A review of action observation in sensorimotor learning in surgery.

REVIEW PAPER

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Abstract

Background: Acquiring new motor skills to learn complex movements and master the use of a diverse range of instruments is fundamental for developing expertise in surgery. Although aspects of skill development occur through trial and error, action observation (watching the performance of another individual) is an increasingly important adjunct for the acquisition of these complex skills prior to performing a procedure, in either practice or real-life scenarios. The aim of this review was to examine the evidence in support of the use of action observation in surgery.

Method: A narrative review of observational learning for surgical motor skills was performed. Searches of PubMed and PsychINFO databases were performed using the terms ‘observational learning’ OR ‘action observation’ AND ‘motor learning’ OR ‘skill learning’.

Results: Factors such as the structure of physical practice, the skill level of the demonstrator, cues for directing attention, and the use of feedback were all found to be important moderators of the effectiveness of observational learning.

Conclusion: Observational learning is an effective method for learning surgical skills. An improved understanding of observational learning may further inform the refinement and use of these methods in contemporary surgical training curricula.

Keywords: observational learning; surgical skills; surgery; motor learning; skill acquisition

Introduction

Surgery is a complex multi-faceted process, at times requiring varying combinations of anatomical expertise, decision-making under pressure, endurance and dexterity. This latter aspect, in particular, is not well-understood in the specific context of surgical training. The recent shift towards minimally-invasive surgery requires the trainee and experienced surgeon to continually develop new motor skills to control novel instrumentation. For this to occur, new neural pathways must be created to govern how surgeon's hand movements deliver the intended action at the tip of the instrument, a process formally known as motor learning[1,2]. Motor learning occurs through a continual refinement of movement control, based on feedback from movement outcomes[3]. An obvious example is through trial and error practice[2,4] where repetition generally leads to reduced errors and improved accuracy in a given task. Watching an expert performance of another individual (i.e. action observation) provides a blueprint of the desired outcome against which subsequent attempts at the task can be evaluated. If used effectively, observation has the potential to make a major contribution to skill learning.

Observational learning already plays a significant role in surgical training, through formal demonstrations of procedures or the opportunity to observe surgery within the operating theatre environment. There is potential to use these methods in a more effective manner, thereby enhancing surgical training, as identified in a recent consensus statement on the use of educational videos for laparoscopy[5]. The increasing shift towards robotically-assisted surgery makes an understanding of the key components of action observation (the who, how and what) even more important. With the surgeon now remote from surgical field, it is even less clear what aspects of the surgery or surgeon should be observed and how a trainee can most effectively learn to navigate the robotic instruments. Therefore, the aim of this review is to give an overview of how motor learning through observation occurs and the factors that are thought to optimise the effectiveness of observational learning.

Methods

A narrative review was conducted to investigate the factors that influence observational learning, and how they affect acquisition of technical skills in surgical training. As this review aimed to give an overview of a range of factors most relevant to surgical training, a narrative, rather than systematic, approach was adopted. Searches of PubMed and PsychINFO databases were run using the terms 'observational learning' OR 'action observation' AND 'motor learning' OR 'skill learning'. Titles and abstracts were screened and reference lists checked for further relevant articles. Additional articles were hand-selected. Rather than providing an exhaustive review of research relating to observational learning of motor skills, a summary of the findings most pertinent to surgical training are outlined. Firstly, an overview of observational learning is presented and secondly key factors in observational learning are reviewed.

Results

Observational learning

Observational learning is the process of watching another individual perform an action prior to engaging in physical practice. The individual being observed is often referred to as the 'model', a term which will be used exclusively for this purpose, to avoid confusion with surgical models. Observational learning of motor skills has been shown to accelerate skill acquisition across a range of complex motor tasks[6,7] and involves adapting one's behaviour in response to the model, rather than a direct imitation. Sheffield[8], and subsequently Bandura[9], suggest that observing another person perform an action creates a representation, or 'perceptual blueprint', of the action that helps the observer recreate the movement. While observation alone is typically less effective than actually performing the task, it is particularly beneficial when used as an adjunct to physical practice[10]. Observation may provide the learner with 'clues' about key aspects of the task, such as the physical constraints, desired movement patterns and subtleties that are difficult to acquire through verbal instruction alone[11].

