Cheating experience: Guiding novices to adopt the gaze strategies of experts expedites the learning of technical laparoscopic skills

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Background. *Previous research has demonstrated that trainees can be taught (via explicit verbal instruction) to adopt the gaze strategies of expert laparoscopic surgeons. The current study examined a software template designed to guide trainees to adopt expert gaze control strategies passively, without being provided with explicit instructions.*
Methods. *We examined 27 novices (who had no laparoscopic training) performing 50 learning trials of a laparoscopic training task in either a discovery-learning (DL) group or a gaze-training (GT) group while wearing an eye tracker to assess gaze control. The GT group performed trials using a surgery-training template (STT); software that is designed to guide expert-like gaze strategies by highlighting the key locations on the monitor screen. The DL group had a normal, unrestricted view of the scene on the monitor screen. Both groups then took part in a nondelayed retention test (to assess learning) and a stress test (under social evaluative threat) with a normal view of the scene.*
Results. *The STT was successful in guiding the GT group to adopt an expert-like gaze strategy (displaying more target-locking fixations). Adopting expert gaze strategies led to an improvement in performance for the GT group, which outperformed the DL group in both retention and stress tests (faster completion time and fewer errors).*
Conclusion. *The STT is a practical and cost-effective training interface that automatically promotes an optimal gaze strategy. Trainees who are trained to adopt the efficient target-locking gaze strategy of experts gain a performance advantage over trainees left to discover their own strategies for task completion. (Surgery 2012;152:32-40.)*

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Because of benefits in terms of patients' recovery times, an increasing number of surgical procedures are being performed using laparoscopic techniques. Despite the advantages, laparoscopic surgery is technically demanding and requires the learning of new psychomotor skills that differ from those needed in conventional open surgery.[1] There is, therefore, a need for a solid theoretical base to guide the development of laparoscopic training curricula.[2-6] Furthermore, because there is evidence of incomplete transfer of technical skills to the operating room,[7,8] it is important that skill learning be tested under transfer conditions designed to mimic some of the stressors experienced in the operating room (eg, evaluative pressure, distractions, time pressure).[9,10] The current study aimed to test the efficacy of a training intervention designed to expedite learning by guiding novices to adopt an expert-like gaze strategy and to test whether any performance advantages remain robust under pressure.

The transition from novice to expert motor-skill performance is characterized by increased biomechanical, metabolic, and neural efficiency.[11,12] Furthermore, the acquisition of novel motor skills (eg, laparoscopy) requires the learning of transformations that relate actions to their sensory

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consequences.[13] First, novices attempt to discover (or adapt previously acquired) basic mapping rules that apply to both motor and sensory signals, using vision to check on the consequences of their movements. However, once mapping calibrations have been established, vision can be used in a feed-forward (proactive) rather than a feedback (reactive) role (ie, gaze is anchored on the target and not on any movement effects).[14,15] These differing psychomotor control strategies have been demonstrated for laparoscopic technical skills: experts fixate primarily on the target to be touched or grasped and seldom need to check the location of the tools (a target-locking strategy), whereas novices, still developing their mapping rules, switch between tracking the consequences of their tool movements and fixating on the target itself (a switching strategy).[16-18]

Examination of the psychomotor processes underpinning surgical technical expertise provides insights that can guide the development of training interventions.[19] However, is it possible to "cheat" experience, or must learners progress through a checking and calibration phase in order to be able to use a more efficient target-locking strategy later? Previous research has demonstrated that trainees can be taught (via video training and verbal feedback) to adopt the target-locking gaze strategies of experts at the outset of learning a virtual reality laparoscopic pointing task.[20] These trainees were able to complete the task more quickly (after the same number of training repetitions) than trainees who had been instructed to focus on their tool movements or were left to learn with no instruction (discovery learning) (DL). This performance advantage remained during a multitasking transfer condition, so it appears that gaze training may be less attentionally demanding than more traditional forms of technical-skill acquisition.[19,20]

