

1 **Original report**

2

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

5

6 Joe Causer PhD¹, Joan N. Vickers PhD², Ryan Snelgrove MD³, Gina
7 Arsenault² and Adrian Harvey MD, FRCS³

8

9 ¹ Brain and Behaviour Laboratory, Liverpool John Moores University

10 ² Faculty of Kinesiology, University of Calgary

11 ³ Faculty of Medicine, University of Calgary

12

13 RUNNING HEAD: KNOT TYING TRAINING

14

15 **Conflicts of interest and sources of funding**

16 There are no conflicts of interest for any author. Funding was provided by the
17 Royal College of Physician and Surgeons, Canada, and the University of Calgary
18 Program for Undergraduate Research Experience.

19

20

21 Please address correspondence to:

22 Dr. Joe Causer

23 Brain and Behaviour Laboratory

24 Faculty of Science,

25 Tom Reilly Building

26 Byrom Street

27 Liverpool

28 L3 3AF

29 Tel - +44 (0) 151 9046242

30 Email – j.causer@ljmu.ac.uk

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

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

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

1 QE research in medicine has demonstrated less experienced surgeons tend
2 to move their vision between the target location and their hand or tool (10).
3 Furthermore, expert surgeons tend to fixate the target location for longer than novice
4 or less experienced surgeons (12, 13). This longer QE enhances cognitive “slowing
5 down”, which Moulton and colleagues found to be characteristic of expert surgeons
6 (7, 22). The expert surgeon cognitively re-focuses and brings an increased level of
7 attention to bear during critical times during an operation.

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

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

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

3 **Methods**

4 Participants

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

11 Equipment

12 A SensoMotoric Instruments (SMI) ETG eye-tracking system (Boston, MA)
13 was used to collect gaze and hand movement data. The SMI-ETG is a lightweight
14 (76 g), glasses mounted binocular system that uses dark pupil tracking to measure
15 point of gaze with a spatial resolution of 0.1 degree and temporal resolution of 30 Hz
16 (33.3ms per frame), with a built-in high-definition scene camera. A Simulab Boss
17 knot tying board (Seattle, WA) was used for the pretest and retention, with blue
18 markers indicating the location of desired knot placement on the parallel tubing at a
19 separation width of 4 cm. An Ethicon knot tying board (Somerville, NJ) was used for
20 the transfer, with a red marker indicating the location of desired knot placement at
21 the center of the hook, which was surrounded by a cylinder (see Figure 1). Both
22 boards were covered with surgical drapes. Ethicon 2-0 Perma-hand silk sutures were
23 used throughout the testing session. A Polar RX300 heart rate monitor (Lake
24 Success, NY) was used to assess changes in heart rate variability between anxiety
25 conditions

26 Procedure

27 All participants completed a pretest and a training phase followed by simple
28 and complex retention tests under conditions of high and low anxiety. In all

1 conditions, participants were required to tie one-handed square knots with three
2 throws. Before the testing session, participants were fitted with the SMI-ETG system
3 and calibrated. The experimental procedure is outlined in Table 1. In the pretest,
4 participants were required to tie three separate knots at the knot placement location
5 on the tubing. Participants then completed a 5-step training program. Step 1:
6 participants in both groups viewed an Ethicon training video on the one-handed
7 square knot, which emphasized the correct movements of the hands and suture.
8 Step 2: participants in the TT group were provided with additional technical
9 instructions taken from the Ethicon knot-tying manual, whereas the QET group was
10 provided with QE instruction, which emphasized a long QE duration on the
11 placement location prior to each throw (13). Step 3: participants in the QET group
12 viewed a video of an expert surgeon using a long QE duration on the placement
13 location, and were encouraged to adopt this this behavior, while the TT group viewed
14 the same video with the gaze cursor removed, thus only the hand and suture
15 movements were visible. Step 4: participants viewed an individual video recorded
16 during the pretest and comparisons were made to the expert model; the TT group
17 viewed their hand movements and further feedback on hand movements was
18 provided; in contrast the QET group viewed a video showing where they were
19 looking during the task, with additional instruction to adopt a long QE duration on the
20 placement location. Step 5: participants completed three more practice knots. Steps
21 2-5 took approximately 5 minutes each and were repeated subsequently twice, with
22 participant videos updated in each phase.