For instance, those learning in dyads (two individuals alternating between physically practicing a task and observing their counterpart practicing the task), perform *at least* as well as those undertaking only trial and error learning, despite engaging in half the number of physical repetitions[12,13]. Additionally, in some scenarios physical practice promotes only 'good-enough' motor patterns – in other words, adaptation and refinement of the movement ends when the task can be completed without errors[4]. Action observation, by contrast, can go one step further and provide a 'blueprint' that helps refine motor patterns towards the standards expected of an expert. In addition, it also now well-accepted that observation is a key component of early stage surgical training for safe skill acquisition of more complex procedures, before exposure to in-vivo training. A final practical benefit is that observational learning is time and resource efficient, as it can be delivered to large groups concurrently through videos, simulators and online learning[14], when direct observation in the time-pressured environment of the operating room is not always possible. With increased adoption of minimally-invasive surgery, the ability to relay 'real-time' or pre-recorded procedures has exponentially increased.

Contribution of observation to motor learning?

The acquisition of skilled performance in a given task depends upon learning within four key areas: [i] developing an effective strategy for gathering information (e.g. where to look); [ii] acquiring knowledge of key features of the task (e.g. necessary steps in the procedure); [iii] learning higher-level skills, such as decision-making and anticipation; and [iv] developing and refining motor skills[15]. Observing the performance of a 'model' may contribute to the development of all four areas. Firstly, during observation, participants tend to produce predictive eye movements, moving attention to objects before they are interacted with, as the 'model' does[16], suggesting that effective information gathering strategies can be developed through observation. Secondly, acquiring knowledge of key task features has been demonstrated in a range of observational studies[6], such as when learning simple hand movement sequences[17]. Thirdly, task strategies in sensorimotor tasks can be directly learned from a 'model'[9], contributing to higher-level decision-making skills. Finally, the development of motor control mechanisms has been repeatedly shown to benefit from observation[6,10,18], although the precise mechanism underpinning this effect is still widely debated. As acquiring safe and effective control of increasingly novel and diverse instrumentation is a major component of contemporary surgical training, the development of motor control mechanisms through observation will be the focus of the remainder of this review. Existing work on the putative human mirror neuron system[19-22] (discussed below) suggests that areas of the human motor cortex are specially adapted to learn motor skills in this way.

The mirror neuron system

The mirror neuron (MN) system[20] refers to a class of neurons within the premotor and motor cortex of primates that are similarly activated when an action is either produced or observed. This system was detected initially through single cell recording in macaque monkeys[21], but the common activity of premotor and parietal motor regions during performance and observation is also well established in humans[20]. As motor areas are activated during observation, the movement is, in effect, simulated within the cortex of the observer. Many surgeons will be familiar with this 'rehearsal' ritual that they describe when trying to 'picture in their head' how they are going to do a particular step of a procedure. Mirror neuron activation allows a representation of the observed action to be developed without physical practice. Therefore, while watching the smooth suturing movements of an expert surgeon, the sensorimotor areas of the brain responsible for those same movements are activated, such that subsequent reproduction of those movements by the observer is facilitated. In this way, mirror neurons may be the mechanism for the 'perceptual blueprint'[8,9] created during observational learning[19,23,24].

Two primary mechanisms have been proposed for how the MN system facilitates motor skill learning via observation; by providing a *direct mapping* from observed to reproduced movements, or by facilitating the understanding of *action intentions* [6 25]. The direct mapping view emphasises that the MN system provides the opportunity for a direct simulation of the observed action in the motor system of the observer, allowing observers to effectively practice the movement without actually carrying it out[16,26]. Alternatively, the MN system may contribute to learning by facilitating an understanding of action intentions[6,22]. If the goals of the observed surgeon can be inferred from their actions, the observer can more effectively learn about the demands of the task. Additionally, there is emerging evidence that observational learning may contribute to the development of motor skills through error signals, in much the same way as physical practice[27]. Indeed similar ventromedial and dorsolateral prefrontal cortical areas, linked to the processing of errors, are activated while watching the errors of others, as when committing errors[27-29]. This third mechanism for learning from errors is particularly relevant when observing an error-strewn model[18]. In error-strewn models, the observer watches performance that is inexpert or characterised by a high error-rate – in doing so, they observe 'pitfalls' and mistakes to avoid.

There is evidence that new motor skills can be acquired, and established ones refined, through the observation of others. A number of factors have been shown to influence the *effectiveness* of action observation for motor skill learning and these will now be outlined; namely, the structure and volume of observed procedures, the characteristics of the person performing the task, mechanisms of feedback, attention and the visual information provided.

