Expert surgeon’s quiet eye and slowing down: expertise differences in performance and quiet eye duration during identification and dissection of the recurrent laryngeal nerve

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Abstract

BACKGROUND: Long quiet eye (QE) duration is central to expertise in sports, while cognitive “slowing down” has been identified as a perceptual skill possessed by skilled surgeons. Eyetracking evidence is lacking about the relationship of QE duration to slowing down in surgeons. The aim of this study was to examine QE duration, hand movement time (MT), fixation location, and fixation duration in highly experienced (HE) and less experienced (LE) surgeons.

METHODS: A mobile eye tracker and camera recorded coupled gaze and hand movements. Performance was quantified by blinded review.

RESULTS: HE surgeons were rated higher than LE surgeons but did not differ in operating time or MT. HE and LE surgeons differed in fixation duration on the ligament of Berry during phases 1 and 2 and QE duration on the recurrent laryngeal nerve in phase 2.

CONCLUSIONS: Long-duration fixation on the ligament of Berry and long-duration QE on the recurrent laryngeal nerve combined with no significant differences in MT provide empirical evidence that HE surgeons cognitively slow down more than LE surgeons during critical phases of the operation.

Recent changes to medical practice and training have produced challenges to the education of new surgeons.1–3 A greater focus on patient safety and work-hour restrictions limit the educational opportunities of surgical trainees.4,5 Although simulators offer the opportunity for practice outside of the operating room, there is a need to improve the efficiency of training through the study and use of new educational techniques.

There is a paucity of research showing how the cognitive and motor skills of expert surgeons differ from those of novices. However, the cognitive and motor behaviors of elite athletes have been studied extensively. From this, we know that the control of gaze and attention is pivotal for successful execution of motor skills, whether for a simple task or for complex coordinated movements. An important finding from this literature is the quiet eye (QE), which is...
defined as the final fixation or tracking gaze that is located on a specific location or object in the visuomotor workspace within 3° of the visual angle for ≥100 ms.6,7 The onset of the QE occurs before a critical movement, and the offset occurs when the gaze deviates off the location or object by >3° for >100 ms. Long-duration QE has been shown to reliably distinguish experts from nonexperts and successful from unsuccessful motor performance.8–10 The QE is thought to represent the time needed to organize the neural networks underlying the precise control of movements.11,12

We adopted Moulton et al.’s13 framework of “slowing down” as the theoretical basis of this research. Moulton et al found that expert surgeons transitioned between modes of automatic control and effortful modes in which the surgeons were situationally responsive to difficult or unexpected events. In the latter mode, slowing down represented the surgeon’s “cognitive re-focusing and increased attention directed toward a particular task.”14 Moulton et al14 stressed that slowing down is a cognitive process and does not “describe the speed of the surgeon’s hand movements.”

Our goal in this study was to empirically determine if slowing down was due to greater cognitive slowing, as would be indicated by longer fixation durations on critical locations, or greater motor slowing, which would be characterized by longer hand movement times. We chose to examine this in a thyroidectomy model because it represents a complex operative skill with limited training opportunities, thus leading to the potential for significant complications.15 Critical to this operation is the successful identification and preservation of the recurrent laryngeal nerve (RLN), a delicate structure, damage to which may lead to significant postoperative morbidity. For this reason, the standard approach to preservation of the RLN occurs in 3 phases: phase 1, identifying the inferior thyroid artery (ITA); phase 2, identifying the RLN; and phase 3, dividing the ligament of Berry (LoBF).16

We hypothesized that effortful moments of slowing down would be characterized by fixations of longer duration on critical structures and/or anchor locations. Anchor locations are areas that enable perceptual awareness not only of the object or location being fixated but relevant locations in the nearby vicinity. We expected highly experienced (HE) surgeons to slow down cognitively more than less experienced (LE) surgeons through the use of a long-duration QE on the RLN. For the purposes of our study, the QE was defined as the final fixation on the RLN before blunt and sharp dissections, movements with the greatest potential of harming the patient.

