Surgery 190 (2026) 109935

Contents lists available at ScienceDirect

Surgery

journal homepage: www.elsevier.com/locate/surg

Cognitive frameworks for intraoperative surgical decision-making: A systematic scoping review

Sanjay Subramanian[a], Mark Michael[a], Leif Berglund, MD[b], Alice Chu, MD[a], Per Jolbäck, RN, PhD[c,d], My Blohm, MD, PhD[e,f], Aleksandra McGrath, MD, PhD[b,*]

[a] Department of Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ
[b] Department of Diagnostics and Intervention (Orthopaedics), Umeå University, Umeå, Sweden
[c] Department of Orthopaedics, Institute of Clinical Science, The Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
[d] Department of Research, Development, Education and Innovation, Skaraborg Hospital, Skövde, Sweden
[e] Department of Clinical Science and Education, Södersjukhuset, Karolinska Institutet, Stockholm, Sweden
[f] Centre for Clinical Research Dalarna, Uppsala University, Falun, Sweden

ARTICLE INFO

Article history:
Accepted 3 November 2025
Available online xxx

Introduction

Traditionally, surgical outcomes have been attributed to individual surgeon factors such as experience, training, and gender, as well as contextual elements like case volume and complexity. More recently, the importance of nontechnical skills such as situational awareness, teamwork, and decision-making has been increasingly recognized. Although factors like cognitive load and time pressure[1] have been studied, the specific cognitive processes that underlie and connect these elements—how surgeons synthesize information, weigh risks, and adapt in real time—remain poorly defined. A deeper understanding of these mental mechanisms is essential to advancing surgical care. This scoping review synthesizes existing cognitive frameworks in surgical decision-making to inform interventions aimed at improving surgical education and intraoperative performance.

Methods

This scoping review adhered to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for scoping reviews guidelines.[2]

Search strategy

A systematic search was developed in collaboration with an information specialist. The searches were conducted on 2 July 2024 across 6 databases (PubMed, Embase, Scopus, Cochrane, Web of Science, and CINAHL). The strategy targeted "intraoperative" and "decision making" concepts (Table). No time or language restrictions were applied.

Study selection

Two independent reviewers screened titles, abstracts, and full texts against predefined criteria. Disagreements were resolved by the senior authors. Studies across all surgical subspecialties and training levels were included. Studies focusing on procedure-specific algorithms, decision support systems, and nonprimary literature (eg, case reports) were excluded. The Preferred Reporting Items for Systematic reviews and Meta-Analyses flow diagram details the screening results (Figure).

Data extraction and synthesis

A structured data-extraction chart was used. After full-text review, 3 reviewers independently identified key themes. Final themes were determined through iterative discussions and consensus among all authors.

Results

Of 5,501 identified records, 19 articles (2003–2021) were included. Five major themes were identified (Table), with some studies contributing to multiple themes.

* Corresponding author: Aleksandra McGrath, MD, PhD, Department of Diagnostics and Intervention (Orthopaedics), Umeå University, Umeå 90187, Sweden.
E-mail address: aleksandra.mcgrath@umu.se (A. McGrath).

https://doi.org/10.1016/j.surg.2025.109935

Table
Overview of studies organized by cognitive themes, with an example of search strategy for PubMed

Example database search	Search string	Search date	Filters applied
PubMed	(("intraop*"[Title/Abstract] OR "Intraoperative Period"[MeSH Terms] OR "peroperat*"[Title/Abstract]) AND ("Decision Making"[MeSH Terms] OR "decision*"[Title/Abstract] OR "decisive*"[Title/Abstract])) NOT ("consensus"[MeSH Major Topic] OR "algorithms"[MeSH Major Topic] OR "practice guidelines as topic"[MeSH Major Topic] OR “diagnostic imaging”[MeSH Major Topic])	2 July 2024	None

