports from the earlier mentioned athletic literature.

Initially, all students participated in a group instruction meeting (week 0) where the authors explained the study purpose and its design. Consent forms were obtained, the surgical material was introduced, and the tasks were presented by the senior residents (V.C. and J.J.N.L.). Furthermore, a series of online videos was sent out to all study participants to familiarize themselves with the surgical tasks. No training materials were provided to take home and the students were asked not to practice outside of the study to ensure a uniform experimental environment.

Each student performed all tasks once per week, for 5 consecutive weeks. Subsequently, this resulted in 5 time points for the control group and 6 time points for the stroboscopic group (Fig. 1). The fifth appointment for the stroboscopic group was a double session where the experimental study participants would first perform all surgical tasks wearing the stroboscopic glasses ( $t_{5a}$ ) and then repeat the entire setup without visual impairment ( $t_{5b}$ ). Our experience in a previous study examining the impact of stress on laparoscopic skill<sup>14</sup> was the reason for choosing the 5-week period. This study was approved by our institutional review board and written informed consent was obtained from all medical students at their first appointment.



**FIGURE 1.** Prospective study design.



**FIGURE 2.** Start layout of every weekly session with tasks #1, #2, and #3, shown from left to right.

### Surgical Tasks

During each weekly appointment, the students in both groups performed the same tasks in a defined consecutive order (Fig. 2). For the first task, the student would perform a basic 2-handed knot tie under tension with 3 square throws using cotton rope and then repeat this assignment another 2 times for a cumulative time (Fig. 3).<sup>15</sup> Errors were counted for each air knot. The second task consisted of 3 individual interrupted sutures on a soft-cushion suturing model using 3-0 silk Ethicon (Ethicon Inc., Somerville, New Jersey) suturing material (Fig. 4).<sup>16</sup> The third task was a simple running stitch of 10 cm length with 10 total incisions using the same 3-0 silk suture on a separate model (Fig. 5).<sup>17</sup> For the 2 suturing tasks, errors were counted for each air knot, slippage, breakage, or missing the premade colored dots. The students were given short breaks among the 3 tasks. The total scores were derived from the ACS curriculum formulas that include the variables of time and number of errors (Table 1). The final score of the stroboscopic students without visual impairment ( $t_{5b}$ ) compared to



**FIGURE 3.** Sample of completed task #1: knot tying.

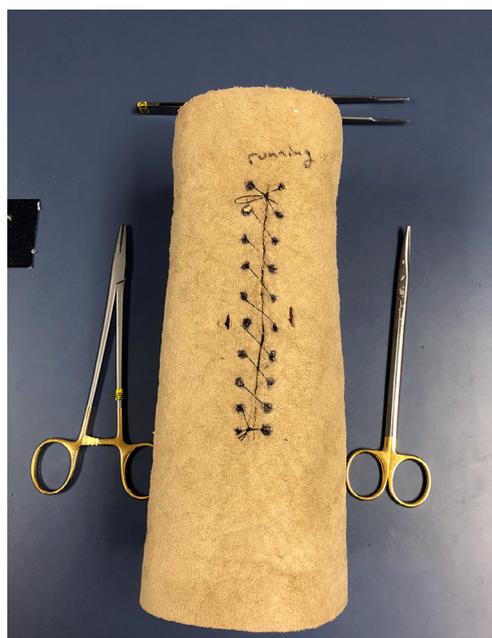


**FIGURE 4.** Sample of completed task #2: 3 interrupted sutures.

the final score of the controls ( $t_5$ ) was the primary outcome measure of this study.

