How can surgical training benefit from theories of skilled motor development, musical skill acquisition and performance psychology?

Andrew W McCaskie, Dianna T Kenny and Sandeep Deshmukh

ABSTRACT

- Trainee surgeons must acquire expert status in the context of reduced hours, reduced operating room time and the need to learn complex skills involving screen-mediated techniques, computers and robotics.
- Ever more sophisticated surgical simulation strategies have been helpful in providing surgeons with the opportunity to practise, but not all of these strategies are widely available.
- Similarities in the motor skills required in skilled musical performance and surgery suggest that models of music learning, and particularly skilled motor development, may be applicable in training surgeons.
- More attention should be paid to factors associated with optimal arousal and optimal performance in surgical training — lessons learned from helping anxious musicians optimise performance and manage anxiety may also be transferable to trainee surgeons.
- The ways in which the trainee surgeon moves from novice to expert need to be better understood so that this process can be expedited using current knowledge in other disciplines requiring the performance of complex fine motor tasks with high cognitive load under pressure.

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By the end of the last century, one of the key surgical training priorities that was advocated by pioneering American surgeon William Halsted — that of independent operating — was declared irretrievably lost, and a call was made for new training methods.[1] Current challenges facing the teaching of technical skills in surgery include the shorter working week for residents, the emphasis on operating-room efficiency which can diminish teaching time and exposure to real patients, and the increasing complexity of the surgical skills required in using screen-mediated techniques, computers and robotics.[2]

It has been estimated that between 15 000 and 20 000 hours are required to train a surgeon.[3] Recently, hours for surgical training have been regulated (to different levels) globally to avoid sleep deprivation. The comparatively longer hours in the United States (80 hours per week; 3840 hours annually) contrast with Europe (48 hours per week; 2304 hours annually) and Australia and New Zealand (60 hours per week; 2880 hours annually).[4] Surgical educators are therefore challenged to both maintain patient safety and enhance the acquisition of surgical skill with reduced annual training hours.

Surgical simulation strategies allow doctors to rehearse surgical skills before performing them on a patient. For example, practising on synthetic and animal tissue to achieve baseline surgical dexterity, in compliance with the principle "no learning curve on patients", has become standard. Another strategy is to specify entry requirements into surgical training, such as using pretests to assess candidates' ability to manipulate objects while viewing their efforts on a laparoscopic monitor. This would reduce the likelihood that trainee surgeons discover, mid-course, that they lack the visuospatial ability to successfully perform laparoscopic procedures.[5]

Training in minimally invasive surgery is increasingly being undertaken through virtual reality simulation for both conventional and robot-assisted procedures. The addition of haptic feedback in robotic procedures appears to reduce surgical errors, especially in knot-tying in an endoscopic model.[6] Machines able to provide this kind of training are expensive, and tend to be available only in specific centres. Nonetheless, simulation cannot fully replicate the experience of the "performance" of an operation.

Theories of acquisition of musical skills, particularly skilled motor performance, are relevant to the development of new surgical training models. Professor Earl Owen, the "father of microsurgery", was a skilled pianist who developed the instruments for microsurgical operations using his "pianist's dexterity".[7] It is difficult to imagine any other fields of endeavour that require more precise and complex fine motor tasks to be performed under pressure than those of musicians and surgeons. Their skills approach the limit of what is physically possible, and are developed only through enormous investments in time (ie, practice) and effort (ie, cognitive and emotional load).

In music learning, the work of Ericsson et al[8] on the role of expertise and deliberate practice might also be a suitable model for surgical training.[9] Surgical simulation is practice before performance in which the virtual environment can be used to analyse hand and finger movements quantitatively. The content of deliberate practice needs careful consideration; options range from low to high correspondence to the final task, including cadaveric material to virtual reality computer systems.

One of the critical differences between musical training and surgical training is that most musicians who achieve expert or elite status on their instruments commenced musical studies as young children — a stage when the human brain is still developing and when the circuitry of the central nervous system is more plastic than in adults. Such intensive training not only modifies cortical maps, but may affect the gross morphology of the central nervous system. For example, a number of important changes occur in the physical dexterity and in the brain structure of advanced and professional pianists (compared with amateurs), including increased symmetrical dexterity between the hands, greater independence of finger movement and more precise control of the duration and force of hand and finger movements. These skills are reflected in the development of similar depths in the central sulcus on the left and right side, attributed to an increase in the area of the motor cortex on the side controlling the non-dominant hand.[10] The effects of musical training may generalise to other skilled fine-motor tasks. For example, prior music experience improved the performance of timed laparoscopic suturing in surgical novices after controlling for video game experience,[11] which is also correlated with laparoscopic skill and which may be a useful, cost-effective surgical training (and leisure) activity for improving screen-mediated procedures.[12]

Given the intensity and cost of surgical training, more attention needs to be paid to theories of skilled motor development.[2] For example, the discovery of mirror neurons explains the seemingly automatic human ability to observe and accurately imitate the actions of others. This skill is apparent within the first weeks of life. Mirror neurons activate not only when an action is executed, but also when it is observed, anticipated or imagined.[13] The activation is greater if the individual has a strong sense of the goal to be achieved.[14] The Suzuki method of music instruction relies almost exclusively on imitation,[15] and may be successful because mirror neurons support the imitation by a novice of the complex, multisensory behaviours of a master practitioner. This would certainly parallel some aspects of the models of surgical training in previous years. The fact that mirror neurons fire during the performance of a task and during kinaesthetic imagery of that task accounts for the effectiveness of both mental rehearsal and observation which, combined with physical practice, may enhance learning and shorten training times.

