Original report

Performing Under Pressure: Quiet Eye Training Improves Surgical Knot-tying Performance

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RUNNING HEAD: KNOT TYING TRAINING

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Abstract

Background: We examined the effectiveness of traditional technical training (TT) and quiet eye training (QET) on the performance of one-handed square knot tying in first-year surgery residents under normal and high anxiety conditions. **Methods**: Twenty surgery residents were assigned randomly to the two groups and completed pretest, training, and simple and complex retention tests under conditions of high and low anxiety. The TT group received traditional instruction on improving hand movements; the QET group received feedback on their gaze behaviors. Participants wore an eye tracker that recorded simultaneously their gaze and hand movements. Dependent variables were: knot tying performance (%), quiet eye duration (%), number of fixations, and total movement time (s). **Results:** Both groups improved their knot tying performance (p < 0.05) from pretest to the low anxiety conditions (mean difference: QET = 28%; TT = 17%), however, only the QET group maintained their knot tying performance in the high anxiety conditions (mean difference: QET = 18%; p < 0.05) with the TT group decreasing their performance close to pretest levels (p > 0.05). The QET group also demonstrated more efficient gaze and hand movements post training. **Conclusions:** These data demonstrate the effectiveness of training gaze behaviors, not only to improve the effectiveness and efficiency of performance, but also to mediate any negative effects of anxiety on performance. These findings may have important implications for medical educators and practitioners, as well as surgeons who may be (re)training or learning new procedures.

Key Words: Gaze, attention, expertise, training, surgery, knots, anxiety, hand movements

Surgery is a highly complex, dynamic and unpredictable environment, with critical decisions and actions being implemented under high levels of anxiety. Despite this, relatively little is known about how simple surgical tasks, such as knot tying, can be affected by increases in anxiety. In other domains with instances of high anxiety, such as law enforcement and sport, anxiety has been shown to decrease cognitive performance and impact negatively on the actions of individuals (1). Specifically, increases in anxiety can affect the efficiency and effectiveness of attention allocation, which leads to individuals not picking up critical information from the environment (2). Attention can be measured indirectly by analyzing gaze behaviors, such as where an individual looks (fixations) and for how long (3). Furthermore, gaze behaviors can be trained in order to overcome the potential negative effects of anxiety (4). The aim of the current study was to examine whether training gaze behaviors in a knot tying task would be more effective than traditional technical training methods for first-year surgery residents.

There are a variety of gaze metrics that can be used as a measure of attention, however, the quiet eye period (QE) has been demonstrated to be a reliable characteristic of both expertise and success. QE is the final fixation on a specific location before the initiation of a critical movement (5, 6). Longer QE periods have been associated with expert performance in sport (7), law enforcement (8), the military (9), and medicine (10). The QE is thought to represent the time required to organize the neural networks controlling the action (3). This assertion is supported by the observation that QE duration increases with task difficulty, as more complex actions usually require increased information processing (11). Although researchers have reported that QE can be affected negatively by anxiety (4), there is evidence that maintaining a longer QE in stressful situations can mediate the negative effects of anxiety and enable the individual to maintain performance levels (4). Results from these training studies have shown that as a consequence of the longer QE, actions can also become more organized leading to a more efficient movement pattern.

QE research in medicine has demonstrated less experienced surgeons tend to move their vision between the target location and their hand or tool (10). Furthermore, expert surgeons tend to fixate the target location for longer than novice or less experienced surgeons (12, 13). This longer QE enhances cognitive “slowing down”, which Moulton and colleagues found to be characteristic of expert surgeons (7, 22). The expert surgeon cognitively re-focuses and brings an increased level of attention to bear during critical times during an operation.

Despite previous studies analyzing gaze and movement behavior in surgical skills (10, 14-16), there is a paucity of literature on how these skills are performed under high-anxiety situations (17). Furthermore, studies to investigate the effectiveness of QE training programs to decrease potentially negative effects of anxiety on surgical skill performance are lacking (18). The two training studies to date using QE in surgical skills training have used novice (19) participants or surgery trainees (20) in low anxiety conditions. Given that surgeons routinely perform complex procedures in highly stressful, unpredictable environments, understanding how anxiety can affect surgical performance and how we can decrease any negative effects of anxiety is critical (21).

The aim of the study is to examine whether a program of either QE training (QET) or traditional technical training (TT) would increase knot tying performance in one-handed square knots in first-year surgery residents under high and low anxiety scenarios. Simple and complex conditions were also included to determine whether there were differences between groups in conditions with demands for high information processing. Gaze and movement data were recorded during all conditions. We predicted that both training groups would increase their knot tying performance after the training, but we hypothesized that the QET group would demonstrate more efficient gaze behaviors post-training, as evidenced by longer QE and fewer fixations. These improvements were expected to be maintained for the

QET group in the high anxiety condition, with a decrement in these metrics predicted for the TT group.

