Improving surgical training: Developing evidence–based interventions from a skill acquisition and psychological perspective

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Executive Summary

As psychologists interested in how skills are acquired and performed under pressure, we have carried out research with partners in a wide range of safety critical and high-pressured environments (including sport, the military, aviation, therapy, and other medical domains). Since 2009, with funding from RCUK (e.g., ESRC) and industry partners (e.g., Intuitive Surgical Ltd.), we have created a portfolio of research related to important issues underpinning the learning and performance of technical surgery skills. This includes:

1. The benefits of gaze training to expedite the early pick up of technical skills,
2. How an understanding of the stress response (challenge and threat evaluations) can benefit surgical performance,
3. The recording of surgeons' mental workload,
4. The validation of simulation and robotic surgery for improved acquisition of technical skills,
5. The key issues to consider when considering observational learning for technical skills (particularly during robotic surgery).

Based on earlier work in sport, we have demonstrated that technical laparoscopic skills can be learned more quickly, be more resilient to stressors (e.g. multi-tasking), and transfer to more complex tasks, if trainees are taught to model expert's eye movements rather than concentrate on what their hands are doing [1] [2] [3]. We have shown that a surgeon's response to stress can have significant impact on their performance [4] [5], and have developed measures that can record how various sources of stress may impact upon the mental workload a surgeon may experience [6]. We have developed measures of neural efficiency to index differences in the way in which laparoscopic skills might be learned [7]. We have also used our understanding of process measures of performance to help validate the use of simulation [8] and to confirm why robotic surgery is easier to use at the outset of training compared to laparoscopic surgery [9]. Recently we have also examined key issues involved when considering 'what and whom' to observe when learning robotic skills (e.g., can we benefit from seeing errors?) [10] [11].

Taken together, we believe that our work could inform some of the critical issues that will arise as the role of the surgeon evolves, especially with regards effective (improved patient safety) and efficient (shorter and more cost effective) training.

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[1] Wilson et al. 2011 Surg Endosc, 25, 3731-9. doi: 10.1007/s00464-011-1802-2.
[2] Vine et al. 2012 Surgery, 152, 32-40, doi: 10.1016/j.surg.2012.10.002.
[3] Vine et al. 2013 Surg Endosc, 27, 3205-13, doi: 10.1007/s00464-013-2893-8.
[4] Vine et al. 2013 JEP Applied, 19, 185-94, doi:10.1037/a0034106
[5] McGrath et al. 2011 BJUI, 108, 795-6, doi:10.1111/j.1464-410X.2011.10558.x
[6] Wilson et al. 2011 WJS, 35, 1961-9, doi: 10.1007/s00268-011-1141-4.
[7] Zhu et al. 2011 Surg Endosc, 25, 2950-5. https://doi.org/10.1007/s00464-011-1647-8
[8] Vine et al. 2014 Surg Endosc, 28, 1788-93, doi: 10.1007/s00464-013-3387-4.
[9] Moore et al. 2015 Surg Endosc, 29, 2553-60, doi: 10.1007/s00464-014-3967-y.
[10] Harris et al. 2017 PlosONE, 12(11): e0188233. doi: 10.1371/journal.pone.0188233.
[11] Harris et al. in press Annals Surg

Outlining the Training Challenge (Opportunity)

We welcome the opportunity to input into this independent RCS commission to consider the changing nature of the role of the surgeon moving forward. Growing demands on service provision will pose substantial challenges for the delivery of effective surgical training. A range of new skills will be required to perform the robotic surgery of the future. Economic pressures require hospitals to deliver increased patient choice and reduced waiting times, despite the fact that surgical trainees inevitably take longer to complete procedures under supervision. Additionally, less time is being allotted for trainees to develop basic surgical skills. In the context of these increasing time and economic pressures, an improved understanding of factors limiting or contributing to the learning and performance of surgical skills is critical. Both the historical apprenticeship model, and recent attempts at developing proficiency-based curricula for training, are somewhat limited given the speed at which technology is changing the nature of the skill-set required.

This changing environment brings new challenges for skill transfer (how easily can current skill training paradigms translate to new demands?) and this is further heightened by the need to:

a. Operate within constraints of shorter training cycles (make training more *efficient*)
b. Consider new ways to make training safer for patients through the use of ex-vivo learning / simulation (make training more *effective*).