Factors influencing the effectiveness of observational learning of motor skills

Observational learning research has focused on well-quantified simple motor movements[7,17,30], where learning is dependent upon acquiring information about the task. In the context of surgical training, however, observational learning must enable the development of motor skills with novel instruments and surgical platforms[4]. Previous findings indicate that observation is indeed an effective method for learning surgical skills[14] and, pragmatically, surgeons have perceived benefit in observing each other's practice since inception of surgery itself. For instance, among students trained on a general surgery virtual reality simulator, those who observed the procedure prior to testing in an animal lab, exhibited significantly improved performance of minimally invasive tasks[31]. Research shows that observational learning of motor skills is affected by many of the same variables as physical practice, such as variability of practice[32], knowledge of results[33], and feedback[34]. This section provides an overview of some of these key factors, with implications for practice.

Physical and observational practice

Much as more frequent physical practice is beneficial for skill learning, more frequent exposure to a task demonstration is thought to advance learning by allowing a more refined blueprint of the task[9]. Previous findings have supported the benefits of repeated observation in learning to reproduce hand actions[35], but in a more complex surgical excision and closure procedure, Custers et al.[36] found no evidence that four observations were more effective than just one. Therefore, it is currently unclear what volume of observation is likely to be optimal for surgical skills.

Motor learning through physical rehearsal has been found to benefit from practice variability[32], where different tasks are interleaved, rather than learned one at a time. Practicing a variety of tasks provides contextual interference, as one task can disrupt the learning of another. Contextual interference may slow initial learning, *but* enable a greater depth of skill retention and more robust transferability to new contexts[37,38]. This contextual interference effect appears to extend to surgical observation[39]. For instance, Welsher and Grierson[39] had learners observe novice and expert models performing a simple endoscopic task, with groups varying in their level of contextual interference. A low interference group saw all expert trials followed by all novice trials, whereas intermediate interference and high interference groups observed semi-interleaved and fully interleaved schedules of expert/novice trials. In line with studies on overt physical practice[32], the low interference group displayed best immediate performance, but the high interference group performed best on a delayed transfer task, indicating better retention of learning. Therefore the inclusion of variable practice schedules, providing learners with a range of models and tasks in a random order, seems likely to benefit the observational learning of surgical skills.

The benefits of observational practice are often maximised through subsequent physical practice[13]. Blandin and colleagues[41] suggested that observation alone cannot develop a task representation as strong as that developed through physical practice. Specifically, development of a ‘motor plan’ can be achieved with observation, but *implementation* of the plan is required for maximal learning. This contention has received experimental support from Weeks and Anderson[10] in the sporting literature, who found that a mixture of physical practice and observation was optimal for learning in the context of a volleyball serve. The benefits of dyadic learning also highlight the efficacy of combined observation and physical practice Therefore combined observation and physical practice may be an optimal strategy, supporting the use of dyad learning in surgical training[11]. Overall, physical practice is necessary to effectively learn motor skills for surgery, but a variety of observational practice is likely to benefit skill acquisition before extensive physical repetitions are introduced. Determining whether a greater volume of observation will also advance learning is likely to require further investigation.

Observing error-strewn versus errorless performance

Traditionally, in both sporting and 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 be equally, or perhaps more beneficial than observing expert performance[29,40,41]. For instance, when lifting unusually weighted novel items, participants make lifting errors based on the *predicted* weight of the object, exerting greater than necessary fingertip and lifting forces for unexpectedly light objects[42]. While these lifting errors usually attenuate over repeated trials, Buckingham et al.[18] found that a group observing an individual making lifting errors (i.e. a novice) made smaller initial over-estimation errors than a group observing an individual well practiced in the task (i.e. an expert). Error-strewn observation drives skill learning through the engagement of error detection and correction processes, which refine motor control much like physical practice[30].

The advantage of error-strewn observation may also extend to the complex motor skills required for surgical tasks. When learning a ring-carrying training task on a robotic platform, [43] there was equivalent learning from expert or novice observation. LeBel and colleagues[41] examined medical students’ performance on an arthroscopic training task following ‘expert observation’, ‘novice observation’ or ‘no observation’ conditions. Participants were required to complete a ‘locate and palpate' task on a virtual knee-surgery simulator and were assessed on time to completion and several measures of instrument control. At a retention test, one week after watching the video, the novice-observing group outperformed both the control and expert-watching group in time to completion and camera path length, indicating an improvement in motor skill through observing errors.