### Questionnaires

In addition to the surgical assignments, the medical students were given a brief self-designed questionnaire at the beginning and at the end of the study. Here, we collected demographic characteristics and asked the



**FIGURE 5.** Sample of completed task #3: 10 cm of simple running sutures. Student misplaced a stitch on the left.

**TABLE 1.** Surgical Score Formulas

Task	Formula
Knot tying	90 – time (s) – number of errors × 10
Interrupted sutures	360 – time (s) – number of errors × 10
Running sutures	600 – time (s) – number of errors × 10

students about their subjective surgical skill level on a 1-5 Likert scale. Furthermore, participants were evaluated weekly with regards to their current anxiety status and their post-trial subjective workload impression using validated questionnaires. The State Anxiety Module of the State-Trait Anxiety Inventory (STAI)<sup>18</sup> was assessed at the beginning of each weekly appointment. It consists of 20 closed statements with 1-4 Likert scales resulting in scores between 20 and 80 points. Higher values indicate greater anxiety. The NASA Task Load Index (NASA-TLX)<sup>19</sup> was administered after each surgical session. It is a multidimensional instrument that consists of six 20-step Likert subscales resulting in overall scores between 0 and 100 points. In particular, we used the short version of the questionnaire ("raw NASA-TLX") without sub-weightings of the scales since this simplified approach has been demonstrated to remain sensitive.<sup>20</sup> The NASA-TLX measures a participant's subjective assessment of the perceived workload. High scores indicate a greater demand or burden with the assigned work.

### Statistics

For all statistical analyses of the data, we used SPSS Version 25.0 (IBM Corp, Armonk, New York). Univariate analysis was performed using the independent t test for continuous and the chi-square test for categorical variables that were compared between the 2 study groups. The generalized linear models in Table 3 were generated using R Version 3.4.4 (The R Foundation for Statistical

Computing, Vienna, Austria). The level of significance was set at 5% or less ( $p < 0.05$ ) for all calculations. The graphs were created with GraphPad Prism 7 (GraphPad Software, La Jolla, California).

## RESULTS

Our 2 groups of medical students were well randomized. Each group had 7 male and 4 female subjects. The average age was  $23.6 \pm 1.9$  years in the stroboscopic and  $24.2 \pm 2.2$  years in the control group ( $p = 0.471$ ). There were also no discrepancies with regards to the year of medical school training ( $p = 0.392$ ). A portion of each cohort had prior surgical rotations (27.3% and 36.4%) so both groups rated themselves fairly low when asked about their basic surgical skills at the beginning of the study ( $1.8 \pm 0.8$  vs.  $2.0 \pm 0.8$ ,  $p = 0.582$ ). These scores improved slightly at the end of the study:  $2.8 \pm 0.7$  vs.  $3.0 \pm 1.0$ ,  $p = 0.576$  (Table 2).

The state module of the STAI questionnaire revealed relatively low scores at all 5 time points of this study indicating a low anxiety. Further, there were no statistical differences in these scores between the 2 study groups (Fig. 6).

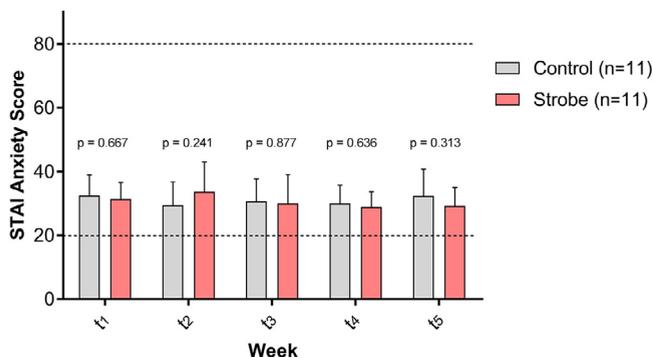
For the first task, knot tying, we saw no discrepancies in surgical performance between the stroboscopic and the control group. Even when the students in the experimental group took off the vision impairing glasses during the fifth week of training, there was no improvement compared to controls ( $t_{5b}$ , Fig. 7, top left). For the second task, simple interrupted suturing, the stroboscopic group appears to have struggled more with corresponding lower scores at all 5 weeks while wearing the glasses. However, at  $t_{5b}$ , their results improved remarkably and the students were significantly superior ( $p = 0.001$ ) compared to the reference group (Fig. 7, top right). An identical trend was observed for the third and