1. Robot-Assisted Surgery

For example, the proliferation of robotic technology means that the surgeon-tool interface has become remote and screen-based. Not only does this have implications for the coherence and performance of the surgical team, but there are serious issues for how trainees might learn how to operate unfamiliar technology in this environment. The human element of the human-machine interface must not be forgotten as the use of technology proliferates, if expensive mistakes are to be avoided.

While our own research (funded by Intuitive Surgical Ltd.) suggests that robotic surgery reveals expedited acquisition of technical surgical skills [12]; demands a lower cognitive workload [9]; and enhances the ability for surgeons to perform under surgical stressors [13] compared to laparoscopy, this does not mean that skill acquisition will 'just happen' in the most effective manner. *What* should the trainee be observing in order to get the best representation of what information the operator is using to make his/her decisions and guide the control of the robotic arms? This may seem like a rather simple question, but is actually a fundamental aspect of observational learning and one which has been changed considerably with the move from open surgery to minimally-invasive surgery and now on to robotic surgery.

1.1. Gaze Training

With experience and through training, experts learn to conserve limited cognitive resources and strategically direct their gaze control system to maximise information acquisition and guide accurate goal-directed motor control and decision-making. There has been interest in examining how experts' eye movements differ from novices [14] and whether novices can be taught to model the strategies of experts. The common underlying principles for eye guidance suggest that behavioural relevance and learning are central to how we allocate gaze. Gaze training seeks to address both these components: informing the learner of the task relevant visual information and providing the opportunity for structured learning.

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[12] Moore et al. 2015 J Robotic Surg, 9, 67-73. doi.10.1007/s11701-014-0493-9.
[13] Moore et al. 2015 J Robotic Surg, 9, 277-84. doi:10.1007/s11701-015-0527-y.
[14] Wilson et al. 2010 Surg Endosc, 24, 2458-64. doi: 10.1007/s00464-010-0986-1

We have published >20 research articles that point to the benefits of having trainees observe the gaze behaviour of expert performers – in sport [15], the military [16], therapy [17], as well as surgery [1 2 3]. The premise behind such training is that novices can benefit from learning the precise eye movements and gaze strategies that experts use to decide, plan and control a course of action for a given task. Rather than having to provide technical instructions, trainees can implicitly pick up the key cues that experts use (but may not always be able to report). The benefits are therefore likely to be due to lower cognitive demands during learning: Visualising, as opposed to verbalising this information may make it more salient and easily 'digested' by the learner.

In the laparoscopic environment, we have revealed benefits for gaze training in terms of how quickly a task is learned [1 2 3]; how well the task can be performed under multi-tasking demands [1]; how durable this learning is over time [2]; and how well the learning transfers to more complex tasks [3]. In each case, these learning advantages were above those obtained from groups who picked up the skill via discovery learning (just being able to practice) or who were provided with videos showing the expert's smooth tool movements. Experts have developed excellent knowledge of the spatial and temporal (sequence) nature in which information needs to be extracted from a scene in order to make good decisions and perform well; visualising this for novices provides an insight into these processes and helps them to acquire appropriate attentional control. Additionally, learners are guided to coordinate the gaze and motor systems in an effective way that simplifies the problem of visually guided movement for the central nervous system [1].

Our research used two methods of training: videos of previously collected expert eye movements [1], and a bespoke video training interface [2 3] that guided trainees when to look at specific targets in the environment. Both methods had advantages, although a benefit of the training template was that it guided performance during actual task execution. As eye tracking technology and machine learning modelling capabilities improve, the ability to offer 'real-time' instruction and feedback in the operating theatre provides incredible possibilities for guided support. An understanding of the skill acquisition principles underlying these effects will be important if surgical educators are to gain the most benefit from the adoption of new technology that influences the human-technology interface.

1.2 Observational Learning

The previous section outlines how a new 'look' at what information we use to train surgeons could have significant benefits with the expected proliferation of robotic surgery. There are other more basic questions about the 'models' we use to train surgeons [11]. The increasing shift towards robotic surgery makes an understanding of the key components of action observation (the who, how and what) even more important. With the main operator now removed from the scene of the eventual action, it is difficult to know what should be observed and how a trainee can make sense of the ultimate movements of the instruments held by the robotic arms.

Action observation is theorised to provide a blueprint that can help refine motor patterns towards the standard of an expert. In addition to these benefits for skill learning, observation also provides an effective substitute for practicing tasks that are potentially dangerous or otherwise impractical, such as during early stage surgical training. A final practical benefit is that observational learning

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[15] Moore et al. 2012 Psychophysiology, 49, 1005-15. doi:10.1111/j.1469-8986.2012.01379.x.