Methods

Participants

Twenty first-year surgery residents (age: 26, range 25-29 years) were recruited for the study. All participants had received basic knot tying training previously as part of their surgical skills module. Participants were randomly assigned equally to either a QET or TT group. All had normal or corrected to normal vision. Participants volunteered for the study, and ethics approval was obtained through the local Conjoint Health Ethics Research Board.

Equipment

A SensoMotoric Instruments (SMI) ETG eye-tracking system (Boston, MA) was used to collect gaze and hand movement data. The SMI-ETG is a lightweight (76 g), glasses mounted binocular system that uses dark pupil tracking to measure point of gaze with a spatial resolution of 0.1 degree and temporal resolution of 30 Hz (33.3ms per frame), with a built-in high-definition scene camera. A Simulab Boss knot tying board (Seattle, WA) was used for the pretest and retention, with blue markers indicating the location of desired knot placement on the parallel tubing at a separation width of 4 cm. An Ethicon knot tying board (Somerville, NJ) was used for the transfer, with a red marker indicating the location of desired knot placement at the center of the hook, which was surrounded by a cylinder (see Figure 1). Both boards were covered with surgical drapes. Ethicon 2-0 Perma-hand silk sutures were used throughout the testing session. A Polar RX300 heart rate monitor (Lake Success, NY) was used to assess changes in heart rate variability between anxiety conditions

Procedure

All participants completed a pretest and a training phase followed by simple and complex retention tests under conditions of high and low anxiety. In all conditions, participants were required to tie one-handed square knots with three throws. Before the testing session, participants were fitted with the SMI-ETG system and calibrated. The experimental procedure is outlined in Table 1. In the pretest, participants were required to tie three separate knots at the knot placement location on the tubing. Participants then completed a 5-step training program. Step 1: participants in both groups viewed an Ethicon training video on the one-handed square knot, which emphasized the correct movements of the hands and suture. Step 2: participants in the TT group were provided with additional technical instructions taken from the Ethicon knot-tying manual, whereas the QET group was provided with QE instruction, which emphasized a long QE duration on the placement location prior to each throw (13). Step 3: participants in the QET group viewed a video of an expert surgeon using a long QE duration on the placement location, and were encouraged to adopt this this behavior, while the TT group viewed the same video with the gaze cursor removed, thus only the hand and suture movements were visible. Step 4: participants viewed an individual video recorded during the pretest and comparisons were made to the expert model; the TT group viewed their hand movements and further feedback on hand movements was provided; in contrast the QET group viewed a video showing where they were looking during the task, with additional instruction to adopt a long QE duration on the placement location. Step 5: participants completed three more practice knots. Steps 2-5 took approximately 5 minutes each and were repeated subsequently twice, with participant videos updated in each phase.

Post-training participants were required to tie three knots in simple (same as pretest; Figure 1a) and complex (the hook inside the cylinder; Figure 1b) retention tests under conditions of low and high anxiety. These took place 10 minutes after the training. In the low anxiety condition, participants were told that the trials were for calibration purposes and would not be compared to other participants. In the high anxiety condition, several ego stressors were used to manipulate anxiety, which have been validated in previous research (4, 22). Being videotaped for assessment purposes increases anxiety and decreases performance (4). A video camera was positioned directly in front of the participants, and they were informed that their course instructors would assess the knots. Participants were told that a ranking system between their peers would be created based on their knot tying performance, and they were given non-contingent feedback that their current performance was in the bottom 25% (23). Data collection took approximately 60 min.

Data management

For each participant, the second knot from each condition was analyzed, creating a total of 100 knots. Each knot consisted of three throws and three movement phases (cross, pass, placement). The data were coded using the Quiet Eye Solutions software (Calgary, CA), which couples automatically the gaze and hand movements and determines total fixations, QE duration, and movement time. The dependent variables were: knot tying performance (%), heart rate variability (ms), percentage QE duration (%), number of fixations, and total movement time (s). Total movement time was defined as the start of the first cross phase until the end of the final placement phase. QE duration was converted to relative time based on percentage of total movement time. A fixation was defined as a stable gaze within 1 degree of visual angle for a minimum of 100 ms. The QE was defined as final fixation on the knot placement location prior to each placement phase. Two independent coders carried out coding, with the objectivity of the data being established using intra-observer (99.0%) and inter-observer (98.1%) agreement methods. Knot tying performance was assessed by an expert surgeon using the Tytherleigh instrument (24), which allows a maximum score of 13 per knot, which was converted to a percentage score.

