Causer, J, Barach, P and Williams, AM

Expertise in medicine: using the expert performance approach to improve simulation training

Article

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Abstract

Context: We critically review how medical education can benefit from systematic use of the expert performance approach as a framework for measuring and enhancing clinical practice. We discuss how the expert performance approach can be used to better understand the mechanisms underpinning superior performance among healthcare providers and how the framework can be applied to created simulated learning environments that present increased opportunities to engage in deliberate practice. **Expert Performance approach:** The expert performance approach is a systematic, evidence-based framework for measuring and analysing superior performance. It has been applied in a variety of domains, but has so far been neglected in medicine and healthcare. In this paper, we outline the framework and demonstrate how it can be effectively applied to medical education. **Deliberate Practice:** Deliberate practice is defined as structured and reflective activity, which is designed to develop a critical aspect of performance. Deliberate practice provides an opportunity for error detection and correction, repetition, access to feedback and requires maximal effort, complete concentration and full attention. The paper provides guidance on how to structure simulated learning environments to encourage the accumulation of deliberate practice. **Conclusions:** We highlight the role of simulation-based training in conjunction with deliberate practice activities such as reflection, rehearsal, trial-and-error learning, and feedback in improving the quality of patient care. We argue that the development of expertise in healthcare is directly related to the systematic identification and improvement of quantifiable performance metrics. In order to optimize the training of expert healthcare providers, advances in simulation technology need to be coupled with effective instructional systems design, with the latter being strongly guided by empirical research from the learning and cognitive sciences.

Introduction

Significant variation in clinical competencies exists between individual providers which may contribute to large variation in patient outcomes and inefficient use of resources[1]. Although increasing experience plays an essential role in achieving proficiency, doing more procedures does not necessarily ensure that expertise will be attained if reflection, feedback, and learning are limited[2]. The development of expertise is thought to be a consequence of the amount of domain-specific deliberate practice accumulated by individuals throughout their career rather than mere exposure to the performance domain. Deliberate practice is defined as "structured activity, which is designed to develop a critical aspect of current performance"[3]. Deliberate practice provides an opportunity for error detection and correction, repetition, access to feedback, complete concentration, and full attention.[3]

Developing expertise in healthcare relates to the systematic identification and improvement of quantifiable performance metrics. In this review, we focus on the effectiveness of simulation in helping to identify and facilitate development of the critical skills that underpin expert performance in healthcare. Specifically, we review the expert performance approach[3] and how it can be utilized to help capture, develop, and sustain expertise in healthcare delivery. We identify advances in simulation technology and explore how the expert performance approach can be integrated into medical education to provide effective and efficient training. Although this is not a systematic review, we conduct a thorough review of literature on simulation and its use in medicine and provide support for the arguments, discussions, and suggestions outlined.

Expert performance approach

An individual's experience in a given domain is not always correlated to a improved performance outcomes, in fact, it can be negatively related[4]. For example, experts in decision making and judgment often fail to display superior performance accuracy, especially in tasks involving predictions of future outcomes when compared with less experienced or skilled counterparts[5]. Ericsson and Smith[6] introduced the expert performance approach in response to this apparent dissonance between professional experience and indicators of expertise. The approach presents a systematic, evidence-based framework for measuring and analysing superior performance in a domain rather than studying the differences between individuals viewed as experts and novices, respectively through subjective, peer-based review [7, 8].

Ericsson and Smith[6] suggest that those studying expertise should focus on trying to capture performance using reliable and objective measures. They present a three-stage framework for capturing and developing expertise (see Figure 1). First, researchers must recreate the task(s) in the laboratory or field with sufficient fidelity to elicit the requisite expertise in a reliable and objective manner. Second, the mechanisms underpinning superior performance should be identified using experimental manipulations and process-tracing measures. Third, activities that lead to performance improvements need to be identified so that the path to competency is clearly defined and can be targeted for training and development. The framework has been successfully utilized in many professional domains, such as in sports[8] and the military[9], but has not been broadly deployed in healthcare. In this review, we discuss how this framework can be used to develop more effective and efficient training environments for healthcare professionals. In particular, we focus on the potential role that simulation in all its various guises may play in providing objective, reliable, and valid methods to capture, assess, and enhance expertise in healthcare.

