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Toward a Model of Human Information Processing for Decision-Making and Skill Acquisition in Laparoscopic Colorectal Surgery

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OBJECTIVE: To create a human information–processing model for laparoscopic surgery based on already established literature and primary research to enhance laparoscopic surgical education in this context.

DESIGN: We reviewed the literature for information-processing models most relevant to laparoscopic surgery. Our review highlighted the necessity for a model that accounts for dynamic environments, perception, allocation of attention resources between the actions of both hands of an operator, and skill acquisition and retention. The results of the literature review were augmented through intraoperative observations of 7 colorectal surgical procedures, supported by laparoscopic video analysis of 12 colorectal procedures.

RESULTS: The Wickens human information-processing model was selected as the most relevant theoretical model to which we make adaptions for this specific application. We expanded the perception subsystem of the model to involve all aspects of perception during laparoscopic surgery. We extended the decision-making system to include dynamic decision-making to account for case/patient-specific and surgeon-specific deviations. The response subsystem now includes dual-task performance and non-technical skills, such as intraoperative communication. The memory subsystem is expanded to include skill acquisition and retention.

CONCLUSIONS: Surgical decision-making during laparoscopic surgery is the result of a highly complex series of processes influenced not only by the operator's knowledge, but also patient anatomy and interaction with the surgical team. Newer developments in simulation-based education must focus on the theoretically supported elements and events that underpin skill acquisition and affect the cognitive abilities of novice surgeons. The proposed human information–processing model builds on established literature regarding information processing, accounting for a dynamic environment of laparoscopic surgery. This revised model may be used as a foundation for a model describing robotic surgery. (J Surg Ed ■:■■■-■■■. © 2017 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: human information processing, surgical education, decision-making, laparoscopic surgery, medical device design

COMPETENCIES: System based practice, practice based learning and improvement, medical knowledge

INTRODUCTION

Laparoscopic surgery has become a popular approach for several procedures previously performed openly.[1-3] The operator coordinates their eyes, hands, and an elongated surgical instrument in a skillful manner, as well as interpreting a 2-dimensional environment on a screen to visualize the anatomy.[4] Furthermore, they are removed from direct contact with the tissues, so their tactile feedback

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is fundamentally different from that experienced during open surgery. Common laparoscopic colorectal surgery procedures include appendectomy, sigmoid colectomy, anterior resection, and total mesocolic excision.[5-8] Laparoscopic surgery has many proven benefits over open procedures, with reduced risk of infection,[9] reduced surgical invasiveness, shorter recovery times,[10] reduced or invisible scars,[11] and lower morbidity and mortality in many common procedures.[12] Laparoscopic colorectal techniques have also been shown to reduce mortality rates.[13,14]

Contextual information is important for learning and skill acquisition. In this regard, identifying stimuli, selecting an appropriate response, and improving memory have an effect on a surgeon's ability to perform surgery.[15] Training skilful and competent surgeons is required to ensure high-quality care and reduce the risk of adverse events. Surgical education plays an important role in the acquisition of surgical skills. However, traditional models by which surgeons are trained have been challenged owing to rapid advances in technology, higher focus on patient-safety, and an overall need for a value-driven health system.[16]

The practice of surgery is becoming increasingly more complex. Evolving surgical education methods should appreciate information processing as, although modern technologies provide tools to offer environments for residents to learn and understand to a greater degree than that offered to previous generations, surgical educators need to use both innovation and technology to make the best use of data and knowledge to train novice surgeons.[17] Grierson[15] states that, while clinical skills are often practiced in chaotic clinical environments, many of the same skills are also regularly carried out under stress-free conditions. Both chaotic and stress-free environments are equally realistic, with the chaotic environment adding a degree of difficulty, more so than realism. Therefore, the different environmental conditions may affect the amount that finite cognitive resources are taxed.

Highly contextual, information rich, or affect-inducing learning environments work to increase the complexity of skill practice.[15] Therefore, newer developments in simulation-based education where operating room (OR) accuracy is paramount must focus on, not only the physical aspects of surgery but also the theoretically supported elements and events that underpin skill acquisition and affect the cognitive abilities of the surgical trainee. Research has shown that surgical information processing is affected by knowledge, expertise, awareness,[18] distraction,[19] and mental resources.[20] However, there are few data available on information-processing models that unify the different information-processing models detailed in the literature. The aim of the present study was to develop a Human Information and Processing (HIP) model for skill acquisition and decision-making in the context of surgical education, based on a review of the literature and primary research in the OR.

MATERIALS AND METHODS

Literature Review and Selection of Primary Model

The literature was reviewed for information-processing models which could be applied to laparoscopic surgery. The short-listed models identified from our search were the Multiple Resource Theory by Wickens (2002), the 2-step model of intraoperative decision-making proposed by Flin et al. (2007), the 3-loop model of decision-making proposed by Harvey and Fischer (2005), the naturalistic model of intraoperative decision-making proposed by Cristancho et al. (2013), and the Wickens model of Human Information Processing (HIP).[21]

The Multiple Resource Theory model describes resources as being parallel, separate, or relatively independent when being used. The model contains 4 dimensions that account for the variances in time-shared performance: stages, perceptual modalities, visual channels, and processing codes. Each of the 4 dimensions contains separate levels of visual and auditory input.[22]

The 2-step model of intraoperative decision-making is based on situation assessment and decision-making. The model proposes 4 types of decision-making: *intuitive*, which is used most often by expert operators; *rule-based*, in which operators follow a set procedure to complete a surgical task; *analytical*, which requires the operator to simultaneously compare a number of possible courses of actions and their outcomes in order to decide on the most suited path; and *creative decision-making*, which is rarely applied to surgery.[23]

The 3-loop model accounts for changes in a skilled person's estimate of the probability of successful performance of a task. An inner loop describes how short-term memory is used by all factors needed to make a decision. A secondary, slow cognitive loop, shows how task feedback is further refined and assimilated into a mental model of the task, supporting the inner loop. The outer loop conveys storage of mental models for all previous tasks.[24]

The naturalistic model of intraoperative decision-making focuses on 3 major and sometimes overlapping components: situation assessment, reconciliation cycle, and gaining information. The proposed reconciliation cycle refers to the continuous, iterative process of gaining and processing information, and anticipating future events. The naturalistic model is more focused on design-making during nonroutine challenges rather than an entire surgical procedure. However, it further substantiated the need for situation assessment and intuitive decision-making to be included in our HIP model.[25]

Based on our review of the above models, including their previous applications to surgical domains, we selected and advanced the Wickens HIP (Fig. 1), which describes information flow between cognitive subsystems, as indicated by the arrows. The Wickens HIP model was previously applied to describe information processing in other high-stress