In a previous study by Wilson et al,[20] gaze training was delivered via a set of explicit verbal instructions, meaning that trainees were conscious of why they were adopting this gaze strategy. Recent research investigating technical-skill acquisition in surgery has highlighted the benefits of implicit motor learning,[21-23] a form of learning in which trainees passively accumulate task-relevant knowledge on an unconscious level and therefore learn skills without building a pool of explicit knowledge. Masters et al have demonstrated that motor skills learned implicitly are not readily available to conscious introspection by the performer, make fewer demands on attention, and are more stable under stress.[21-23] The current study aimed to determine whether a software template could be used to manipulate the information presented on a video monitor of a laparoscopic training box in such a way that it would cause novices to adopt passively, and therefore implicitly, a target-locking gaze strategy (ie, they automatically adopt a strategy without knowing why). We predicted that learners would demonstrate a performance advantage over a control group (using DL) that did not use the template and had the normal full view of the scene.

METHODS

Participants. A total of 27 novice participants who had not received any laparoscopic training volunteered to take part in the study (17 males, 10 females; mean age, 21 years; range, 6 years). Institutional ethical approval was obtained prior to the commencement of the study, and all participants provided written informed consent before testing started. Participants were both left- and right-hand dominant (17 right, 10 left) and were divided randomly into 2 treatment groups (see below). Previous research has revealed significant differences in performance under pressure between explicit gaze training and DL interventions with group sizes of 10 ($t\,[19] = 4.86$, $P < .001$, Cohen d = 2.17),[20] so the larger group sizes in the current study were expected to have sufficient power to show significant effects.

Apparatus and task. Testing took place on a 3-Dmed (Franklin, OH) standard minimally invasive training system (MITS) with a joystick SimScope that was based in a training room at the Exeter Surgical Health Services Research Unit, Exeter, UK. The ball pick-and-drop task from the 3Dmed training tasks was used for this study because previous research has used similar tasks to train students in the eye-hand coordination required for laparoscopy.[24,25] To complete the task, participants had to use a single instrument (with the dominant hand) to move 6 foam balls (diameter ~ 5 mm) placed on stems of different heights, into a cup (Fig 1, *A*). The balls had to be grasped from their stems and placed into the cup individually and in a numbered sequence. Participants were asked to complete the task as quickly and as accurately (ie, no dropped balls) as possible.

Participants were fitted with a Mobile Eye gaze registration system (Applied Science Laboratories, Bedford, MA), which measures the eye-line of gaze using dark pupil tracking (see Wilson et al[17,18] for a detailed description of the equipment). A circular cursor, representing 1 degree of visual angle with a 4.5 mm lens, indicating the location of

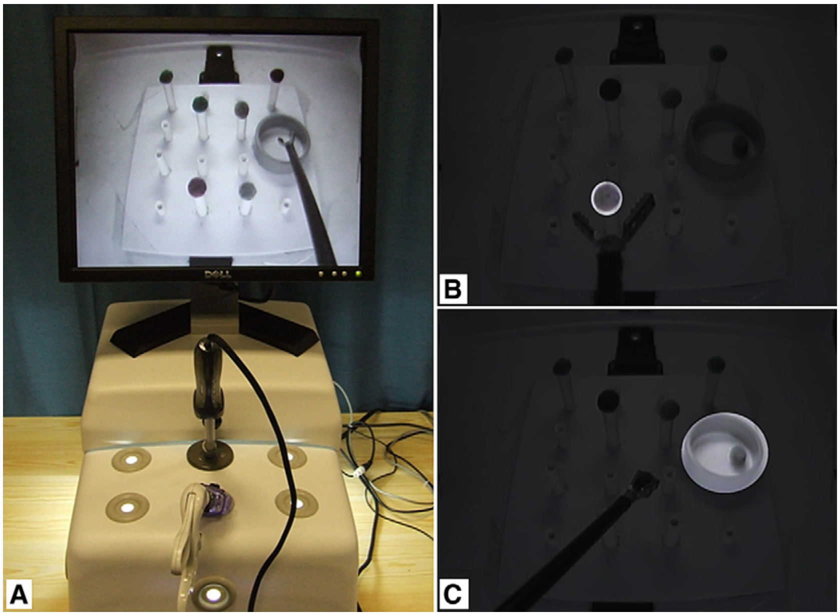

Fig 1. (*A*) The testing setup, showing the 3-Dmed laparoscopic trainer and the ball pick-and-drop task with full vision of the screen (Discovery Learning group). (*B*, *C*) The Surgical Training Template (STT) used by the Gaze-Trained group occludes the full field of view with a translucent mask, ensuring that only the next relevant target is highlighted: either the next ball to be picked up (*B*) or the cup in which the grasped ball is dropped (*C*).

gaze in a video image of the scene (spatial accuracy of ±0.5 degrees of visual angle; 0.1 degree precision) is viewed in real time and recorded at 25 Hz for subsequent offline analyses.