Methods

Three HE and 7 LE surgeons volunteered. Ethical approval was obtained through the University of Calgary Conjoint Health Ethics Research Board. The HE surgeons were subspecialists who self-reported that they had completed >200 thyroidectomies. The LE surgeons were 4th-year and 5th-year residents and/or general surgeons who self-reported <200 procedures. Although the exact length of the learning curve for thyroidectomy has not been exactly elucidated, it has been shown that surgeons with higher volume experience with thyroidectomy have decreased complications.17 More recent studies of experienced thyroid surgeons’ adopting new operative approaches (endoscopic or robotic) in thyroidectomy have shown the learning curve to be 50 cases.18,19 If the learning curve in surgeons already considered “expert” in the basic procedure is this long, it is likely that the learning curve for a novice in thyroid surgery would be significantly longer. For this reason, we set the standard for HE surgeons very high at >200 and for LE surgeons lower than this.

Protocol

Each surgeon performed a thyroid lobectomy on a cadaver model, randomly assigned to the right or left side. The cadavers were prepared with the skin incision made, subplatysmal flaps raised, and strap muscles dissected off the thyroid. The same surgical instruments were made available to all the surgeons. After eye tracker fitting and calibration were complete, surgeons were read standard instructions to identify and dissect the RLN to its insertion at the level of the cricothyroid muscle with the same care that would be taken during an operation on a live patient. An assistant was provided for retraction at the direction of the surgeon.

Equipment

Gaze data were collected using the Mobile Eye tracker (Applied Sciences Laboratory, Bedford, MA) coupled to an external camera that videotaped the surgeon’s hand movements. The Mobile Eye is a light (76 g), glasses-mounted, monocular corneal reflection system that measures point of gaze with an accuracy of 1.0° of visual angle, precision of .05°, and a frequency of 30 Hz (33.3 ms/frame). We coupled the duration of the surgeon’s hand movements with their fixation and QE durations to specific surgical locations during the 3 phases (Fig. 1). Gaze and motor data were monitored continuously throughout the operation and synchronized later in the laboratory using Final Cut Pro (Apple Corporation, Cupertino, CA).

Data management and coding

Table 1 presents the number of thyroidectomies per surgeon, total operating time, total duration of the 3 phases, and the duration of each phase. Operative performance was quantified by independent, blinded review of the video data by an expert surgeon using the University of Toronto Global Rating Scale of Operative Performance. The phases
were coded frame by frame using Quiet Eye Solutions software. This program coupled the phases of the operation, types of hand movements, and fixation locations and automatically computed QE duration. A fixation was defined when the surgeon’s gaze dwelled on a location for 100 ms within 1° of visual angle. Coding was carried out by 2 independent coders, and intraclass correlations were determined for phase, fixation location, fixation duration, and QE duration. $R$ values ranged from .90 to .94.

**Statistical analysis**

Operative performance (global rating scores) was analyzed using both parametric (analysis of variance [ANOVA]) and nonparametric (Mann-Whitney $U$ test) procedures. Movement times were analyzed by phase, using factorial ANOVA of expertise $\times$ type of movement. QE duration on the RLN was analyzed by expertise and phase using factorial ANOVA. Greenhouse-Geisser epsilon was used to control for violations of sphericity in the repeated-measures designs, and adjusted $P$ values are reported as necessary. The significance level was set at $P < .05$.

**Results**

**External blinded review of performance**

Median scores were analyzed using the Mann-Whitney $U$ test (phases combined and each phase separately). HE and LE surgeons differed on respect for tissue, $U (n = 30) = 189, P < .0001$ (HE surgeons’ mean rank, 26.0; LE surgeons’ mean rank, 11.0); time/motion, $U (n = 30) = 189, P < .004$ (HE surgeons’ mean rank, 22.5; LE surgeons’ mean rank, 12.5); instrument handling, $U (n = 30) = 189, P < .004$ (HE surgeons’ mean rank, 22.5; LE surgeons’ mean rank, 12.5); knowledge of instruments, $U (n = 30) = 189, P < .0001$ (HE surgeons’ mean rank, 26.0; LE surgeons’ mean rank, 11.0); flow of operation, $U (n = 30) = 189, P < .03$ (HE surgeons’ mean rank, 17.8; LE surgeons’ mean rank, 14.5); use of assistant, $U (n = 30) = 189, P < .0001$ (HE surgeons’ mean rank,

**Table 1** Characteristics of HE and LE surgeons: number of thyroidectomies performed, total operating time, trial duration (sum of phases), and phase durations