Statistical analysis

Knot tying performance, QE duration, number of fixations, and total movement time were analyzed using separate 2 x 5 mixed design ANOVAs, with group (QET, TT) as the between-subjects factor and condition (pretest, simple low anxiety, simple high anxiety, complex low anxiety, complex high anxiety) as the within-groups factor. Heart rate variability was analyzed using a 2 x 2 mixed design ANOVA, with group (QET, TT) as the between-subject factor and anxiety (low anxiety, high anxiety) as the within-subjects factor. Effect sizes were calculated using partial eta squared values (η_p^2). The alpha level for significance was set at 0.05 with Bonferroni adjustment to control for Type 1 errors. Data presented in parentheses are mean values and standard error of the mean.

Results

Group and condition main effects for all ANOVAs are reported in Tables 2 and 3, respectively.

Knot tying performance (%)

The ANOVA revealed a group by condition interaction ($F_{4,72}$, = 2.78, p = 0.03, η_P^2 = 0.13; see Figure 2). As predicted, both the QET and TT groups significantly increased their knot tying performance from pretest to the low anxiety conditions ($p <$ 0.05). While the QET group maintained performance in the high anxiety conditions, the TT group performance decreased to pretest levels. These results suggest that the QET group had developed a strategy that enabled them to maintain performance, even under high anxiety conditions, whereas the performance if the TT group deteriorated.

Heart rate variability (ms)

The beat-to-beat fluctuation of the heart rhythm decreases under conditions that require increased mental effort and/or during anxiety inducing situations due to changes in the baroreflex blood pressure control subsystem (25). In the current study, we measured heart rate variability to ensure that our anxiety manipulation was effective. A lesser heart rate variability is indicative of an increase in anxiety. As predicted, participants had less heart rate variability in the high anxiety condition (748 $\pm$ 26 ms) compared to the low anxiety condition (818 $\pm$ 29 ms) ($F_{1,18}$, = 36.25, $p <$

0.001, $\eta_P^2 = 0.67$). As expected, there were no between-group differences ($p > 0.05$). These data provide evidence that the anxiety manipulation was successful.

Quiet eye duration (%)

The ANOVA showed a group by condition interaction ($F_{4,72}$, = 5.91, $p < 0.001$, $\eta_P^2 = 0.25$; see Figure 3). The QET group increased their QE duration significantly from pretest (9 $\pm$ 3 %) to the low anxiety conditions ($p < 0.05$), and maintained a significant improvement in the high anxiety conditions ($p < 0.05$). In contrast, the TT group reduced their QE duration from pretest to the two complex conditions ($p <$ 0.05), with no significant differences between pretest and either of the simple conditions ($p > 0.05$). These data demonstrate that the gaze behavior of the TT became less efficient in the complex conditions, whereas, the data suggest that the strategy of the QET group was more robust, even under high anxiety and increased complexity.

Number of fixations

The QET group decreased the number of fixations from pretest to all post-training conditions ($p < 0.05$; see Figure 4). The ANOVA revealed a group by condition interaction ($F_{4,72}$, = 8.13, $p < 0.001$, $\eta_P^2 = 0.31$). The TT group demonstrated no significant difference in number of fixations between the pretest and simple low anxiety condition ($p > 0.05$), however, there was an increase in number of fixations from the pretest to both high anxiety and complex conditions ($p < 0.05$). The TT group increased fixations as the complexity and anxiety increased, which is indicative of a less efficient strategy susceptible to distractions. In contrast, the QET group maintained a more efficient strategy post training, which appeared to enable them to cope with the increased processing demands in the complex condition.

Total movement time (s)

Participants in the QET group reported a faster total movement time compared to the TT group ($p < 0.05$; see Figure 5). Total movement time was significantly slower in the complex high anxiety condition compared to pretest and all other post-training conditions ($p < 0.05$). These data indicate that the QET led indirectly to a faster movement time compared to the TT group. Increases in total movement times are expected in more complex conditions due to increased programming demands. There was no group by condition interaction.

Discussion

The aim of the study was to examine whether a QET or TT program would lead to increased performance in knot tying in one-handed square knots in first-year surgery residents under conditions of high and low anxiety, as well as simple and complex conditions. We hypothesized that the QET and TT groups would increase their knot tying performance from pretest to all post-training conditions. The QET group would demonstrate more efficient gaze behaviors post training, as indexed by longer QE durations and fewer fixations. These improvements were expected to be maintained in the QET group in the high anxiety conditions, with a decrement in these metrics predicted for the TT group.