**TABLE 2.** Demographic and Personal Details

Variable	Control Group (N = 11)	Stroboscopic Group (N = 11)	p Value
Gender (%)			1.000
Male	7 (63.6)	7 (63.6)	
Female	4 (36.4)	4 (36.4)	
Age, years (mean ± SD)	$23.6 \pm 1.9$	$24.2 \pm 2.2$	0.471
Year of medical school (%)			0.392
1	6 (54.5)	3 (27.3)	
2	1 (9.1)	3 (27.3)	
3	4 (36.4)	4 (36.4)	
4	0 (0.0)	1 (9.1)	
Prior surgical rotations (%)	3 (27.3)	4 (36.4)	0.647
Subjective surgical skills (study start, mean ± SD)*	$1.8 \pm 0.8$	$2.0 \pm 0.8$	0.582
Subjective surgical skills (study finish, mean ± SD)*	$2.8 \pm 0.7$	$3.0 \pm 1.0$	0.576

SD, standard deviation.

\*On a Likert scale from 1 (very poor) to 5 (very good).



**FIGURE 6.** Results of the STAI questionnaire.

final task, the running stitch. After inferior performance during  $t_1 - t_{5a}$ , the stroboscopic group showed immediately higher scores after removal of the vision-reducing glasses ( $p = 0.024$ , Fig. 7, bottom left). Overall, novice surgical students did suffer significant performance setbacks while wearing the vision impairing glasses. The statistically positive effect appeared only after the glasses are removed and the subjects are allowed to work in their normal visual environment.

At the end of the study ( $t_{5b}$ ), our weekly and post-trial administered NASA-TLX also revealed that the students in the experimental group had a much lower perception ( $p = 0.001$ ) of the surgical workload (Fig. 7, bottom right).

Table 3 further delineates how the NASA values indirectly correlated with the surgical scores of both suturing tasks ( $p = 0.038$  and  $p = 0.025$ ). In other words, the students were retrospectively able to evaluate their own suturing performance fairly accurately. The NASA-TLX did not correlate with the knot-tying scores of the first tasks ( $p = 0.137$ ). Nevertheless, the driving force and most significant factor for improving surgical skill was the increasing experience of each additional session. The variable “week” was highly significant ( $p < 0.01$ ) in all 3 models (Table 3).