Training groups. Participants were randomly assigned to either a gaze training (GT) or a discovery learning (DL) control group. The GT group (n = 14) performed the task using a surgery training template (STT) designed to force the participants to adopt passively the target-locking gaze patterns that experts learn to adopt over time. The STT is a piece of video software that captures the field of view from the 3-Dmed SimScope and enables it to be manipulated by the experimenter in real time. Specifically, it generates a gray translucent mask (set at 75% opacity), which is overlaid on the field of view, partially occluding the scene (and, in particular, the moving tool). This template is yoked to the task layout on the screen in advance of the experiment so that key locations in the display can be highlighted (unmasked) as they become relevant. Figure 1, *B* shows how a ball is highlighted (unmasked) by the experimenter as the participant initiates the movement of the grasper toward it. Once the ball has been grasped, the experimenter presses a mouse button so that the cup becomes the next unmasked target (Fig 1, *C*). Once the ball has dropped into the cup, the next target ball in sequence is unmasked and the procedure is repeated until all 6 balls have been attempted. The experimenter has the flexibility to change the next target location if a ball is knocked off its stem or dropped before reaching the cup; the experimenter simply presses a key to highlight the next ball in sequence. The DL group (n = 13) did not use the template and so had a normal view of the scene (Fig 1, *A*). Neither group received any verbal or written instructions about how to complete the task.

Procedure. Participants arrived at the laboratory at prearranged times. They read an information sheet describing the aims of the study before completing a demographic questionnaire and providing written informed consent. Participants were fitted with the eye tracker, and it was calibrated using a 6-point calibration chart placed on the MITS monitor. Calibration was checked every second trial to ensure that the eye tracker had not moved.

Participants first completed a baseline trial in which a normal view of the screen was given to both groups, and baseline measures of performance and gaze strategy were taken. The training phase consisted of 50 trials of the task (similar to the mean number of trials for proficiency on the Fundamentals of Laparoscopic Surgery peg transfer task[25]) divided by rest periods into 10 blocks of 5 trials (a total of 300 ball 'grasp and drop' attempts). Throughout training, the GT group performed the task with the adapted view provided by the STT software, whereas the DL group performed the task under normal viewing conditions.

Following training, a test phase required all participants to perform the task 2 more times in 2 counterbalanced manipulations (4 trials in total) and under normal viewing conditions. In a nondelayed retention test, participants were simply asked to complete the task as they had previously, whereas stress was induced in a pressure condition by combining competition and time pressure with evaluation-threat instructions. Previous research has demonstrated that time pressure causes a significant stress effect for trainees performing similar grasp-and-place technical skills.[10] Evaluation threat was also induced by informing participants that their performances would be compared to those of all other participants in the study and that their performance scores would be displayed in a published league table, with participants who improved their best performance by 10% receiving a financial reward (£10). Previous research has also suggested that evaluation threat is particularly stressful for novice trainees.[7,26] At the end of the test phase, participants were thanked for their participation and debriefed about the aims of the study. The participants who managed to improve their performance were paid accordingly.

Measures. *Performance*: Performance was assessed in terms of task completion time[10,20,24,25] and an accuracy measure indexed by the number of balls knocked off (NBKO) the stem during grasping. A performance error measure was deemed important because there tends to be an overemphasis on completion times in studies of the learning of technical skills.[27] Not only is accuracy a critical component of technical-skill proficiency, but pressure may exert its influence on one or both of these performance measures due to speed-accuracy tradeoff decisions. Completion time was measured by a stopwatch, and each time a ball was knocked off its stem or dropped before reaching the cup, this outcome was recorded.