It seems intuitive, however, that the provision of a mixture of expert and novice models would provide the greatest benefit for learning, through the development of error detection and correction mechanisms from the novice, and the ideal blueprint from the expert. [44] During a simple timing task, participants observing a mixed schedule outperformed novice or expert observation at a retention test. They were also better at estimating the magnitude of errors observed in the model, indicating the development of error detection mechanisms. Taken together, these findings challenge the traditional master/apprentice approach, where a trainee only learns from an expert surgeon. Watching the mistakes of other trainees during dyadic learning may help learners avoid making similar errors which, in practical terms, is a convenient and cost-effective method of enhancing learning.

Feedback

Feedback about performance (i.e. knowledge of results) is important for trial-and-error motor learning[33], as it provides a signal that movements need to be adapted. If observational learning of motor skills depends on similar cognitive processes to physical practice[34], feedback about the observed performance should have a major effect on learning. [30] When learning the timing of a simple movement, providing biased feedback about the timing error (e.g. adding 100ms) biased the subsequent movements of the model and the observer similarly. In a medical setting,[45] the performance on a simulated central line insertion task following mixed (novice and expert) observation, either with or without feedback regarding the status of the model was compared. In this study, performance was improved when the status of the model was given, suggesting explicit feedback may be advantageous when observing errors. Several studies have, however, found beneficial effects of observing errors in the absence of explicit feedback[18,40], which may be due to development of error detection mechanisms. As a result, the role of feedback when observing error-strewn performance requires further investigation.

[33] The guidance hypothesis suggests that, while feedback is necessary for learning, overly-frequent knowledge of results can lead to feedback dependency and hinder learning. In a movement timing task[46] information was provided about the model's performance on either every trial (100% condition) or one in three trials (33% condition) during observation. Feedback on 33% of trials was most beneficial for learning, in line with the guidance hypothesis, suggesting partial feedback aids learning through developing error-detection ability[47]. In the context of surgical training, when observation occurs during simulated procedures or in the operating room, some feedback about outcomes may be beneficial, but allowing learners to watch and develop their error detection abilities is key.

Attention to key information

The role of attention is key in action observation, since no learning can occur if features of the display are not attended to and perceived accurately[9]. The value of effective deployment of attention was demonstrated experimentally by Janelle and colleagues[48] who compared learning of a soccer pass from video demonstrations, with and without visual cues (arrows in the videotape to areas of interest, like the standing foot) and verbal cues (descriptions of crucial elements of the task, such as placing the standing foot parallel to the ball). Participants given both visual and verbal cues demonstrated better movement form and reduced error in passing to a target. [49] Cueing participants to key features of a golf swing during observation improved both immediate and delayed performance for swing execution. Similarly, in a surgical setting, attending to the right information may benefit the acquisition of motor skills. While assessing observational learning of early motor skills on a robotic platform, Harris et al.[43] recorded point of gaze during video observation. It was found that increased time spent observing the surgical instruments, rather than irrelevant areas, was subsequently linked to more efficient control of surgical instruments.

One well-established method for accelerating skill learning is observing the eye movement patterns of experts[50]. This method of feed-forward training provides the observer with a video of the task, overlaid with a cursor indicating the point of gaze of the expert. This allows the observer to learn what information they should pay attention to. Additionally, the adoption of expert-like gaze behaviours has been found to benefit motor skill execution, through accelerated acquisition and robustness under pressure[50-52]. [53] Ppoint-of-gaze videos obtained previously from an expert surgeon have been used to train medical students in an eye-hand coordination task on a laparoscopic surgical simulator. Participants observing the eye movements of experts learned more quickly than movement trained or discovery learning groups, and displayed improved performance under multitasking conditions. This form of observational training both cues attention to key information, and facilitates motor skills through a more direct perceptual-motor route[50].