Knot tying performance significantly increased from pretest to both low anxiety conditions. Although the QET group improved their performance significantly more than the TT group, these data demonstrate that both QET and TT techniques are effective methods of training knot tying. These findings support literature from other domains that have indicated the effectiveness of training QE and the association between longer QE and successful performance (3, 20, 26-28). When training QE, it is important to develop similar cognitive processes and knowledge structures exhibited by experts (18); this ensures that critical information defined by experts is used to make decisions and execute actions, leading to a more efficient and effective strategy to improve skills. This strategy of attending to the salient information at critical times, and cognitively “slowing down” (29) during these critical phases is enhanced in the QE condition enabling improvements in knot tying performance, but also could lead to more precise knot placement and potentially less rates of error. This is imperative because incorrectly placed sutures may result in a knot slippage, unintentional shear force or undue ischemia of tissue, which can lead to knot failure and postoperative hemorrhage (30, 31).

Previous research has highlighted the paucity of research into the effect of anxiety on surgical skills, and also the lack of formal training to overcome these effects (17). Despite both groups improving their knot tying performance from pretest to the low anxiety conditions, only the QET group maintained their knot tying performance under conditions of high anxiety; performance of the TT group significantly decreased close to pretest levels. These data suggest that the mechanisms developed in the QET intervention enabled participants to decrease the negative effects of anxiety through maintenance of their QE focus on the knot placement location, rather than on the mechanics of knot tying and hand motion, which constituted the instruction for the TT. Directing gaze to critical target locations during a movement may be beneficial in several ways. Firstly, it may provide a single relevant point of focus around which movements and actions can be orientated. Secondly, it may enable the participants to control their emotional state, through the use of a long duration QE focus that is continually relevant to the task. Thirdly, it may limit the amount of erroneous information processed from the environment, allowing the participant to attend selectively to the information critical to successful performance; this training also enables the participant to use coping strategies to overcome the stressful environment. During an operation, this increased QE may not only increase performance on the primary task, but also free up processing resources to deal with other information sources, or for communication between the surgical team.

As we would expect, those participants in the QET group demonstrated more efficient visual strategies as evidenced by significantly longer QE durations and fewer fixations compared to the TT group. When the eyes move from one fixation location to another using rapid eye movements called saccades, visual information is suppressed. Therefore, a greater number of short duration fixations will decrease the amount of information processed. Fixating more areas is a characteristic of novice eye movements. Usually, novices do not know where the relevant cues are in a task environment, and therefore use a greater number of fixations to scan the whole environment (32). This strategy deceases the amount of information they are accruing from the critical areas of the task, which leads to poorer execution. In the current study, the QET group used fewer fixations of longer duration, to the final placement location of the knot, which appears to ensure placement accuracy and appropriate tension of the knot. These results were exaggerated in the complex condition under high anxiety, when the demands of attention were increased. These findings support the slowing down (29) and other literature demonstrating that engaging in more systematic strategies of cognitive focus can enable performers to overcome the demands of anxiety-provoking scenarios (4).

Our study highlights the importance of understanding how technical skills are acquired, and how even simple skills can break down under high anxiety situations. During an operation, when slight misjudgments or poor decision making can have catastrophic consequences, and thus, the importance of allocating attention to critical cues and salient information at the relevant time points is essential. Out study provides evidence that with the correct training, surgeons can overcome the limits of attentional capacity, by employing strategies that highlight and refocus attention during critical tasks.

Our study has several limitations. There was a relatively small sample size used in the current study; future studies should look to identify differences in training effectiveness with a larger sample, of different skill levels. Although we included a transfer condition (complex condition) in this study, a more representative transfer should examine tying knots or tracking knot tying performance in a live operation. Also, longitudinal studies of resident education examining how these training interventions impact on learning are required.

In summary, these data demonstrate the effectiveness of training gaze behaviors, not only to improve the effectiveness and efficiency of performance, but also to mediate any negative effects of anxiety on performance. These findings have important implications for medical educators and practitioners, as well as surgeons who may be (re)training or learning new procedures. The emergence of advanced technologies in medical simulation provide an opportunity to acquire different strategies to procure and measure technical skills, without the risk to patient safety (21).

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Figure Captions

Figure 1. a) Simulab Boss knot tying board, used for the pretest and retention, with markers indicating desired location of knot placement; b) Ethicon knot tying cylinder used for the transfer test, with marker indicating location of desired knot placement at the center of the hook. The black circle indicates where the participants is looking.

Figure 2. Knot tying performance (mean % $\pm$ SEM) for the quiet eye (QET) and technical training (TT) groups in the pretest and simple and complex conditions under high and low anxiety (* QET significantly different to TT, $p < 0.05$).

Figure 3. Quiet eye duration (mean % $\pm$ SEM) for the quiet eye (QET) and technical training (TT) groups in the pretest and simple and complex conditions under high and low anxiety (* QET significantly different to TT, $p < 0.05$).

Figure 4. Total movement time (mean s $\pm$ SEM) for the quiet eye (QET) and technical training (TT) groups in the pretest and simple and complex conditions under high and low anxiety (* QET significantly different to TT, $p < 0.05$).