23 Post-training participants were required to tie three knots in simple (same as
24 pretest; Figure 1a) and complex (the hook inside the cylinder; Figure 1b) retention
25 tests under conditions of low and high anxiety. These took place 10 minutes after the
26 training. In the low anxiety condition, participants were told that the trials were for
27 calibration purposes and would not be compared to other participants. In the high
28 anxiety condition, several ego stressors were used to manipulate anxiety, which have

1 been validated in previous research (4, 22). Being videotaped for assessment
2 purposes increases anxiety and decreases performance (4). A video camera was
3 positioned directly in front of the participants, and they were informed that their
4 course instructors would assess the knots. Participants were told that a ranking
5 system between their peers would be created based on their knot tying performance,
6 and they were given non-contingent feedback that their current performance was in
7 the bottom 25% (23). Data collection took approximately 60 min.

8 Data management

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

26 **Statistical analysis**

27 Knot tying performance, QE duration, number of fixations, and total
28 movement time were analyzed using separate 2 x 5 mixed design ANOVAs, with

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

9 **Results**

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

12 Knot tying performance (%)

13 The ANOVA revealed a group by condition interaction ($F_{4,72} = 2.78, p = 0.03,$
14 $\eta_p^2 = 0.13$; see Figure 2). As predicted, both the QET and TT groups significantly
15 increased their knot tying performance from pretest to the low anxiety conditions ($p <$
16 0.05). While the QET group maintained performance in the high anxiety conditions,
17 the TT group performance decreased to pretest levels. These results suggest that
18 the QET group had developed a strategy that enabled them to maintain performance,
19 even under high anxiety conditions, whereas the performance of the TT group
20 deteriorated.

21 Heart rate variability (ms)

22 The beat-to-beat fluctuation of the heart rhythm decreases under conditions
23 that require increased mental effort and/or during anxiety inducing situations due to
24 changes in the baroreflex blood pressure control subsystem (25). In the current
25 study, we measured heart rate variability to ensure that our anxiety manipulation was
26 effective. A lesser heart rate variability is indicative of an increase in anxiety. As
27 predicted, participants had less heart rate variability in the high anxiety condition (748
28 ± 26 ms) compared to the low anxiety condition (818 ± 29 ms) ($F_{1,18} = 36.25, p <$

1 0.001, $\eta_p^2 = 0.67$). As expected, there were no between-group differences ($p > 0.05$).

2 These data provide evidence that the anxiety manipulation was successful.

3 Quiet eye duration (%)

4 The ANOVA showed a group by condition interaction ($F_{4,72} = 5.91, p < 0.001,$
5 $\eta_p^2 = 0.25$; see Figure 3). The QET group increased their QE duration significantly
6 from pretest ($9 \pm 3\%$) to the low anxiety conditions ($p < 0.05$), and maintained a
7 significant improvement in the high anxiety conditions ($p < 0.05$). In contrast, the TT
8 group reduced their QE duration from pretest to the two complex conditions ($p <$
9 0.05), with no significant differences between pretest and either of the simple
10 conditions ($p > 0.05$). These data demonstrate that the gaze behavior of the TT
11 became less efficient in the complex conditions, whereas, the data suggest that the
12 strategy of the QET group was more robust, even under high anxiety and increased
13 complexity.

14 Number of fixations

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

25 Total movement time (s)

26 Participants in the QET group reported a faster total movement time compared
27 to the TT group ($p < 0.05$; see Figure 5). Total movement time was significantly
28 slower in the complex high anxiety condition compared to pretest and all other post-

1 training conditions ($p < 0.05$). These data indicate that the QET led indirectly to a
2 faster movement time compared to the TT group. Increases in total movement times
3 are expected in more complex conditions due to increased programming demands.
4 There was no group by condition interaction.

5 **Discussion**

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

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

1 knot slippage, unintentional shear force or undue ischemia of tissue, which can lead
2 to knot failure and postoperative hemorrhage (30, 31).