Whilst two studies.[48] [49] have found beneficial effects of cueing, they are based on assumptions about which information was important. In some well-studied non-surgical tasks like the golf swingthe key information for coaching is relatively clear. For surgical tasks, however, the optimal focus of attention throughout the task may not be so apparent. For example, is it more beneficial to watch only the movement of the instruments, only the surgeon's hands, or a combination of both? Research on point light displays, where dots of light presented against a black background are easily recognised as human movements, has indicated that the movement of the end effector (here the surgical instrument) often provides the key information[6,55]. To develop the use of attentional cueing during surgical observation, comparing observation of the instrument effects versus how the surgeon controls the instrument may be needed. Nonetheless, cueing of attention and observation of eye movements both hold promise for improving observational motor learning techniques. Online videos of expert-like eye movements during surgical procedures could be used as a convenient and cost-effective practice tool for trainees to learn optimal gaze strategies.

Quality of observational display

In order to develop expert-like motor skills, an observer may need to be exposed to a range of sensory outcomes, in addition to binary success/failure feedback[56]. Therefore, the quality of what is observed, in terms of visual, auditory and other sensory information may have a significant impact on learning. Advances in 3D viewing systems within robotic platforms and surgical simulators provide additional depth information in the visual display, but findings are equivocal regarding their effect on observational learning. A study [57] examined the performance benefits of viewing a 2D versus stereoscopic 3D video demonstration of a surgical training task. While stereoscopic depth cues are important for reaching and grasping movements[58], and have been shown to benefit robotic surgical performance[59], there was no learning benefit and no difference in surgical instrument control for 3D versus 2D observation. Similar results have been found regarding live versus video demonstrations. Rohbanfard and Proteau[60] demonstrated that even though a live demonstration produces greater activation of cortical motor areas, there was no difference in learning between live and video conditions in a movement timing task. Additionally, there was little effect of observer viewpoint on task learning[60]. Together, these results suggest that when key information is provided, the fidelity and perspective afforded by expensive 3D viewing systems and/or live observation may offer limited benefit over standard video observation.

Discussion

Recommendations for surgical training

Technical proficiency is only one aspect of becoming a surgeon, however, both open and minimally-invasive surgery provide substantial challenges for developing expertise with novel instruments. Growing demands on service provision are currently posing additional difficulties for the delivery of effective surgical training. Economic pressures require hospitals to deliver improved patient care, at a lower cost, with reduced wait times, which at times may be competing with the need for delivery of surgical training. Additionally, due to working hours restrictions, less time is being allotted for trainees to develop basic surgical skills[61]. This tension has impacted on the opportunities for surgical residents/trainees to be exposed to certain training scenarios or conditions recommended for their level of training[62]. In the context of these increasing time and economic pressures, learning from observing experts or peers may provide some mitigation and deliver a cost-effective way of acquiring and consolidating motor skills.

It appears that motor skills for surgery can be developed through action observation. The putative mirror neuron system may facilitate learning through activating cortical motor areas which correspond to observed movements. Key variables that influence the effectiveness of observational learning of motor skills have been identified. Observational learning can be maximised in similar ways to physical motor learning, such as infrequent knowledge of results and variability of both the task and model. Simple adjustments to training can make use of these benefits. This review has also highlighted the potential efficacy of observing error-strewn performance during surgical training[18,40,41], particularly in the early stages of skill learning. Consequently, dyad learning provides an effective and resource-efficient training method by combining observation and physical practice[10,11,38], in addition to providing trainees with the opportunity to observe error-strewn performance. Therefore, trainees should be encouraged to practice tasks in alternation, rather than under the direct instruction of an expert mentor.

The benefits of action observation appear to be maximised by arranging learning to make key features salient, such as through cueing attention to the end movement of the instrument[48]. Additionally, observation of expert-like gaze patterns has been found to be effective for assisting skill learning[63]. Given the growing opportunities provided by e-learning, online access to a range of videos illustrating optimal gaze behaviour in surgical procedures, from a range of models, across a variety of tasks may allow trainees to develop their skills at any time, from any location[5]. Overall, a greater understanding of motor skill development through action observation, and implementation of the above recommendations may contribute to more effective use of observation during surgical training.

Observational learning of motor skills affords an opportunity for acquiring complex motor patterns that cannot be verbalised. Observational learning can be used when physical practice would be impractical or inappropriate. In particular, amid shifts towards competency based training[64], there is increased scrutiny with regard to trainee surgeons moving on to real-world practice ahead of time[65,66]. In response to these issues, observational learning can provide a cost-effective and convenient way of maximising skill acquisition in parallel to or before in-vivo surgical experience. To this end, the mechanisms of motor learning discussed here provide a background for improving the use of observational learning methods within surgical training curricula.

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