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Expertise</th>
<th>Number of thyroidectomies</th>
<th>Total operating time (min)</th>
<th>Total phase duration (min)</th>
<th>Phases of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phase 1 (min)</td>
</tr>
<tr>
<td>S1</td>
<td>HE</td>
<td>300</td>
<td>27.6</td>
<td>8.7 (31.7%)</td>
<td>2.1 (23.4%)</td>
</tr>
<tr>
<td>S2</td>
<td>LE</td>
<td>55</td>
<td>28.4</td>
<td>6.4 (22.6%)</td>
<td>1.9 (28.8%)</td>
</tr>
<tr>
<td>S3</td>
<td>HE</td>
<td>2875</td>
<td>18.6</td>
<td>5.5 (27.1%)</td>
<td>1.9 (37.6%)</td>
</tr>
<tr>
<td>S4</td>
<td>LE</td>
<td>40</td>
<td>27.1</td>
<td>11.7 (41.8%)</td>
<td>3.7 (29.6%)</td>
</tr>
<tr>
<td>S5</td>
<td>LE</td>
<td>38</td>
<td>41.4</td>
<td>12.9 (31.2%)</td>
<td>3.5 (27.1%)</td>
</tr>
<tr>
<td>S6</td>
<td>LE</td>
<td>25</td>
<td>35.1</td>
<td>10.1 (28.6%)</td>
<td>2.9 (28.4%)</td>
</tr>
<tr>
<td>S7</td>
<td>HE</td>
<td>4,000</td>
<td>26.2</td>
<td>5.0 (19.2%)</td>
<td>.9 (19.0%)</td>
</tr>
<tr>
<td>S8</td>
<td>LE</td>
<td>30</td>
<td>21.2</td>
<td>6.2 (29.6%)</td>
<td>1.0 (15.9%)</td>
</tr>
<tr>
<td>S9</td>
<td>LE</td>
<td>20</td>
<td>57.1</td>
<td>16.1 (28.2%)</td>
<td>6.3 (38.9%)</td>
</tr>
<tr>
<td>S10</td>
<td>LE</td>
<td>30</td>
<td>32.4</td>
<td>12.5* (38.5%)</td>
<td>.6* (25.2%)</td>
</tr>
<tr>
<td>Mean</td>
<td>HE</td>
<td>2,391.7</td>
<td>24.1</td>
<td>6.4 (26.0%)</td>
<td>1.6 (26.7%)</td>
</tr>
<tr>
<td>Mean</td>
<td>LE</td>
<td>34.0</td>
<td>34.7</td>
<td>10.8 (31.5%)</td>
<td>3.2 (27.7%)</td>
</tr>
</tbody>
</table>

*HE = highly experienced; LE = less experienced.

*Actual sum of phases.

†Total coupled data because of eye tracker malfunction.
26.0; LE surgeons’ mean rank, 11.0); knowledge of special procedures, $U(n = 30) = 189, P < .004$ (HE surgeons’ mean rank, 22.5; LE surgeons’ mean rank, 12.5); overall performance, $U(n = 30) = 189, P < .004$ (HE surgeons’ mean rank, 26.0; LE surgeons’ mean rank, 11.0); and quality of the final product, $U(n = 30) = 189, P < .004$ (HE surgeons’ mean rank, 22.5; LE surgeons’ mean rank, 12.5). In phase 1, HE surgeons scored higher on all 9 items, while in phase 2, HE and LE surgeons differed on 8 of 9 items (the exception was flow of operation). In phase 3, HE surgeons were rated significantly higher on 4 items: respect for tissue, knowledge of instruments, use of assistant, and overall performance. No differences were found for time/motion, instrument handling, flow of operation, knowledge of specific procedures, and quality of the final product.

To determine if changes occurred in any of items across the phases, an expertise (HE, LE) × phase ANOVA with repeated measures across the 9 items was followed by univariate follow-up of each subitem. Significant differences were found due to expertise, $F(1, 712) = 3.31, P < .04$ (HE surgeons’ mean, 3.86 ± .05; LE surgeons’ mean, 2.85 ± .03). HE and LE surgeons differed on “respect of tissue,” $F(1, 89) = 25.53, P < .0001$; by phase, $F(2, 89) = 3.05, P < .05$; and the interaction of expertise by phase, $F(2, 89) = 3.40, P < .04$. Fig. 2 shows that LE surgeons scored significantly lower than HE surgeons during phase 2, $F(1) = 18.74, P < .0001$, and phase 3, $F(1) = 4.31, P < .0001$.