[16] Moore et al. 2014 Mil Psychol, 26, 355-65. doi.10.1037/mil0000039

[17] Wood et al. 2017 PLoS ONE 12(2): e0171782. doi:10.1371/journal. pone.0171782

is time and resource efficient, as it can be delivered to large groups concurrently through videos, simulators, and online learning, when direct observation in the time-pressured environment of the operating room is not possible (please read our recent review for more detail [11]). An important practical rationale for observational learning in robotic surgery is that not every trainee will have access to a robotic platform. Creative ways to provide initial 'experience' (e.g., via evidence-based training videos) is important to put trainees further along the learning curve when they finally sit at the robotic console.

Traditionally, in sporting or surgical settings, observation of an expert model is used to establish the 'perceptual blueprint' for optimal performance: learners observe the ideal tennis backhand or suturing technique and attempt to do likewise. Growing evidence suggests, however, that observing error-strewn, or novice, performance may also be beneficial for skill acquisition. Error-strewn observation drives skill learning through the engagement of error detection and correction processes, which refine internal representations of motor control, much like physical practice [11]. In a recent study we found similar benefits from observing a novice model compared to an expert model on the acquisition of a technical skill on the DaVinci robot [10]. The determination of suitable observational models to improve skill acquisition for surgical trainees will be a key issue if training is to be efficient and effective.

2. Objective measures of workload and effort

Although patient safety and cost effectiveness of training will be the most important factors driving changes to curricula, it will also be important to determine the effect of technology changes on the surgeon operator. While we appreciate that self-report measures have their place here (and we developed a surgery specific workload index – the SURG-TLX - for this purpose [6]) objective measures can provide moment-to-moment data on the surgeon's physical and mental state. As sensor technology (so-called 'wearables') becomes more developed in the next five-ten years, the opportunities for this field of enquiry will expand further.

Even with the technology available currently we have been able to assess differences in neural efficiency between different types of laparoscopic learning techniques, using electroencephalography [7]. Such measures, as they develop, will enable us to be able to determine the mental strain trainees are under as they try to engage with new technology and pick up new skills. This is important, as surgeons may not show outward signs of being under strain until it is too late, leading to errors being made that may affect patient safety. Monitoring critical indices will enable real-time feedback of an operator's state in terms of measures like gaze control [18] and heart rate variability [9], which may provide advanced warning of upcoming overload. Again, the modelling of any interaction of these variables will be supported by advances in machine learning algorithms in the next decade. This will be especially important as the NHS seeks to promote greater longevity of one of their most skilled (but expensive) workforce in the operating room - the expert surgeon.

3. Acute Stress

Closely linked to the concept of mental workload is the concept of stress. Our expertise is in the measurement and mitigation of acute stress across domains as varied as sport, military, aviation, therapy and surgery. Acute stress is an important issue for patient safety and as such understanding why skills break down under pressure, and developing training that might mitigate against such effects, is critical. We have recently developed a theoretical framework to explain the influence of stress appraisals on subsequent attentional control and performance of real-

[18] Wilson et al. 2011 Surg Endosc, 25, 2268-74. doi:10.1007/s00464-010-1546-4

world perceptual motor skills [19]. This framework is based on our extensive previous empirical work that has manipulated pressure to explore the psychophysiological, attentional, neural, and kinematic influences on performance (see [19] for a review).

We have revealed that individuals who perceive stress to be a *challenge* (i.e. who perceive they have sufficient coping resources to deal with the situational demands) perform better than individuals who perceive stress to be a *threat* (i.e. who perceive that situational demands outweigh their resources to cope) across a range of pressurised environments; including competitive sport [20], commercial pilot licence checks [21], anaesthetist selection centre [22], and a laparoscopic skills test [4]. We have also shown that it is possible to understand the antecedents of these states [23]; manipulate their evaluations via simple instructional alterations; and index the changes via self-report and psychophysiological indices [24]. Perhaps most importantly, we have also shown that it is possible to train individuals in such ways that they are more likely to adopt a challenge state: via gaze training [25], and via reappraisal training [26 27].