Insert Figure 1 here

Stage 1: Capturing expert-performance

In this initial stage of the expert performance approach, the emphasis is on creating scenarios and environments that are representative of the real-world and include the same perceptual and cognitive processes. In healthcare, the use of simulated environments is becoming more prevalent and the technology more advanced, providing opportunities to create representative environments for testing and training[10]. The types of simulators are varied, including for example, complex task trainers for endoscopic and catheter based procedures, ultrasound simulators, standardized patients, computer-based case simulations, full length mannequin computer controlled simulators, and surgical devices incorporating touch, audio, and visual simulation[11, 12]. Virtual reality devices are also rapidly reaching an early stage of implementation[13]. These environments allow educators to provide repeatable, controlled clinical scenarios that can closely match the demands of a real-world task (stage one in Figure 1) without jeopardizing patient health[14]. Simulators and virtual reality environments are currently being utilized in various medical domains such as in cardiovascular medicine[15], emergency medicine[16], midwifery[17], and gynaecology[18]. The data gathered in these studies suggest that simulation-based mastery and learning exercises that embrace the principles of deliberate practice can be used to improve the performance of complex skills.

However, concerns remain when using simulations for training and performance enhancement, particularly in regards to the validity of the measurements and methods employed and the extent to which they adequately capture the demands and complexity of the real world[19, 20]. Historically, there have been concerns about the physical and psychological fidelity of simulators[21]. The early simulators were low in fidelity and did not allow 'real-world' representations to be accurately produced, and therefore differences as a function of expertise were difficult to ascertain[1]. More recently, high-fidelity simulators have been developed that better recreate the demands of the operating theatre and hospital wards, providing an opportunity to more accurately measure expertise. Several recent reports provide a modicum of construct validity for the use of simulators in healthcare. For example, Cormier et al.[22] used a high-fidelity medical simulation to distinguish between low and high performing student nurses based on their ability to prioritize patient care more effectively. Similarly, Schijven and Jakimowicz[23] highlighted the potential of simulations to differentiate expert from novice surgical providers. These authors used a simulation task that required clipping and cutting the cystic duct and artery during a laparoscopic cholecystectomy. A group of expert and novice surgeons were familiarized with the simulator and each performed the task three times. The expert group scored significantly higher on the second and third attempts when compared with the novice group. Moreover, the experts demonstrated significantly faster completion times on all three attempts. These results demonstrate the potential application of simulators in providing a representative task to examine skill-based differences in surgical skills[24, 25]. It is important to note that there were no differences in performance between the two groups in the first trial. This latter finding suggests that there is a need to provide sufficient opportunity for providers to familiarize themselves with the simulator in order to become comfortable with the demands and constraints of the task.

Although recent published reports have clearly highlighted the potential value of using simulators to capture expert performance in healthcare settings, there remain opportunities to capture expertise *in-situ* during routine medical procedures. For example, it is possible to capture certain process-tracing measures (see Figure 1; discussed in more detail in stage 2), such as verbal reports, video-based coding of behaviours and movement efficiency, and point-of-gaze data *in situ*[1]. The collection of such data could easily be implemented in less complex and more frequent activities, such as during ward rounds, x-ray and scan analyses and in general patient assessment. However, the use of such invasive measures may prove more difficult in tasks such as surgery, as the complexity of the real-world scenario varies, and cases are often unpredictable, and difficult to control and reproduce key variables. In these latter cases, simulators offer several advantages due to their ability to present reproducible and controlled environments and to eliminate/reduce risks to patient safety[26]. Clearly, a suitable balance is required between the need to maintain external or ecological validity on the one hand and the desire for internal validity and experimental control on the other.

In summary, in many instances simulators offer healthcare providers the closest environment to the real world that is currently possible without compromising patient care. Clearly, researchers and expert clinicians need to pool knowledge and engage in meaningful discussions as to how best to develop the most representative task environments[27]. It is critical that these tasks engage the same knowledge structures and perceptual-cognitive processes that are used in the real patient care so as to ensure that performance is accurately captured and an appropriate opportunity is provided for training and development.