There is already some evidence from a virtual reality simulator study that mental practice is beneficial for novice surgeons.[16] Dyadic practice (ie, peer practice in pairs) is another cost-effective strategy that maximises both physical and mental rehearsal.[9] Capitalising on the mirror neural mechanism, it is possible that complex physical techniques may be learnt (after long, deliberate practice) and subsequently performed with little conscious or deliberate effort or verbal instruction (provided that all the necessary cognitive learning in anatomy and physiology has already occurred, and there is no surgical emergency).

Once tasks are learnt to a performance standard, they need to be repeatedly reproduced as optimally and as reliably as possible under a wide range of environmental contingencies; for example, from practice to a competitive event, from rehearsal to performance, or from simulation to actual surgery. Optimal arousal precedes optimal performance; optimal arousal is dependent on a large number of interdependent factors that include trait anxiety (ie, the general propensity to worry and be anxious), state anxiety (ie, situational anxiety), performance anxiety, personality characteristics, cognitive capacity, cognitions, physiological arousal, task complexity, task mastery (including motor skill), situational factors, and availability of working memory resources.[17] Unsurprisingly, recent work has identified that stress and anxiety can impair surgical performance.[16] There is scope for much greater attention to these factors in surgical training.

It has been proposed that the expert model developed in musical[18] and sport[19] training could be applied to help to finetune surgical training. This model involves the systematic study of experts and non-experts in order to identify the factors that differentiate the performance of the two groups. At its most mechanistic, peak performance is achieved by managing three key components: maximising correct responses, eliminating incorrect responses and encouraging maximal transfer from training/practice/simulation to competition/performance/live surgery.[20] To put it succinctly, "the mind of expert motor performance is cool and focused".[19] Expert performance precludes distractions or intrusions. Instructions with an external focus (ie, instructions directed at the required task and its attainment) during learning of most complex motor tasks in sport and music are more effective than instructions that direct attention to the performer's body movements. With sufficient practice, externally focused instructions also support the development of automaticity (ie, the performance of a complex motor sequence with minimal cognitive load in execution).[9]

Experts exhibit an economy of motor planning both at the level of central neural programming and subsequent motor unit activation that is not evident in novices. Novices engage in more cognitive activity than experts to execute a motor skill that they are learning. Cognition will activate areas of the brain (cerebellum and basal ganglia) not specifically required for the execution of the motor task; similarly, if novices have more difficulty filtering out or excluding irrelevant information, their brains will also show activation in the limbic area (posterior cingulate cortex, amygdala–basal forebrain complex and basal ganglia); the lower the motor skill, the higher the activation in the posterior cingulate cortex. These areas of the brain do not activate during the motor planning of experts.[19] The experienced or expert surgeon is ergonomically more efficient than the novice, uses fewer, more efficient and more precise movements, and demonstrates better instrument handling skills. The ways in which the trainee surgeon moves from novice to expert need to be better understood. Specific training experiences that enhance this process need to be identified and included in surgical training to help the transition of the novice surgeon to the surgical expert as quickly, efficiently and safely as possible.

In this brief article, we have necessarily focused on motor skill development, but attention, cognition, prior learning, and memory all play a crucial role in the final motor expression of complex learning in both music and surgery.[21] For musicians, technical dexterity serves a musically aesthetic performance. For surgery, the technical skill requisites are foundational in the same way, and these must serve other capacities such as clinical judgment and decision making. Qualities such as concentration, anticipation and an ability to listen are key elements in musical practice and performance, and using lessons from music has been advocated as a means of improving surgical performance.[22] However, care must be taken in how far to take this metaphor — "Music doesn't make you better at math, conjugating Latin doesn't make you more logical, brain training games don't make you smarter. Accomplished people don't boost their brains with intellectual calisthenics; they immerse themselves in their fields."[23]

We conclude that knowledge of how musicians are trained can be useful in terms of understanding, refining and reducing the time spent in surgical training. Aspects of deliberate practice and expert status, derived from musical performance theory, are examples of areas already incorporated, to some degree, in surgical training program design. We are currently exploring the extent to which other aspects of musical training, such as applications of theories of skilled motor development and preparation for peak performance, can similarly usefully be incorporated into surgical training.

Competing interests

None identified.

Author details

Andrew W McCaskie, MMus, MD, FRCS, Professor of Orthopaedic Surgery[1]
Dianna T Kenny, ATCL, MA, PhD, Professor of Psychology and Music[2]
Sandeep Deshmukh, MB BChir, MA, Academic Foundation Doctor[1]

1 Musculoskeletal Research Group, Institute of Cellular Medicine, Medical School, Newcastle University, Newcastle Upon Tyne, UK.

2 Australian Centre for Applied Research in Music Performance, University of Sydney, Sydney, NSW.

Correspondence: dianna.kenny@sydney.edu.au

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