Themes	Study title	First author, yr
Cognitive processing models	When surgeons face intraoperative challenges: A naturalistic model of surgical decision making.	Cristancho 2013[3]
	Thinking like an expert: Surgical decision making as a cyclical process of being aware.	Cristancho 2016[4]
	How do surgeons make intraoperative decisions?	Flin 2007[5]
	Surgeons' intraoperative decision making and risk management.	Pauley 2011[6]
	Intraoperative decision-making by ophthalmic surgeons.	Pauley 2013[7]
	Toward a model of human information processing for decision-making and skill acquisition in laparoscopic colorectal surgery.	White 2018[8]
	How do pediatric neurosurgeons make intraoperative decisions?	Granek 2021[9]
Essential skills and competencies	Preparation for challenging cases: What differentiates expert from novice surgeons?	Ghaderi 2021[10]
	What are the principles that guide behaviors in the operating room?	Madani 2017[11]
	Intraoperative decision-making: More than meets the eye.	Pugh 2011[12]
Balancing internal and external factors	Pediatric neurosurgeons' philosophical approaches to making intraoperative decisions when encountering an uncertainty or a complication while operating on children.	Granek 2021[13]
	First, do no harm.	Leung 2012[14]
	Justifying our decisions about surgical technique: Evidence from coaching conversations.	Kanters 2018[15]
Context-dependent decision-making	‘Slowing down when you should’: Initiators and influences of the transition from the routine to the effortful.	Moulton 2010[16]
	The call, the save, and the threat: Understanding expert help-seeking behavior during nonroutine operative scenarios.	Novick 2015[17]
Limitations of existing models/bias	Cognitive bias and dissonance in surgical practice.	Richburg 2023[18]
	Estimate or calculate? How surgeons rate volumes and surfaces.	Schuld 2012[19]
	Causes and prevention of laparoscopic bile duct injuries: Analysis of 252 cases from a human factors and cognitive psychology perspective.	Way 2003[20]
	Understanding clinical uncertainty: What is going on when experienced surgeons are not sure what to do?	Cristancho 2013[21]

Cognitive processing models

Decision-making was described as a cyclic process of data acquisition, processing through pattern recognition and mental modeling, and subsequent action. Frameworks distinguished between intuitive (fast, experience-based), rule-based (protocol-driven), and analytical (deliberate) modes of thinking, with surgeons fluidly shifting between them on the basis of case complexity and familiarity. Expertise influences these processes; experts use richer mental imagery to anticipate complications, whereas novices rely more on descriptive rules. Comprehensive models incorporate phases like perception, attention, decision-making, and memory (storing experiences for future reference), highlighting how stress and nonroutine situations can trigger a shift from intuitive to deliberate reasoning.

Essential skills and competencies

Specific cognitive skills influence how surgeons respond to intraoperative challenges. A 3-phase model of error management outlined the cognitive demands of error prevention (anticipating potential issues before they arise, using previous knowledge of potential pitfalls and cognitive skills to anticipate novel challenges), recognition (diagnosing and assessing the source of a problem when it occurs), and rescue (implementing corrective action). Advanced cognitive competencies—such as pattern recognition, threat and risk perception, forward planning, and real-time strategy adjustment—evolve with expertise. Training methods like cognitive task analysis were shown to bridge technical and cognitive domains, improving metacognitive awareness and adaptability.

Balancing internal and external factors

Decision-making is influenced by patient-specific, procedural, and interpersonal factors. Surgeons subconsciously weigh competing priorities such as patient safety, protocol adherence, and institutional norms. These influences were categorized as "avowed" (explicit, eg, optimal outcome), "unavowed" (implicit, eg, balancing teaching with efficiency), and "disavowed" (downplayed, eg, reputational or financial concerns). In teaching hospitals, for example, surgeons balance the unavowed need for resident education with the avowed goal of patient safety.

Context-dependent decision-making

Surgical judgment is highly influenced by context. The concept of “slowing down when you should” reflects transitions from automatic to deliberate decision-making. This can be proactive (on the basis of anticipated challenges) or situational (in response to unexpected findings). The latter demands greater cognitive effort. Help-seeking in complex situations is also context-dependent, driven by both explicit technical needs and tacit motives such as seeking moral support or political cover for major plan changes. Cultural barriers like concerns over autonomy or reputation may delay necessary help-seeking.

Limitations and adaptations of existing models

Cognitive biases limit rational decision-making. Anchoring bias leads to overreliance on initial information, even when later evidence suggests a different course of action. Overconfidence bias, an overestimation of the accuracy of one's decisions, can lead to