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

24 As we would expect, those participants in the QET group demonstrated more
25 efficient visual strategies as evidenced by significantly longer QE durations and fewer
26 fixations compared to the TT group. When the eyes move from one fixation location
27 to another using rapid eye movements called saccades, visual information is
28 suppressed. Therefore, a greater number of short duration fixations will decrease the

1 amount of information processed. Fixating more areas is a characteristic of novice
2 eye movements. Usually, novices do not know where the relevant cues are in a task
3 environment, and therefore use a greater number of fixations to scan the whole
4 environment (32). This strategy decreases the amount of information they are
5 accruing from the critical areas of the task, which leads to poorer execution. In the
6 current study, the QET group used fewer fixations of longer duration, to the final
7 placement location of the knot, which appears to ensure placement accuracy and
8 appropriate tension of the knot. These results were exaggerated in the complex
9 condition under high anxiety, when the demands of attention were increased. These
10 findings support the slowing down (29) and other literature demonstrating that
11 engaging in more systematic strategies of cognitive focus can enable performers to
12 overcome the demands of anxiety-provoking scenarios (4).

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

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

1 In summary, these data demonstrate the effectiveness of training gaze
2 behaviors, not only to improve the effectiveness and efficiency of performance, but
3 also to mediate any negative effects of anxiety on performance. These findings have
4 important implications for medical educators and practitioners, as well as surgeons
5 who may be (re)training or learning new procedures. The emergence of advanced
6 technologies in medical simulation provide an opportunity to acquire different
7 strategies to procure and measure technical skills, without the risk to patient safety
8 (21).

9 **References**

- 10
11 1. Eysenck MW, Calvo MG. Anxiety and performance: the processing efficiency
12 theory. *Cognition & Emotion*. 1992;6(6):409-34.
- 13 2. Eysenck MW, Derakshan N, Santos R, Calvo MG. Anxiety and cognitive
14 performance: attentional control theory. *Emotion*. 2007;7:336-53.
- 15 3. Causer J, Janelle CM, Vickers JN, Williams AM. Perceptual training: What
16 can be trained? In: Hodges NJ, Williams AM, editors. *Skill Acquisition in Sport:
17 Research, Theory and Practice*. London: Routledge; 2012. p. 306-324.
- 18 4. Causer J, Holmes PS, Smith NC, Williams AM. Anxiety, movement
19 kinematics, and visual attention in elite-level performers. *Emotion*. 2011;11(3):595-
20 602.
- 21 5. Vickers JN. Control of visual attention during basketball free throw. *Am J
22 Sports Med*. 1996;3:93-7.
- 23 6. Vickers JN. Advances in coupling perception and action: the quiet eye as a
24 bidirectional link between gaze, attention, and action. *Prog Brain Res*. 2009;174:279-
25 88.
- 26 7. Causer J, Bennett SJ, Holmes PS, Janelle CM, Williams AM. Quiet eye
27 duration and gun motion in elite shotgun shooting. *Med Sci Sports Exerc*.
28 2010;42(8):1599-608.

- 1 8. Vickers JN, Lewinski W. Performing under pressure: Gaze control, decision
2 making and shooting performance of elite and rookie police officers. *Hum Mov Sci.*
3 2011;31(1):101-17.
- 4 9. Ward P, Farrow D, Harris KR, Williams AM, Eccles DW, Ericsson KA.
5 Training perceptual-cognitive skills: can sport psychology research inform military
6 decision training. *Military Psychology.* 2008;20:S71-S102.
- 7 10. Wilson M, McGrath J, Vine SJ, Brewer J, Defriend D, Masters R.
8 Psychomotor control in a virtual laparoscopic surgery training environment: gaze
9 control parameters differentiate novices from experts. *Surg Endosc.* 2010;24:2458-
10 64.
- 11 11. Williams AM, Singer RN, Frehlich SG. Quiet eye duration, expertise, and task
12 complexity in near and far aiming tasks. *J Mot Behav.* 2002;34(2):197-207.
- 13 12. Harvey A, Vickers JN, Snelgrove R, Scott M, Morrison S. Expertise
14 differences in performance and quiet eye duration during identification and dissection
15 of the recurrent laryngeal nerve. *The American Journal of Surgery.* 2014;207(2):187-
16 93.
- 17 13. Vickers JN, Harvey A, Snelgrove R, Stewart A, MacKenzie C, Arsenault G.
18 Expertise differences in quiet eye duration during surgical knot tying. *International*
19 *Journal of Sport Psychology.* in press.
- 20 14. Law B, Atkins MS, Kirkpatrick AE, Lomax AJ, Mackenzie CL. Eye gaze
21 patterns differentiate novice and experts in a virtual laparoscopic surgery training
22 environment. *Eye tracking research & applications symposium on eye tracking*
23 *research & applications;* NY: ACM Press; 2004. p. 41-8.
- 24 15. Zheng B, Tien G, Atkins SM, Swindells C, Tanin H, Meneghetti A, et al.
25 Surgeon's vigilance in the operating room. *Am J Surg.* 2011;201(5):673-7.
- 26 16. Wilson MR, Vine SJ, Bright E, Masters RS, Defriend D, McGrath JS. Gaze
27 training enhances laparoscopic technical skill acquisition and multi-tasking
28 performance: a randomized, controlled study. *Surg Endosc.* 2011;25(12):3731-9.