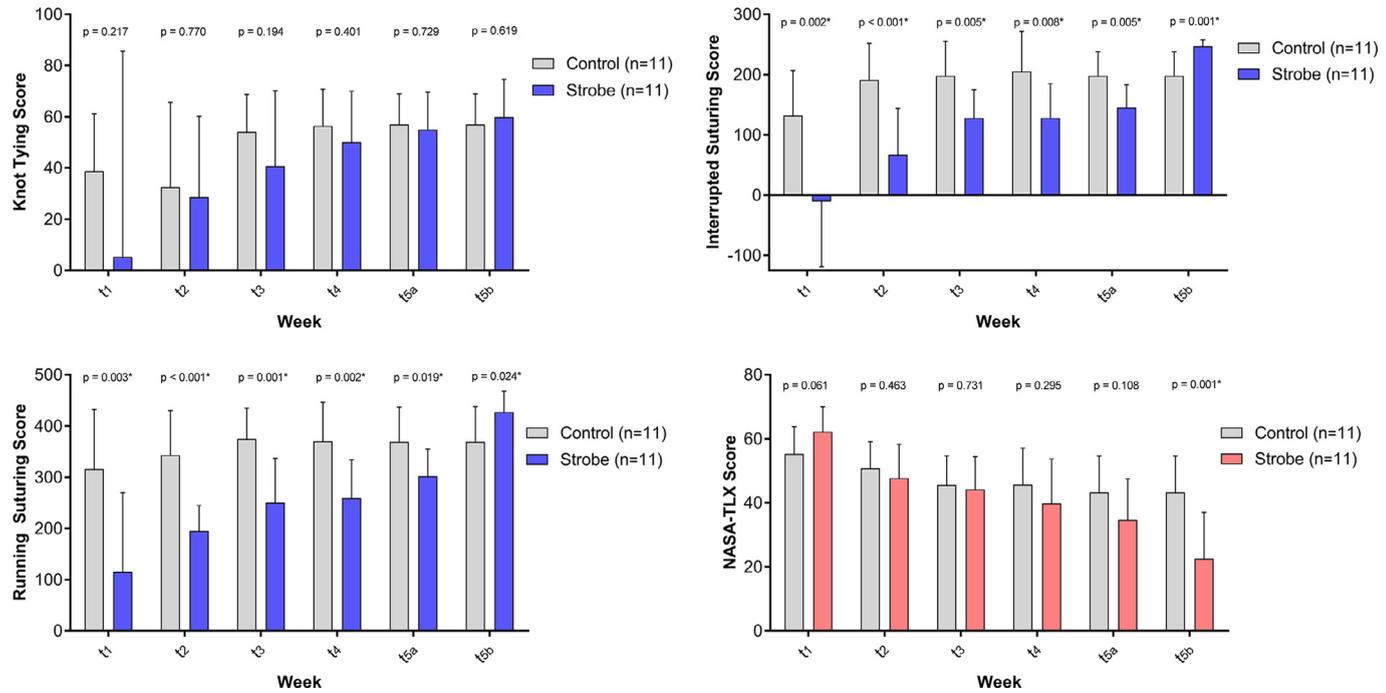
## DISCUSSION

When humans are forced to work in adverse visual conditions, do they deliver superior performance upon return to their normal environment? This theory has previously been tested and confirmed in a variety of experimental settings. For instance, the positive effect of intermittent visual impairment was demonstrated on cognitive function and memory.<sup>9</sup> The same research group also reported on improved visual perception in a controlled study.<sup>8</sup> Smith and Mitroff further published their results of quicker reaction times in participants who trained with stroboscopic glasses similar to ours.<sup>10</sup> These early studies all share the common limitation that the outcome measures were

obtained through subjects who reacted to graphic stimuli in front of 2-dimensional screens. The exact mechanism accelerating the learning curve is still fairly unknown<sup>9</sup>: a likely assumption is that over time, subjects learn to anticipate upcoming movements and preemptively adjust their motor response. Nevertheless, further investigations followed and tested the performance of athletes in a real 3-dimensional environment. Vision-impaired learning had significant improvement on the batting quality of collegiate baseball players<sup>12</sup> and skating skills of ice hockey professionals.<sup>13</sup> We subsequently aimed to implement these study designs of previous articles into the field of surgery.

In order to create 2 uniform cohorts, we exclusively enrolled medical students who reported no prior participation in any suturing or basic surgical courses. The randomization process resulted in an equal distribution of our subjects in terms of demographic and personal details (Table 2). These baseline data were an indicator for similar surgical skill between the two groups at the beginning of the study—a potential bias that had to be imperatively avoided. The anxiety data extracted from the STAI questionnaires (Fig. 6) revealed no significant differences between our 2 study groups throughout the 5 weekly sessions. The questionnaire was administered to control for extraordinary circumstances of our medical students who may be subject to distress with board examinations, busy clinical rotations, and personal commitments. In the past, stress has been linked to poor operative proficiency.<sup>21-23</sup> Our final data were on par with previous publications from the computational and sports-related sciences. After our 5-week regimen, the students in the stroboscopic group had significantly higher surgical scores for both suturing tasks. On the other hand, there was no improvement at all for the knot tying (Fig. 7). This suggests that intermittently impaired vision has positive training enhancement when surgeons are faced with more intricate assignments that require multiple steps to completion (loading needle, stitch, instrument knot, and cut). Anecdotally, select stroboscopic students even reported that knot tying felt easier with closed eyes to avoid distractions from the flickering vision. The post-trial NASA-TLX questionnaire confirmed the calculated surgical scores from the viewpoint of the study participants. There was a statistical correlation between the subjectively assessed operative workload and the objectively measured surgical scores for interrupted and running suturing (Table 3). The 22 medical students were, therefore, able to judge their weekly outcome fairly accurately.