**Total operating time**

HE surgeons completed the operation in fewer minutes than LE surgeons, but the difference was not significant. HE surgeons averaged 24.1 ± 28 minutes and LE surgeons 34.7 ± 4.4 minutes (Table 1).

**Hand movement time**

Movement time differed by type of movement (blunt dissections, sharp dissections, palpate, pause, retract, change instrument) but not by expertise or phase. No significant differences were found for the interaction of expertise and type of movement during phase 1, $F(5, 31) = .48, P < .79$; phase 2, $F(5, 29) = .30, P < .30$; phase 3, $F(5, 32) = 1.18, P < .34$; or overall, $F(5, 115) = .74, P < .59$ (Fig. 3).

**Fixation duration**

Fifteen locations were fixated in total, but only 6 (hands, ITA, LoFb, RLN, thyroid, and tissue) had sufficient data (>5%) to be analyzed, accounting for 90% of the total (Fig. 4). During phase 1, differences in fixation duration were found due to location, $F(5, 40) = 6.92, P < .0001$, and the interaction of expertise by location, $F(5, 40) = 4.09, P < .004$. HE surgeons’ fixations were longer on the LoFb (HE surgeons, 24.3% and 24.7 seconds; LE surgeons, 3.7% and 3.78 seconds), $F(1) = 6.09, P < .02$, and LE surgeons’ fixations were longer on tissue (HE surgeons, 16.1% and 14.2 seconds; LE surgeons, 49.7% and 80.1 seconds), $F(1) = 16.1, P < .0002$. During phase 2, differences were found for location, $F(5, 40) = 5.29, P < .0008$, and the interaction of expertise by location, $F(5, 40) = 4.99, P < .001$. HE surgeons spent a higher percentage of phase time on the LoFb (HE surgeons, 39.8%; LE surgeons, 11.0%), $F(1) = 12.75, P < .0008$, but did not
differ in absolute time (HE surgeons, 26.23 seconds; LE surgeons, 27.33 seconds). HE surgeons’ fixations were longer on the RLN (HE surgeons, 25.2% and 13.9 seconds; LE surgeons, 4.5% and 7.8 seconds), while the LE surgeons continued to fixate tissue (HE surgeons, 18.4% and 8.5 seconds; LE surgeons, 38.7% and 66.8 seconds), $F(1) = 5.62, P = .01$, $F(1) = 8.39, P < .006$.

**Quiet eye duration**

No QE results are presented for phase 1 because the RLN was not yet visible. QE duration in phases 2 and 3 differed due to expertise, $F(1, 136) = 18.70, P < .0001$; phase, $F(1, 136) = 3.92, P < .05$; and the interaction of expertise by phase, $F(1, 136) = 4.59, P < .03$. HE surgeons’ QE duration was $1,647.64 \pm 245$ ms and LE surgeons’ QE duration was $872.12 \pm 91.47$ ms. In phase 2, HE surgeons’ QE averaged $2,406.70 \pm 559.15$ ms, and LE surgeons’ QE duration averaged $844.07 \pm 227.58$ ms, $F(1) = 12.82, P < .0001$. No differences were found in phase 3 (Fig. 5).

**Comments**

External blinded review of LE surgeons’ surgical performance was significantly lower on all 9 global rating scores, in particular during phases 2 and 3 for “respect of tissue.” When fixation duration was analyzed by location, HE and LE surgeons differed in all 3 phases. During phase 1, the HE surgeons had longer fixations on the LoF, suggesting that they used it as a perceptual anchor with which to determine the location of the RLN relative to the ITA, even when the nerve was not yet visible. A possible reason is that the LoF is a relatively stable location, unlike the ITA and RLN, which vary greatly by patient. 16,20 The LE surgeons did not use the LoF as an anchor; instead, they spent more than half of phase time fixating on unidentified, irrelevant tissue, with no discernible pattern to their attention. This attention characteristic persisted through to phase 2, in which the LE surgeons continued to devote most of their time to randomly examining tissue. Meanwhile, the HE surgeons fixated the LoF and successfully located the RLN, which they fixated an average of 25.2% (13.9 seconds) of phase time compared with 4.4% (7.8 seconds) for the LE surgeons. It was also during phase 2 that the greatest difference in QE duration on the RLN was found, with the HE surgeons averaging 2.5 seconds per blunt and sharp dissection compared with <1 second for the LE surgeons.