- 1 17. Wanzel KR, Kneebone R, Woloshynowych M, Nestel D, Moorthy K, Kidd J, et
2 al. The effects of stress on surgical performance. *The American Journal of Surgery*.
3 2006;191:5-10.
- 4 18. Causer J, Williams AM. Professional expertise in medicine. In: Lanzer P,
5 editor. *Catheter-based Cardiovascular Interventions – Knowledge-based Approach*.
6 NY: Springer; 2012. p. 97-112.
- 7 19. Vine SJ, Masters RS, McGrath JS, Bright E, Wilson MR. Cheating
8 experience: Guiding novices to adopt the gaze strategies of experts expedites the
9 learning of technical laparoscopic skills. *Surgery*. 2012;152(1):32-40.
- 10 20. Causer J, Harvey A, Snelgrove R, Arsenault G, Vickers JN. Quiet eye training
11 expedites surgical knot tying: A randomized controlled study. *The American Journal*
12 *of Surgery*. 2014.
- 13 21. Causer J, Barach P, Williams AM. Expertise in medicine: using the expert
14 performance approach to improve simulation training. *Med Educ*. 2014;48(2):115-23.
- 15 22. Wilson M. From processing efficiency to attentional control: a mechanistic
16 account of the anxiety-performance relationship. *International Review of Sport &*
17 *Exercise Psychology*. 2008;1(2):184-201.
- 18 23. Wilson M, Vine SJ, Wood G. The influence of anxiety on visual attentional
19 control in basketball free throw shooting. *J Sport Exerc Psychol*. 2009;31:152-68.
- 20 24. Tytherleigh MG, Bhatti TS, Watkins RM, Wilkins DC. The assessment of
21 surgical skills and a simple knot-tying exercise. *Ann R Coll Surg Engl*. 2001;83:69-
22 73.
- 23 25. Berntson GG, Bigger JT, Eckberg DL, Grossman P, Kaufmann PG, Malik M,
24 et al. Heart rate variability: origins, methods, and interpretive caveats.
25 *Psychophysiology*. 1997;34:623-48.
- 26 26. Causer J, Holmes PS, Williams AM. Quiet eye training in a visuomotor control
27 task. *Med Sci Sports Exerc*. 2011;43(6):1042-9.

- 1 27. Harle SK, Vickers JN. Training quiet eye improves accuracy in the basketball
2 free throw. *Sport Psychol.* 2001;15:289-305.
- 3 28. Vickers JN. *Perception, Cognition and Decision Training: The Quiet Eye in*
4 *Action.* Champaign, IL: Human Kinetics; 2007.
- 5 29. Moulton CA, Regehr G, Mylopoulos M, MacRae HM. Slowing down when you
6 should: a new model of expert judgment. *Acad Med.* 2007;82(10):S109-S16.
- 7 30. Scott D, Scott LM, Howe BL. Training anticipation for intermediate tennis
8 player. *Behav Modif.* 1998;22(3):243-61.
- 9 31. Sosa JA, Bowman HM, Tielsch JM, Powe NR, Gordon TA, Udelsman R. The
10 importance of surgeon experience for clinical and economic outcomes from
11 thyroidectomy. *Ann Surg.* 1998;228(3):320.
- 12 32. Mann DTY, Williams AM, Ward P, Janelle CM. Perceptual-cognitive expertise
13 in sport: A Meta-Analysis. *J Sport Exerc Psychol.* 2007;29:457-78.
- 14
- 15

1 **Figure Captions**

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

6
7 Figure 2. Knot tying performance (mean % \pm SEM) for the quiet eye (QET) and
8 technical training (TT) groups in the pretest and simple and complex conditions
9 under high and low anxiety (* QET significantly different to TT, $p < 0.05$).

10

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

14

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

18