Target locking: To assess the effect of the STT on gaze strategy, the gaze videos were analyzed manually in a frame-by-frame manner by 2 experimenters using video playback software (Gaze Tracker; Eye Response Technologies, Charlottesville, VA). For each grab-and-drop attempt, the location of the fixation (target ball, cup, tool, other) was identified and the duration of time fixating on that location was then calculated.[17,18,20] A measure of target locking was computed by subtracting the percentage of time spent fixating the tool from the time spent fixating the target (either ball or cup) during each trial; a higher score therefore reflected more time spent on target locking.[20] A fixation was defined as duration of gaze on a single location (within 1 degree of visual angle) for at least 120 ms (≥3 frames of video data).[17,18,20] Fixations on other areas of the screen were ignored for the purpose of this analysis. The researchers analyzing the gaze data were blind to the condition and the assigned training group of each of the participants so as to protect against analysis bias.

Table I. Gaze-trained and discovery-learning groups' mean (standard deviation) performance and gaze strategy scores at baseline (familiarization attempt using normal viewing conditions)

	Completion times	*Accuracy (NBKO)*	*Target locking (%)*
Gaze trained	60.3 (22.4)	2.7 (0.9)	40.8 (19.1)
Discovery	67.2 (31.9)	3.3 (1.2)	44.0 (29.4)

NBKO, Number of balls knocked off.

Stress: A multidimensional conceptualization of stress[10,28] was adopted by using mean heart rate (HR) and the validated shortened version of the state trait anxiety inventory (STAI).[29] A Polar HR monitor (Kempele, Finland) was used, and recordings were manually taken every 10 seconds throughout each condition in the test phase to allow an average measure of HR to be computed over the course of the trial. The STAI consists of 6 statements (I feel calm; I fell tense; I feel upset; I am relaxed; I am content; I am worried), which require a response on a Likert scale from 1 (not at all) to 4 (very much). The positive items were reverse scored so that a higher total score reflected a higher state anxiety (with scores ranging from 4 to 24). This instrument was completed after each condition in the test phase.

Statistical analysis: To determine whether there were any pre-existing differences between groups at baseline, performance and target-locking gaze strategy data were subjected to a between-group independent samples *t* test. Performance data recorded during the training period (10 blocks of 5 trials) were subjected to 2 (group; GT versus DL) × 10 (learning-block) mixed-design ANOVAs. Performance, target locking, and stress measures taken during the test phase were all subjected to 2 (group; GT versus DL) × 2 (condition; retention versus pressure) mixed-design ANOVAs. Relevant significant main and interaction effects were followed-up by Bonferroni-corrected post hoc *t* tests. Effect sizes were calculated using a partial eta squared ($\eta_p{}^2$) test for omnibus comparisons and a Cohen d test for simple comparisons.

RESULTS

Baseline differences. Results (Table I) show that there were no significant differences between

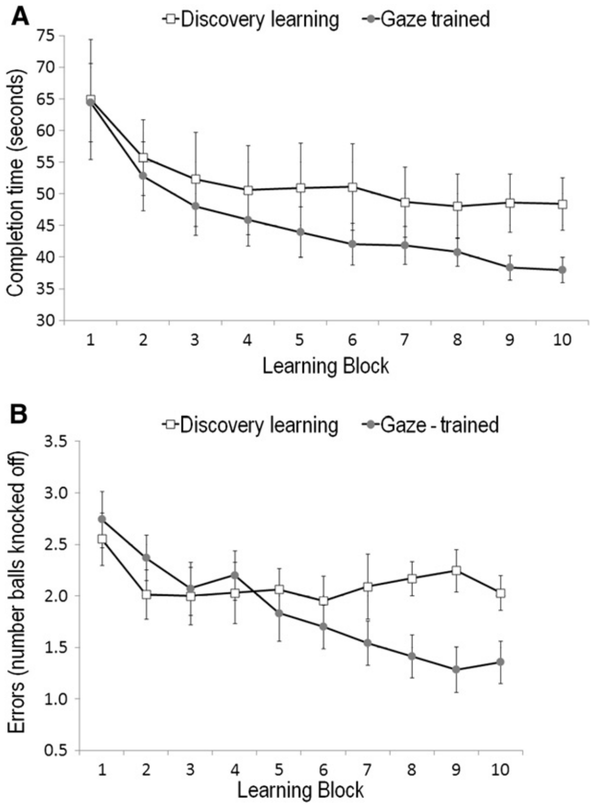

Fig 2. (*A*) Mean (± standard error) completion time (seconds) and (*B*) performance error (number of balls knocked off) for both the Discovery Learning and the Gaze-Trained groups across the 10 blocks of learning (5 trials in each block).