Stage 2: Identifying mechanisms underlying expertise

Once a representative task has been developed, the specific mechanisms, knowledge structures, and technical abilities needed to successfully complete the task can be measured. Process-measures such as verbal reports, gaze behaviours, movement efficiency, and behavioural analysis can identify the concurrent processes that mediate individual differences during superior performance[8, 28]. The effectiveness of each of these measures and how they have previously been applied in a medical setting is discussed below.

Insert Figure 2 here

Think-aloud verbal protocols, both concurrent and retrospective, have been used to reveal the refined knowledge and reasoning strategies underpinning superior performance[29]. These techniques are useful to identify the domain specific knowledge that experts utilize in order to perform the task. For example, Lesgold et al.[30] reported that expert radiologists demonstrate longer reasoning chains with more of their comments being interlinked and interconnected to at least one other chain. These findings highlight how experts store and organize knowledge in a more coherent manner enabling them to better access and retrieve this information to solve simplex tasks.

Verbal reports can also be used to identify cognitive structures in complex tasks. Joseph and Patel[31] examined how domain specific knowledge impacts on diagnostic reasoning by collecting retrospective verbal reports. A sample of experts (endocrinologists) and physician non-experts (cardiologists) were asked to solve a range of endocrine cases. The expert group selected more relevant and critical cues from the case history, compared to the physician non-expert group who focused on significantly more irrelevant cues. The experts generated more links to related critical or relevant cues and showed better organization of their domain knowledge.

This domain specific knowledge can be critical when key information is unavailable. McRobert et al.[32] examined skill-based differences in cognitive processes and how they are altered as a function of removing context-specific information related to the patient's medical condition. The results suggest that experts employ complex domain-specific memory representations which enable them to easily retrieve task-specific information and make better judgments compared with less expert counterparts[33, 34].

It is clear from the information presented above that experts are accessing a considerable bank of domain specific information that is seemingly available instantly, suggesting a more efficient memory retrieval system. According to the long-term working memory theory (LTWM)[33], skilled individuals are able to bypass the limitations in storage by acquiring skills that encode information with numerous and elaborate retrieval cues that are related to prior knowledge. The time required to encode and retrieve options is reduced with the development of retrieval structures through an extended period of deliberate practice.

After extensive practice in the domain, experts index information in such a way that they can successfully anticipate future retrieval demands and quickly update the knowledge they need to address the question or challenge at hand. If representative tasks can be developed that enable practitioners to sustain engagement in domain specific deliberate practice, over time critical knowledge structures and more efficient memory processes could be developed.

Ericsson and colleagues proposed the LTWM theory to explain how experts can reduce the amount of information needed to create a coherent representation of the visual scene by selectively attending to only the pertinent information in the display. Expert performance in many domains is characterized by fewer fixations of longer duration, supporting the premise that experts extract more task relevant information from each fixation. Law et al.[35] examined the eye movements of expert and novice surgeons performing a one-handed task on a computer-based laparoscopic surgery simulator. The novice group required more visual feedback when compared to experts about the tool position needed to complete the task. The experts had a tendency to maintain their gaze on the target, while manipulating the tool and monitoring its movement in the periphery, whereas the novice group demonstrated a much more variable gaze pattern, fixating on the tool and target intermittently. These findings were corroborated by Wilson et al.[36] who found that experienced surgeons employed significantly longer fixation durations on the target location than novices in a virtual laparoscopy surgical task. These data suggest that by measuring gaze strategies researchers can identify critical visual information that experts use in order to plan and control their movements when attempting to complete complex clinical tasks. As well as using more efficient gaze behaviours and elaborate memory structures, experts tend to have more efficient motor control strategies. Experts usually take less time and less effort to complete tasks. For example, Richards et al.[37] examined instrument forces and torque applied during a cholecystectomy and a Nissen fundoplication in a pig model between expert and novice surgeons. Lower forces and torques were identified in novices during tissue dissection, whereas experts demonstrated higher forces and torques when performing tissue manipulation. Novice surgeons required significantly more time to complete the task and made more non-goal oriented movements compared to their expert counterparts while applying larger forces and torques when not needed. These data highlight the most effective and efficient method of completing clinical tasks in order to provide accurate training and instruction for those learning novel tasks.

In summary, a range of process-tracing measures may be recorded during simulation (and/or *in-situ*) in order to develop a comprehensive representation of expertise in a given task. Once identified, medical educators can design and implement specific training environments and interventions via engagement in deliberate practice that enable the underlying processes and mechanisms to be developed.