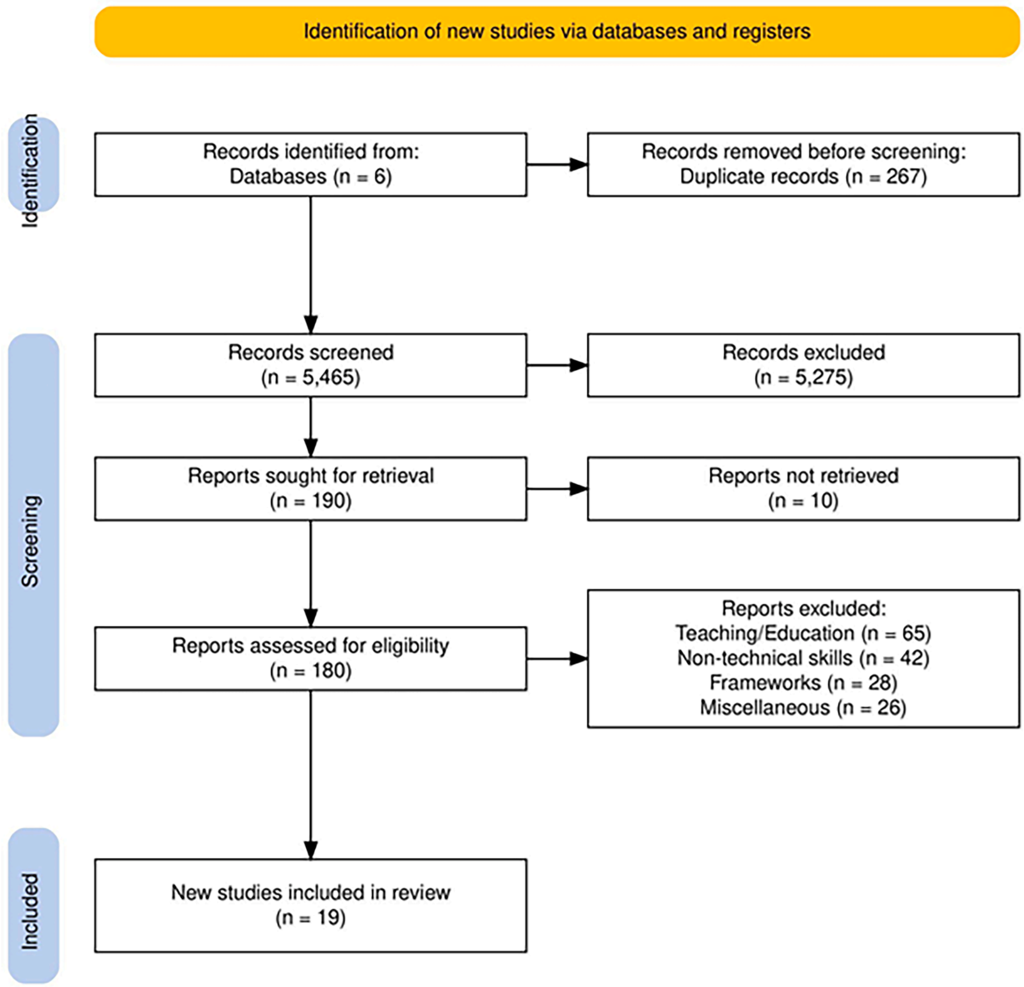

Figure. Preferred Reporting Items for Systematic reviews and Meta-Analyses flow chart for study selection.

preventable errors, whereas cognitive dissonance—mental discomfort arising from conflicting evidence or ideas—may impair clarity. To mitigate these biases, the Reconciliation Cycle model proposes 3 steps: assessing the situation, reconciling options, and implementing decisions.[4] These steps are bridged by 2 transitions: active reconciliation (immediate adjustments) and confirmatory reconciliation (ensuring revised plans align with observations). This model reframes protocol deviation not as failures, but as necessary adaptations.

Discussion

Surgical decision-making is influenced by the interplay between internal factors, such as cognitive load and inherent biases, and external factors, including patient variables, situational context, operating room dynamics, and time pressure. This review confirms that intraoperative decisions rely on balancing intuitive and analytical thinking,[1] whereas managing mental workload and mitigating biases like anchoring.[4] A critical differentiator is metacognition, the capacity to monitor and regulate one's own thought processes during surgery. This underscores the need to integrate cognitive training into surgical education.

Curricula should explicitly teach metacognitive skills, such as segmenting complex procedures into discrete cognitive components[22] and recognizing moments that require a deliberate "slow down" for analytical reasoning. Training under controlled cognitive load has been shown to improve performance, with these skills transferring effectively to real operative environments.[23] Practical tools include structured checklists to counteract bias and team-based protocols (eg, preoperative briefings) to reduce over-reliance on intuition.

Although the generalizability of current cognitive models requires validation in real-time surgical settings, their core principles support integrating reflective practices into surgical workflows. Promoting a culture of continuous learning through regular debriefings, feedback, and critical reflection can refine intraoperative decision-making, enhance patient safety, and strengthen critical reasoning over time.

Data availability statement

The research data are available from the corresponding author (aleksandra.mcgrath@umu.se) upon reasonable request.

Funding/Support

No funding has been received for this project.

Conflict of Interest/Disclosure

The authors have no conflicts of interest to declare.

Acknowledgments

We thank information specialist Stephen Modica for his assistance in developing the search strategy.