Table II. Mean (standard deviation) stress response (heart rate and State Trait Anxiety Inventory) for the gaze trained and discovery learning groups in retention and pressure conditions

	Retention	*Pressure*
Heart rate (bpm)		
Gaze trained	77.9 (26.5)	83.3 (30.9)
Discovery	81.2 (12.9)	80.1 (14.9)
STAI (4-24)		
Gaze trained	10.4 (3.2)	15.6 (5.2)
Discovery	10.2 (2.4)	14.5 (4.1)

STAI, State Trait Anxiety Inventory.

groups at baseline for completion time: t (25) = 0.65; P = .51; performance accuracy (NBKO) t (25) = 1.56; P = .13; or for percentage of target-locking fixations: t (22) = 0.31; P = .76.

Learning phase. *Performance, completion time*: Results revealed a significant main effect for block: F(9,225) = 13.97; $P < .01$; $\eta_p^2 = .36$); but there was no significant main effect for group, F(1,25) = 0.89; P = .36; η_p^2 = .04; and no interaction effect, F(9,225) = 0.86; P = .57; η_p^2 = .03. Both groups improved with practice, and post hoc tests revealed that completion times were significantly faster than baseline from block 7 onward (Ps < .05). The learning phase completion time data are presented in Fig 2, *A*.

Performance, accuracy (NBKO): Results revealed a significant main effect for block: F(9,225) = 6.93; $P < .01$; η_p^2 = .22, and a significant interaction effect: F(9,225) = 4.45; $P < .01$; η_p^2 = .32. There was no significant main effect for group: F(9,25) = 0.98; P = .33; η_p^2 = .04. Follow-up tests revealed that the GT group continued to improve to a greater extent than the DL group and knocked off significantly fewer balls than did their DL counterparts in learning blocks 8 ($P < .05$); 9 ($P < .01$); and 10 ($P < .05$). The learning-phase performance accuracy data are presented in Fig 2, *B*.

Test phase. *Stress, HR*: Results revealed no significant main effects for condition: F(1,25) = 1.22; P = .28; η_p^2 = .05; or group: F(1,25) = 0.00; P = .99; η_p^2 = .00; and results revealed no interaction effects: F(1,25) = 2.69; P = .11; η_p^2 = .10. The stress response data are presented in Table II.

Stress, STAI: Results revealed a significant main effect for condition: F(1,25) = 23.06; $P < .001$; η_p^2 = .48; but no main effect for group: F(1,25) = 0.34; P = .56; η_p^2 = .01; and no interaction effects: F(1,25) = 0.22; P = .64; η_p^2 = .01. Both groups of participants reported higher anxiety in the pressure condition than in the retention condition. The stress response data are presented in Table II.

Performance, completion time: Results revealed a significant main effect for group: F(1,25) = 5.53; $P < .05$; η_p^2 = .18, but no significant main effect for condition: F(1,25) = 1.60; P = .22; η_p^2 = .06, and no interaction effect, F(1,25) = 0.00; P = .95; η_p^2 = .01. The GT group generally completed the task more quickly than the DL group. The test-phase performance data are presented in Fig 3.

Performance, accuracy (NBKO): Results revealed a significant main effect for condition: F(1,25) = 6.00; $P < .05$; η_p^2 = .19; and for group: F(1,25) = 14.32; $P < .01$; η_p^2 = .36, but no interaction effect: F(1,25) = 0.41; P = .53; η_p^2 = .02. The GT group was generally more accurate (knocked off fewer balls) than the DL group, but both groups knocked off more balls in the pressure condition than in the retention condition. The test-phase performance data are presented in Fig 3.