Stage 3: Acquiring expertise

The relationship between expert performance and the volume of domain-specific deliberate practice has been consistently demonstrated across diverse professional domains, including sports[38], music[3], business[39], nursing[7], and academia[40, 41]. These studies suggest that engagement in structured practice leads to the development of task-specific knowledge that helps skilled individuals focus their attention on more pertinent areas of the display, making it easier to surmise situational probabilities from events previously experienced. These task-specific adaptations enable the more effective processing of contextual information[42]. Medical simulators enable individuals and teams of professionals to engage in safe learning scenarios that involve feedback, the repetition of skills, processes and procedures, detect and solve errors or diagnostic problems, within an environment which requires full attention and concentration[43, 44]. For example, simulators can accurately mirror human responses to such procedures as induction of general anaesthesia, tracheal intubation, and cardiopulmonary resuscitation including proper chest compressions with adequate force. Such capabilities provide controlled opportunities for systematic learning and the deliberate practice of a wide range of cognitive and technical skills[45, 46]in scenarios representative of the real-world[41, 42].

The benefits of deliberate practice in the medical domain have been documented. For example, Wayne et al.[47] examined the role of deliberate practice on the ability of surgical residents to master thoracentesis skills. Performance of the clinical skills test improved by 71% with all residents exceeding the mastery standard. The accumulation of medical knowledge can also be improved with deliberate practice. Moulaert et al.[48] examined the effects of deliberate practice on the academic achievements of medical students. Positive correlations were reported demonstrating the impact of deliberate practice on academic performance. Furthermore, McGaghie et al.[49] conducted a meta-analysis of the effects of practice and learning outcomes in medical-based simulation training. A strong association was reported between the hours of deliberate practice accumulated on the medical simulators and standardized learning outcomes. Similarly, Issenberg et al.[50] reported that high-fidelity medical simulations facilitate learning. The results from these meta-analyses demonstrate the need to integrate the deliberate practice framework in training to achieve more effective skill acquisition.

Although significant effects have been reported in training studies involving the use of simulators, most of these reports lack the scientific rigor employed in other non-clinical domains[1]. Several papers report less than rigorous experimental designs, using qualitative and subjective performance measures. Traditional experimental designs involving pre- and post-test measures of performance and appropriate measures of retention and transfer are rare. There have been no attempts to record process-tracing measures during acquisition to ascertain how the underlying processes and mechanisms alter with practice[1]. Such inconstancies and poor experimental designs have led to inconclusive findings that limit the ability to generalize findings to other domains or scenarios. Scientific literature from other domains such as from sports[21] and the military[51] provide examples of how to develop more suitable experimental designs to determine the most effective learning environments for using simulators. This latter body of literature highlights the need to create an environment where students and trainees can perform repetitive behaviours and receive feedback and instruction to ensure development of key skills. These environments should be challenging, and individuals should be encouraged to detect their errors, reflect on their workflow and outcomes, and correct their own errors.

A particular benefit of simulations is that they enable clinicians to attempt the most challenging and demanding cases and engage in trial and error learning and problem solving without putting the safety of patients at risk[11]. Critical cases, which may arise infrequently in clinical settings, can be reproduced in a simulation providing greater opportunity for deliberate practice. Simulators also open up possibilities for scenario simulation where decision-making is multi-layered and context specific[52] (stage three in Figure 1). For example, scenarios that involve large teams, working with missing or incorrect information and with unexpected or complicated cases are not regularly seen in a real-world environment yet are easily replicated in a simulation.

Conclusions

We argue that the development of expertise in healthcare is directly related to the systematic identification and improvement of quantifiable performance metrics. Moreover, in order to develop expert and safe providers of healthcare, supervised practice must start at a very early stage of training and importantly, must be maintained at high daily levels for many years, perhaps a decade or more[3]. The effects of extended deliberate practice, coaching and feedback, on performance are more far-reaching than is commonly believed and might explain why centralization of highly specialized care such as cancer, paediatric cardiac surgery, cystic fibrosis and more requires high volumes of practice by the entire clinical microsystem[53-55].