CRediT authorship contribution statement

Sanjay Subramanian: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mark Michael:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Leif Berglund:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Alice Chu:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Per Jolbäck:** Writing – review & editing. **My Blohm:** Writing – review & editing, Supervision, Conceptualization. **Aleksandra McGrath:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used Microsoft Copilot for language editing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article. No generative AI was used in the preparation of the manuscript.

References

1. Yule S, Paterson-Brown S. Surgeons' non-technical skills. *Surg Clin North Am*. 2012;92:37–50.
2. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169:467–473.
3. Cristancho SM, Vanstone M, Lingard L, LeBel ME, Ott M. When surgeons face intraoperative challenges: a naturalistic model of surgical decision making. *Am J Surg*. 2013;205:156–162.
4. Cristancho SM, Apramian T, Vanstone M, et al. Thinking like an expert: surgical decision making as a cyclical process of being aware. *Am J Surg*. 2016;211:64–69.
5. Flin R, Youngson G, Yule S. How do surgeons make intraoperative decisions? *Qual Saf Health Care*. 2007;16:235–239.
6. Pauley K, Flin R, Yule S, Youngson G. Surgeons' intraoperative decision making and risk management. *Am J Surg*. 2011;202:375–381.
7. Pauley K, Flin R, Azuara-Blanco A. Intra-operative decision making by ophthalmic surgeons. *Br J Ophthalmol*. 2013;97:1303–1307.
8. White EJ, McMahon M, Walsh MT, Coffey JC, O'Sullivan L. Toward a model of human information processing for decision-making and skill acquisition in laparoscopic colorectal surgery. *J Surg Educ*. 2018;75:749–757.
9. Granek L, Shapira S, Constantini S, Roth J. How do pediatric neurosurgeons make intraoperative decisions? *World Neurosurg*. 2021;150:e353–e360.
10. Ghaderi I, Korovin L, Farrell TM. Preparation for challenging cases: what differentiates expert from novice surgeons? *J Surg Educ*. 2021;78:450–461.
11. Madani A, Vassiliou MC, Watanabe Y, et al. What are the principles that guide behaviors in the operating room? Creating a framework to define and measure performance. *Ann Surg*. 2017;265:255–267.
12. Pugh CM, Santacaterina S, DaRosa DA, Clark RE. Intra-operative decision making: more than meets the eye. *J Biomed Inform*. 2011;44:486–496.
13. Granek L, Shapira S, Constantini S, Roth J. Pediatric neurosurgeons' philosophical approaches to making intraoperative decisions when encountering uncertainty or complications while operating on children. *J Neurosurg Pediatr*. 2021;28:76–85.
14. Leung A, Luu S, Regehr G, Murnaghan ML, Gallinger S, Moulton C. First, do no harm": balancing competing priorities in surgical practice. *Acad Med*. 2012;87:1368–1374.
15. Kanters AE, Shubeck SP, Sandhu G, Greenberg CC, Dimick JB. Justifying our decisions about surgical technique: evidence from coaching conversations. *Surgery*. 2018;164:561–565.
16. Moulton C, Regehr G, Lingard L, Merritt C, MacRae H. Slowing down when you should": initiators and influences of the transition from the routine to the effortful. *J Gastrointest Surg*. 2010;14:1019–1026.
17. Novick RJ, Lingard L, Cristancho SM. The call, the save, and the threat: understanding expert help-seeking behavior during nonroutine operative scenarios. *J Surg Educ*. 2015;72:302–309.
18. Richburg CE, Dossett LA, Hughes TM. Cognitive bias and dissonance in surgical practice: a narrative review. *Surg Clin North Am*. 2023;103:271–285.
19. Schuld J, Kollmar O, Seidel R, Black C, Schilling MK, Richter S. Estimate or calculate? How surgeons rate volumes and surfaces. *Langenbecks Arch Surg*. 2012;397:763–769.
20. Way LW, Stewart L, Gantert W, et al. Causes and prevention of laparoscopic bile duct injuries: analysis of 252 cases from a human factors and cognitive psychology perspective. *Ann Surg*. 2003;237:460–469.
21. Cristancho SM, Apramian T, Vanstone M, Lingard L, Ott M, Novick RJ. Understanding clinical uncertainty: what is going on when experienced surgeons are not sure what to do? *Acad Med*. 2013;88:1516–1521.
22. Almukhtar A, Caddick V, Naik R, et al. Objective assessment of cognitive workload in surgery: a systematic review. *Ann Surg*. 2025;281:942–951.
23. Sankaranarayanan G, Odlozil CA, Wells KO, et al. Training with cognitive load improves performance under similar conditions in a real surgical task. *Am J Surg*. 2020;220:620–629.