Target-locking fixations: Results revealed a significant main effect for group: F(1,22) = 4.75; $P < .05$; η_p^2 = .18, with the GT group target locking

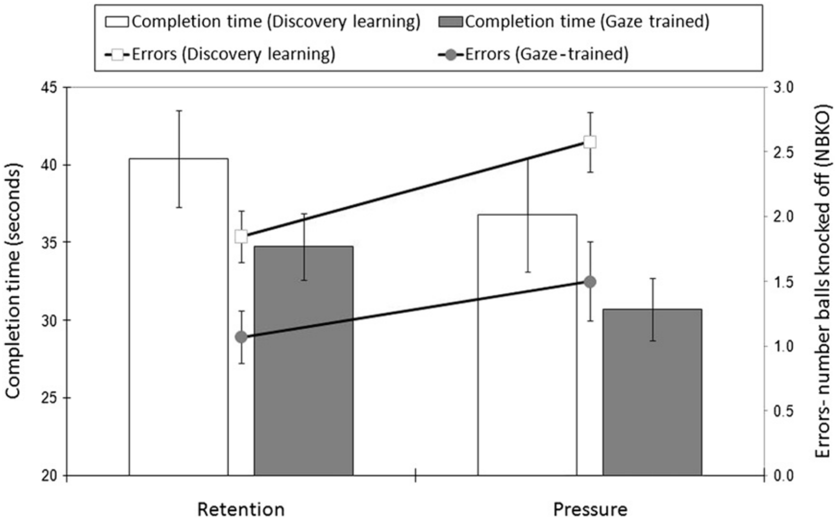

Fig 3. Mean (± standard error) completion time (seconds) and errors (numbers of balls knocked off) for both the Discovery Learning and the Gaze-Trained groups in retention and pressure trials.

significantly more than their DL counterparts. The main effect for condition approached significance: F(1,22) = 3.44; $P = .07$; $\eta_p^2 = .14$, with both groups using less target locking under pressure. There was no interaction effect: F(1,22) = 0.08; $P = .78$; $\eta_p^2 = .01$. The test-phase target-locking data are presented in Fig 4.

DISCUSSION

The overriding aim of this study was to test the utility of a training device that guided novices to adopt implicitly the gaze strategies of expert laparoscopists. Previous research has revealed that novices who are taught to adopt a target-locking strategy (via explicit verbal instruction) perform better in retention and multitasking conditions than discovery learners or novices given video feedback related to their movement efficiency.[20] It has been suggested that such training allows the body to self-organize motor recruitment while goal-directed attentional resources have to focus only on controlling one visuomotor parameter, ie, target location.[30,31] The objective of the current study was to determine whether such gaze-training benefits also applied to other forms of stress (eg, evaluative threat and time constraint). Furthermore, the explicit verbal instructions used in previous research to guide the gaze strategies of trainees were replaced by a software template designed to guide novices to adopt a target-locking strategy in an implicit manner.

Both groups got faster over the 50 trials of learning (6 ball grasp-and-drop attempts per trial) (Fig 2, *A*); the GT and DL groups reduced their baseline completion time by 43% and 26%, respectively. The accuracy results revealed differential effects for learning; the DL group failed to improve accuracy after the second trial, whereas the GT group continued to improve accuracy throughout learning (Fig 2, *B*). Indeed, the GT group revealed a 49% improvement in accuracy over the learning phase, whereas the DL group revealed only a 23% improvement. It is interesting to note that this difference is unlikely to be due to inherent disparities in the makeup of the groups because no differences in performance (or gaze strategy) were measured at baseline (Table I).

The test-phase data revealed that the superior performance evident in the GT group toward the end of training remained once the template was removed. The members of the GT group were both faster and more accurate than those of the DL group during the test phase, in which both groups were presented with the same unrestricted view of the scene (Fig 3). This performance advantage was underpinned by a more expert-like (target-locking) gaze strategy; three quarters of the GT group's fixation time was spent on the relevant target at retention, compared to only 60% in the DL group (Fig 4). It is noticeable that the members of the DL group did increase their target-locking percentages between baseline and retention (from 44% to 60%), reflecting that experience alone leads to an increase in target-locking fixations. However, the GT group's target locking percentages are closer to those of experienced surgeons in previous studies[17,18] and therefore suggest that, to an extent, experience can be cheated.[19,20] These findings