We propose that the expert performance approach offers a systematic framework to capture and facilitate performance in healthcare settings. Furthermore, the evidence, albeit mostly from non-medical fields, and increasingly in healthcare, is that despite anecdotal evidence suggesting that expert performance reflects innate abilities/capacities or the passive accumulation of experience, expertise actually arises through prolonged and dedicated engagement in deliberate practice activities. An extended engagement in well-structured, domain-specific deliberate practice in suitable environments can expedite skill development. We believe that health providers can develop mechanisms that contravene the basic working memory capacity/processing limits by using simulation in all its various guises linked with deliberate practice. We suggest that the scientific study of expert performance can improve understanding of the limits and structure of human adaptation as well assisting in creating safe training environments and structures that lead to improved healthcare provision. The framework might also help understand how the expert performance model can be applied to teams and lead to sustained, high performing clinical microsystems.

It is clear that there are a number of variables that determine whether, and how long, it will take an individual to achieve expertise in healthcare. There appears to be a strong case for promoting engagement in deliberate practice activities that allow the build-up of domain-specific declarative and procedural knowledge. Physical and virtual-reality simulators offer an opportunity to engage in these practice behaviours under controlled conditions. Educators should be encouraged to embrace new technology to develop a more interactive and ecologically valid learning environment.

More research is needed to establish a stronger evidence-based practice for the optimal use of simulation in healthcare. Without a systematic framework for guiding and structuring learning opportunities in simulation environments, improvements in performance may be limited and non-sustainable. Those involved in designing medical training curriculum need to work with scientists, clinicians, and practitioners to ensure that contemporary technology is used effectively and efficiently to maximize the return on investment and promoting improved patient safety and healthcare value. Learning and simulation performance measures must be based on scientific evidence, account for individual and team-level performance differences, capture process and outcome measures, adhere to standards of reliability and validity, and address real or perceived barriers to measurement. In order to optimize the development of future generations of expert healthcare provides, advances in simulation technology need to be coupled with effective instructional systems design, with the latter being strongly guided by contemporary research from the learning and cognitive sciences.

References

[1] Causer J, Williams AM. Professional expertise in medicine. In: Lanzer P, ed. *Catheter-based Cardiovascular Interventions – Knowledge-based Approach*. Springer, NY, 2012; 97-112.

[2] Ericsson KA, Starkes JL. *Expert performance in sport*. Champaign, IL Human Kinetics; 2003.

[3] Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev*. 1993;**100**:363-406.

[4] Shanteau J, Stewart TR. Why study expert decision making? Some historical perspectives and comments. *Organ Behav Hum Decis Process*. 1992;**53**:95-106.

[5] Camerer CF, Johnson EJ. The process-performance paradox in expert judgement: How can the experts know so much and predict so badly? In: Ericsson KA, Smith J, eds. *Toward a General Theory of Expertise: Prospects and Limits*. Cambridge University Press, NY, 1991; 195-217.

[6] Ericsson KA, Smith J. Prospects and limits of the empirical study of expertise: An introduction. In: Ericsson KA, Smith J, eds. *Toward a General Theory of Expertise: Prospects and Limits*. Cambridge University Press, NY, 1991.

[7] Ericsson KA, Whyte J, Ward P. Expert performance in nursing: reviewing research on expertise in nursing within the framework of the expert-performance approach. *Advances in Nursing Science*. 2007;**30**:E58-E71.

[8] Williams AM, Ericsson KA. Perceptual-cognitive expertise in sport: some considerations when applying the expert performance approach. *Hum Mov Sci*. 2005;**24**:283–307.

[9] Williams AM, Ericsson KA, Ward P, Eccles DW. Research on expertise in sport: implications for the military. *Military Psychology*. 2008;**20**:S123-S145.

[10] Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education. *JAMA: the journal of the American Medical Association*. 2011;**306**:978-988.

[11] Streufert S, Satish U, Barach P. Improving medical care: the use of simulation technology. *Simulation & Gaming*. 2002;**32**:164-174.

[12] Okuda Y, Bryson EO, DeMaria S, et al. The utility of simulation in medical education: what is the evidence? *Mt Sinai J Med*. 2009;**76**:330-343.

[13] Thijssen AS, Schijven MP. Contemporary virtual reality laparoscopy simulators: quicksand or solid grounds for assessing surgical trainees? *The American Journal of Surgery*. 2009;**199**:529-541.