We believe that these findings are relevant for surgery training moving forward as surgeons will be expected to deal with more and more complexity, and the degree to which they feel that they can cope will influence outcomes [28]. Our research shows that the environment (e.g. social support) and personal coping resources can influence these evaluations, and so should be considered a key component of any training curriculum. In some cases this may be via simple changes in the way a training surgeon frames the task (see [24] for an example), or it may be in terms of providing reappraisal training ("my increased arousal is beneficial for performance" - see [26]).

4. Surgical simulation: Virtual reality training

Our work in laparoscopy and robot-assisted surgery has sought to show how virtual reality simulation might be validated [29 30]. Here we used novel eye tracking methodology to validate simulations from the user's perspective, and establish the perceptual, psychological and pedagogical validity of the simulator. We also explored how such technologies may reduce surgical workload and expedite the skill acquisition process [9 12 13]. As surgical training moves away from expensive 'free-standing' simulators, towards head mounted virtual reality simulation training, we believe that the expertise and skills needed to test and validate simulations will be critical. Drawing heavily on our experiences with simulation training in surgery and aviation, and with financial support from an RCUK grant, we established a virtual reality training organisation that designs, build and validates virtual reality training for safety critical industries. This organisation, Cineon Training (www.cineon.training), has a growing portfolio of work in the Nuclear industry, designing training to expedite both technical skill learning, and more complex decision making and safety learning. We believe that designing be-spoke, clinician lead training,

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[19] Vine et al. 2016 Front Psychol, 7:1671. doi.10.3389/fpsyg.2016.01671.
[20] Moore et al. 2013 J Sport Exerc Psychol, 35, 551-62.
[21] Vine et al. 2015. Anxiety Stress Coping, 28, 467-77, doi. 10.1080/10615806.2014.986722.
[22] Roberts et al. 2016. Adv Health Sci Educ, 21, 323-39. Doi, 10.1007/s10459-015-9629-6.
[23] Moore et al. 2014. Int J Psychophysiol, 93, 267–73, doi:10.1016/j.ijpsycho.2014.05.009.
[24] Moore et al. 2012 Psychophysiology, 49, 1417–25. doi: 10.1111/j.1469-8986.2012.01449.x
[25] Moore et al. 2013 Int J Sport Ex Psychol, 11, 169-83. doi: 10.1080/1612197X.2013.773688.
[26] Moore et al. 2015 J Sport Exerc Psychol, 37, 339-43. http://dx.doi.org/10.1123/jsep.2014-0186.
[27] Sammy et al. 2017 Anxiety Stress Coping, 30, 619-29. Doi.10.1080/10615806.2017.1330952.
[28] McGrath et al. 2011 BJU-Int, 108, 795-6. doi:10.1111/j.1464-410X.2011.10558.x
[29] Bright et al. 2014 J Surg Educ 71, 434-9. doi.org/10.1016/j.jsurg.2013.11.006.
[30] Bright et al. 2012 Int J Surgery 10, 163-6. doi:10.1016/j.ijsu.2012.02.012.

using computer generated virtual reality and 360° video is the future of virtual reality surgical training, and we have the skill-set to do this.

4. Practical Application of this Research

A key component of our research portfolio is that our work is co-designed with clinicians (esp. Mr John McGrath, consultant urologist, Exeter RD&E) to ensure that our findings can actually have some impact on the training curricula developed locally. Additionally, we also have had an international reach via research partnerships with colleagues in Hong Kong, and international surgical companies [31]. We believe that this call from the RCS provides the opportunity for us to further engage with the surgical community and to offer our support to those individuals and organisations who are responsible for creating training curricula and determining best practice.

Conclusion

To conclude, the aim of this brief report was to identify areas where expertise in psychological / skill acquisition theory and practice might support the development of surgical training during the upcoming period of flux, where training time is under pressure and where the skill set required might be changing beyond the knowledge of current trainers. The surgeon of the future will need to be able to pick up new skills, work seamlessly with new technology, and perform under pressure with less supervision and training time than the current workforce. The effects of these issues will clearly influence patient safety, but will also impact upon recruitment and training costs. Additional support - from outside of the surgical field - may be required to ensure that these processes are optimised based on cutting edge evidence. We believe that our work (which spans surgery, sport, aviation, therapy and the military) could inform some of the critical issues that will arise as the role of the surgeon evolves, especially with regards effective (improved patient safety) and efficient (shorter and more cost effective) training.

If anyone on the Commission would like further detail on anything written in this summary document, we would be happy to present to the Commission, or write a more targeted follow-up report.

[31] Roy et al. 2015. Sci World J, *Article ID 340246,* doi:10.1155/2015/340246