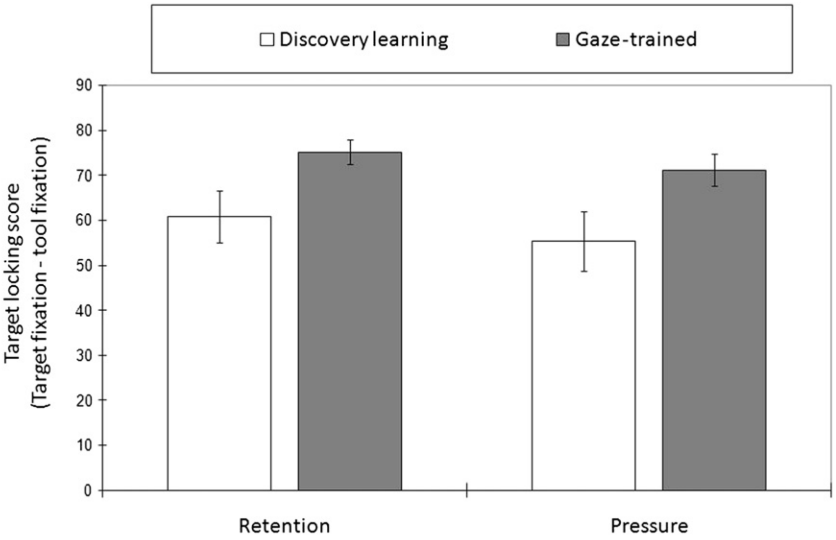

Fig 4. Mean (± standard error) target locking fixation score (% time fixating target − % time fixating tool) for both the Discovery Learning and the Gaze-Trained groups in retention and pressure trials.

therefore provide strong support for the contention that accurate eye movements are a key precursor to accurate limb movements in visually guided tasks,[14,15,20] even when eye movements are guided passively. Because the GT participants were not provided with feedback or information about the benefits of a target-locking strategy, motivational (eg, Hawthorne) effects cannot explain their performance advantage.

We also predicted that because of the lower attentional demands of both gaze training (as opposed to discovery learning)[20] and implicit (as opposed to explicit) motor learning,[21] the GT group should be less affected by a stress manipulation designed to preempt attentional resources. The results only partially supported this hypothesis. Although the GT group still performed significantly better than the DT group under pressure, both groups experienced performance degradation under pressure. Specifically, both groups reported higher levels of anxiety (Table II) and knocked off more balls under pressure (Fig 3) than they did in the retention condition. Both groups also revealed poorer gaze control (target-locking strategy) under pressure as opposed to retention (Fig 4).

There is an intrinsic relationship between the goal-directed control of gaze and motor outputs, so alterations in gaze are likely to cause associated perturbations in movement accuracy.[15,32] Anxiety's negative impact on performance has been linked to increased distractibility and impairments in attentional control.[33] Therefore, changes in efficient visual attentional control due to increased anxiety are likely to lead to impairments in visually guided motor control. Indeed, previous research across a range of athletic skills has revealed that increased anxiety significantly impairs visual attentional control and subsequent visuomotor performance.[30,31,34,35] Although we have previously shown that individuals who are trained to focus their gaze optimally tend to resist the negative impacts of stress on attention and motor performance,[20,31] this was not the case in the current study. It is possible that the previous explicit intervention by Wilson et al[20] may have been successful in aiding performance under pressure by providing individuals with a coping strategy that they can consciously adopt (ie, focus on ensuring that they maintain goal-directed focus). In the current study, expert eye movements were learned passively; therefore, this strategy may not have been consciously available to participants once the template was removed. Future research should examine whether the addition of some form of explicit instruction (similar to that that offered by Wilson et al[20]) is important in providing an explicit coping strategy that trainees can adopt under stress.[36] Second, the utility of other forms of implicit motor learning[21-23] and how they may be applied to gaze training in learning laparoscopic technical skills requires further research attention.

In conclusion, the current study revealed that trainees who are trained to adopt the efficient target-locking gaze strategy of experts gain a performance advantage in a laparoscopic grasping task over trainees left to discover their own strategies. The results reveal that the benefits found in more explicit methods of training students to learn a target-locking strategy[20] can also be uncovered in a more passive and implicit manner that requires no expert trainer to provide verbal instructions and feedback. Furthermore, because the STT can be coupled with relatively inexpensive video box trainers (cf. virtual reality simulators), it may be a practical and cost-effective training interface for expediting the acquisition of technical skill. However, future research should continue to test the utility of such an interface for a variety of tasks and experience levels.

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