In 2003, the Accreditation Council for Graduate Medical Education installed a strict 80-hour work limit across all fields of residency. This has spurred some concerns within the surgical subspecialties where high quality hands-on practical training and clinical experience are both challenging to maintain.<sup>24</sup> Graduating surgeons not



**FIGURE 7.** Results of surgical tasks # 1, #2, #3, and the NASA-TLX questionnaire.

**TABLE 3.** Generalized Linear Models for the 3 Surgical Scores

Variable	Estimate	Standard Error	t Value	p Value
<i>Task 1: Knot tying ~ week + NASA-TLX</i>				
Week	5.924	1.942	3.051	0.003*
NASA-TLX	-0.351	0.234	-1.496	0.137
<i>Task 2: Interrupted sutures ~ week + NASA-TLX</i>				
Week	24.394	6.308	3.867	<0.001*
NASA-TLX	-1.599	0.761	-2.101	0.038*
<i>Task 3: Running sutures ~ week + NASA-TLX</i>				
Week	20.822	4.675	4.454	<0.001*
NASA-TLX	-1.275	0.564	-2.260	0.025*

\*Significant with  $p < 0.05$ .

only have to exhibit adequate soft skills to interact with patients and colleagues, and possess endless theoretical knowledge, but must also be proficient at dexterous tasks. Many surgical training programs have, therefore, inaugurated inanimate simulation models to train their residents and students outside the operating room.<sup>25-29</sup> Standardized curricula<sup>2-4</sup> subsequently monitor performance and provide immediate feedback. Our study is the first in literature to introduce the stroboscopic glasses to the surgical setting and confirms the positive findings from prior physiological experiments. In our simulation lab, but also in prior stroboscopic studies,<sup>8-13</sup> the flickering eyewear was worn as an inexpensive and simple adjunct tool without causing discomfort or any adverse reactions: no student had to interrupt, postpone, or cancel a session due to the flickering of the glasses. Their training effect, however, was substantial as they improved the surgical skills of our stroboscopic group for both suturing tasks. We are confident that these findings can be additionally enhanced using more complex surgical tasks from the ACS/APDS curriculum.<sup>1</sup> Eyewear that intermittently limits visibility may, therefore, be a useful training method for novice surgeons to accelerate their progress early in their careers.

Despite its randomized-controlled design, this study is not without certain restrictions. Prior articles reported that positive outcomes wear off after prolonged follow-up<sup>10</sup> ("use it or lose it" principle<sup>30</sup>), so surgeons need to repeat the training regimen in regular intervals. Furthermore, our findings originated from fairly unskilled medical students who were novices to the surgical field. The stroboscopic impact may not be as profound in senior residents and fellows, not to mention board-certified surgeons. Upcoming studies should also evaluate the impact of impaired vision training on the more complex surgical procedures, such as laparoscopic tasks or vessel anastomoses. It is unclear if the positive effect would be even greater or if the subjects would instead be overwhelmed and reach a point of fatigue that would void all training effects. This phenomenon is illustrated by the infamous Yerkes Dodson law from 1908.<sup>31</sup>

## CONCLUSION

Our study is the first to introduce the principle of intermittent visual impairment to the surgical field. Using enrolled medical students as novice surgeons, we were able to show an immediate positive learning effect of stroboscopic vision in this randomized-controlled study. After just a 5-week training program, the stroboscopic students had significantly improved scores for both suturing tasks compared to their counterparts in the control group. Periodically restrictive vision can, therefore, be a useful tool in the hands-on education of inexperienced surgical staff. Additional research, particularly with more advanced tasks from the ACS/APDS curriculum, is necessary to confirm our pioneering findings and expand the knowledge on this topic.

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