In phase 3, HE and LE surgeons were similar in fixation duration to all locations except tissue, which continued to attract longer duration fixations among LE surgeons. The main location fixated by both HE and LE surgeons was the LoF, which was fixated in >55% (117 seconds) of phase time. This pattern appears appropriate to successful and safe completion of the operation, as risk to the RLN is greatest during phase 3. 4 With time, all the LE surgeons, except 1, completed the operation successfully.
Although the groups differed in fixation and QE durations relative to specific locations during the phases of the operation, HE and LE surgeons did not differ in total operating time or movement time by phase or type of hand movement. This is indicated in the fact that the LE surgeons were able to complete the operation in similar time as the HE surgeons. These results therefore provide empirical support for Moulton et al’s finding that “slowing down” represents the surgeon’s cognitive refocusing or increased attention directed toward a particular task and describes the surgeon’s experience during the critical moments of surgery. The term is not meant to describe the speed of the surgeon’s hand movements, nor does it imply that the surgeon in any way slows down temporally, although both may occur. The LE surgeons were competent surgeons, but when required to dissect and isolate the RLN, their lack of experience with this particular procedure led to their fixation locations and durations being significantly different from those of the HE surgeons.

It is difficult to study a large number of elite performers at 1 center, but given the limitation of a small cohort, the results suggest that during the early phases of the operation, the HE surgeons mentally visualized the entire operation. This task required knowledge of all the steps and a 3-dimensional representation of the operation composed of a high percentage of fixations on the LofB and near equal durations on the ITA and RLN (see Fig. 4). In contrast, the LE surgeons did not use the LofB as an anchor but instead spent most of their time (>60%) on irrelevant, undefined tissue. Clearly, the LE surgeons had difficulty discerning the relationship among the LofB, ITA, and RLN, an attention deficit that persisted until the final phase of the operation, when the LE surgeons seemed to catch up perceptually. The shorter QE duration of the LE surgeons may mean they had not yet established a concentrated focus on the RLN, nor did they fixate the operative site in a way that showed that they had cognitive command of the operation. It may be for this reason that the external evaluator assessed the LE surgeons significantly lower in terms of respect of tissue. The results further suggest that the problems encountered by the LE surgeons in the early phases were largely perceptual, thus agreeing with previous studies showing that errors leading to poor performance or injury are due more to errors in focus of attention, rather than deficits in the surgeons physical skills.

**Future directions: quiet eye training in surgery**

The goal of QE training is to help novices acquire the QE characteristics and “slowing down” cognitive abilities of experts sooner in their careers. QE training programs have been shown to have dramatic improvements in performance in a number of motor tasks. Furthermore, QE training has been shown to reduce anxiety and enhance performance under high levels of pressure, conditions common in surgery. QE programs are typically carried out in 5 steps. First, expertise research similar to the present study is carried out to determine the 5 QE characteristics of expert surgeons (location, onset, offset, duration, and critical movement). Second, the resident is tested with a mobile eye tracker and coupled motor camera as he or she performs a similar operation. Third, residents are taught how to focus on critical locations using video modeling (see Fig. 1, Supplemental Video) thus allowing the trainee to witness the operation performed through the eyes of an expert surgeon. Fourth, the trainee receives feedback on his or her QE focus compared with the expert. During this process, questions are asked that probe what the resident understands about attention characteristics relative to anatomic landmarks and critical movements in the operation. Finally, the trainee is allowed to repeat the operation and compare his or her performance with that of the expert independently and repeat as necessary.

**Conclusions**

We believe that QE training may help residents acquire the focus of attention of expert surgeons earlier in their training, leading to improved visual attention and decision making and a reduction in errors. QE training may be a powerful new training technique to help residents acquire the QE characteristics and “slowing down” cognitive abilities of expert surgeons, thereby reducing the negative effects of stress on surgical performance.

**Appendix A. Supplementary data**

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.amjsurg.2013.07.033.

**References**