[14] McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. *Med Educ*. 2010;**44**:50-63.

[15] Fox KF. Simulation-based learning in cardiovascular medicine: benefits for the trainee, the trained and the patient. *Heart*. 2012.

[16] Wang EE, Quinones J, Fitch MT, et al. Developing technical expertise in emergency medicine: The role of simulation in procedural skill acquisition. *Acad Emerg Med*. 2008;**15**:1046–1057.

[17] Cooper S, Cant R, Porter J, et al. Simulation based learning in midwifery education: A systematic review. *Women and Brith*. in press.

[18] Geller EJ, Schuler KM, Boggess JF. Robotic Surgical Training Program in Gynecology: How to Train Residents and Fellows. *Journal of Minimally Invasive Gynecology*. 2011;**18**:224-229.

[19] Reznek MA, Rawn CL, Krummel TM. Evaluation of the educational effectiveness of a virtual reality intravenous insertion simulator. *Acad Emerg Med*. 2002;**9**:1319-1325.

[20] Dormans J. Beyond iconic simulation. *Simulation & Gaming*. 2011.
[21] Ward P, Williams AM, Hancock PA. Simulation for Performance and Training. In: Ericsson KA, Charness N, Feltovich PJ, Hoffman RR, eds. *The Cambridge Handbook of Expertise and Expert Performance*. Cambridge University Press, Cambridge, UK, 2006; 243-262.
[22] Cormier EM, Pickett-Hauber R, Whyte J. Cognitions and clinical performance: a comparison of high and low performing baccalaureate nursing students. *International Journal of Nursing Education Scholarship*. 2010;**7**:Article27.
[23] Schijven M, Jakimowicz J. Construct validity: experts and residents performing on the Xitact LS500 laparoscopy simulator. *Surg Endosc*. 2003;**17**:803-810.
[24] Verner L, Oleynikov D, Holtmann S, Haider H, Zhukov L. Measurements of the level of surgical expertise using flight path analysis from da Vinci Robotic Surgical System. *Medicine Meets Virtual Reality*. 2003;**11**:373-378.
[25] Haluck RS, Webster RW, Snyder AJ, et al. A virtual reality surgical simulator trainer for navigation in laparoscopic surgery. In: Westwood JD, Hoffman HM, Mogel GT, Stredney D, Robb RA, eds. *Medicine Meets Virtual Reality 2001: Outer space, inner space, virtual space*. IOS Press, Amsterdam, 2001; 171-177.
[26] Schmidt E, Goldhaber-Fiebert SN, Ho LA, McDonald KM. Simulation exercises as a patient safety strategy: A systematic review. *Ann Intern Med*. 2013;**158**:426-432.
[27] Ericsson KA, Williams AM. Capturing naturally occurring superior performance in the laboratory: Translational research on expert performance. *J Exp Psychol Appl*. 2007;**13**:115-123.
[28] Ericsson KA, Simon HA. *Protocol Analysis: verbal Reports as Data*. Cambridge, MA Bradford Books/MIT Press; 1993.
[29] Hoffman RR, Shadbolt NR, Burton AM, Klein G. Eliciting knowledge from experts: a methodological analysis. *Organ Behav Hum Decis Process*. 1995;**62**:129-158.
[30] Lesgold A, Rubinson H, Feltovich P, Glaser R, Klopfer D, Wang Y. Expertise in a complex skill: Diagnosing X-ray pictures. In: Chi M, Glaser R, Farr MJ, eds. *The Nature of Expertise*. Erlbaum, Hillsdale, NJ, 1988; 311-342.
[31] Joseph GM, Patel VL. Domain knowledge and hypothesis generation in diagnostic reasoning. *Med Decis Making*. 1990;**10**:31-46.
[32] McRobert AP, Causer J, Vassiliadis J, Watterson L, Kwan J, Williams AM. The influence of context-specific information on quality of treatment during a simulated real-life emergency medicine decision-making task. *British Medical Journal: Quality & Safety*. in press.
[33] Ericsson KA, Kintsch W. Long-term working memory. *Psychol Rev*. 1995;**102**:211-245.
[34] Patel V, Arocha JF, Zhang J. Thinking and Reasoning in Medicine. In: Holyoak KJ, Morrison RG, eds. *The Cambridge Handbook of Thinking and Reasoning*. Cambridge University Press, New York, 2005.
[35] Law B, Atkins MS, Kirkpatrick AE, Lomax AJ, Mackenzie CL. Eye gaze patterns differentiate novice and experts in a virtual laparoscopic surgery training environment. *Eye tracking research & applications symposium on eye tracking research & applications* ACM Press, NY, 2004; 41-48.
[36] Wilson M, McGrath J, Vine SJ, Brewer J, Defriend D, Masters R. Psychomotor control in a virtual laparoscopic surgery training environment: gaze control parameters differentiate novices from experts. *Surg Endosc*. 2010;**24**:2458-2464.
[37] Richards C, Rosen J, Hannaford B, Pellegrini C, Sinanan M. Skills evaluation in minimally invasive surgery using force/torque signatures. *Surg Endosc*. 2000;**14**:791-798.

[38] Ward P, Hodges NJ, Starkes JL, Williams AM. The road to excellence deliberate practice and the development of expertise. *High Ability Studies*. 2007;**18**:119-153.
[39] Unger JM, Keith N, Hilling C, Gielnik MM, Frese M. Deliberate practice among South African small business owners: Relationships with education, cognitive ability, knowledge, and success. *Journal of Occupational and Organizational Psychology*. 2009;**82**:21-44.
[40] Simonton DK. *Creativity in Science: Chance, Logic, Genius, and Zeitgeist*. Cambridge Cambridge University Press; 2004.
[41] Ericsson KA, Nandagopal K, Roring RW. Toward a science of exceptional achievement: Attaining superior performance through deliberate practice. *Ann N Y Acad Sci*. 2009;**1172**:199-217.
[42] Williams AM. Perceiving the intentions of others: how do skilled performers make anticipation judgments? *Prog Brain Res*. 2009;**174**:73-83.
[43] Williams AM, Ford PR, Eccles DW, Ward P. Perceptual-cognitive expertise in sport and its acquisition: implications for applied cognitive psychology. *Appl Cogn Psychol*. 2010;**25**:432–442.
[44] Barach P, Satish U, Steuffert S. Healthcare assessment and performance. *Simulation & Gaming*. 2001;**32**:147-151.
[45] Seymour NE, Gallagher AG, Roman SA, O'Brien MK, Bansal VK, Andersen DK. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Ann Surg*. 2002;**236**:458-463.
[46] Gallagher AG, Ritter EM, Champion H, Higgins G, Fried MP, Moses G. Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. *Ann Surg*. 2005;**241**:364-372.
[47] Wayne DB, Barsuk JH, O'Leary KJ, Fudala MJ, McGaghie WC. Mastery learning of thoracentesis skills by internal medicine residents using simulation technology and deliberate practice. *Journal of Hospital Medicine*. 2008;**3**:48-54.
[48] Moulaert V, Verwijnen MGM, Rikers R, Scherpbier AJJA. The effects of deliberate practice in undergraduate medical education. *Med Educ*. 2004;**38**:1044-1052.
[49] McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. Effect of practice on standardised learning outcomes in simulation-based medical education. *Med Educ*. 2006;**40**:792-797.
[50] Issenberg SB, McGaghie WC, Petrusa ER, Gordon DL, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach*. 2005;**27**:10-28.
[51] Ward P, Farrow D, Harris KR, Williams AM, Eccles DW, Ericsson KA. Training perceptual-cognitive skills: can sport sychology research inform military decision training. *Military Psychology*. 2008;**20**:S71-S102.
[52] Christensen U, Heffernan D, Barach P. Microsimulators in medical education: An overview. *Simulation & Gaming*. 2001;**32**:247-258.
[53] Ke KM, Hollingworth W, Ness A. The costs of centralisation: a systematic review of the economic impact of the centralisation of cancer services. *European Journal of Cancer Care*. 2012;**21**:158-168.
[54] Patel RS, Hewett J, Hickey SA. Patient burden of centralization of head and neck cancer surgery. *J Laryngol Otol*. 2004;**118**:528-531.
[55] Stitzenberg KB, Sigurdson ER, Egleston BL, Starkey RB, Meropol NJ. Centralization of cancer surgery: implications for patient access to optimal care. *J Clin Oncol*. 2009;**27**:4671-4678.