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TITLE: A scoping review of Distributed Cognition in acute care clinical decision-making

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ABSTRACT

Background

In acute care settings, interactions between providers and tools drive clinical decision-making. Most studies of decision-making focus on individual cognition and fail to capture critical collaborations. Distributed Cognition (DCog) theory provides a framework for examining the dispersal of tasks among agents and artifacts, enhancing the investigation of decision-making and error. This scoping review maps the evidence collected in empiric studies applying DCog to clinical decision-making in acute care settings and identifies gaps in the existing literature.

Methods

The five stages of a scoping review were followed. The search was run in eight databases up to September 29, 2020. Two authors independently screened titles, abstracts, full texts, and performed data extraction. A third author helped achieve consensus. Data was charted in a narrative summary and multiple figures. A thematic analysis was conducted.

Results

Thirty-seven articles were included. The majority (n=30) used qualitative method~~ologie~~s (observations, interviews, artifact analysis) to examine the work of physicians (n=28), nurses (n=27), residents (n=16), and advanced practice providers (n=12) in intensive care units (n=18), operating rooms (n=7), inpatient units (n=7) and emergency departments (n=5). Information flow (n=30) and task coordination (n=30) were the most frequently investigated elements of DCog. Provider-artifact (n=35) and provider-provider (n=30) interactions were most explored. Electronic (n=18) and paper (n=15) medical records were frequently described artifacts. Prominent themes included: (1) information flow, (2) task coordination, (3) team communication, (4) situational awareness, (5) electronic medical record (EMR) design, (6) systems-level error, and (7) distributed decision-making.

Conclusions

DCog is an underutilized framework for examining how information is obtained, represented, and transmitted through complex clinical systems. DCog offers mechanisms for exploring how technologies, like EMRs, and workspaces can help or hinder clinical decision-making. Additionally, it provides a novel approach for investigating how systems-level errors arise and are propagated through acute healthcare settings.

KEY WORDS: Distributed cognition, clinical-decision making, systems-level error, acute care settings, scoping review

BACKGROUND

Clinical decision-making is a complex, contextual, evolving process that involves information processing, evaluation of evidence, and application of relevant knowledge to select appropriate interventions that provide high quality care and reduce risk of patient harm [1]. Clinical decision-making in acute care environments is ~~inherently~~ particularly challenging. Over time, a single case engages multiple practitioners, informants, and tools contributing to outcomes in a dynamic context. Historically, the study of clinical decision-making has largely been conducted through the lens of an individual clinician’s cognitive processes [1], using Information and Dual Processing Theories to explain decision-making and errors [2, 3]. However, exclusive focus on individuals ignores the multifarious collaborative interactions and tools supporting clinical work in practice [4].

Distributed Cognition (DCog) theory views cognitive tasks as dispersed over a set of experts, tools, and coordination processes [5] and may provide additional insights into decision-making and error. DCog sits within a broader continuum of theories known as *Situativity* that identify cognition as occurring within specific physical and cultural contexts [3, 6]. DCog has been used to examine complex tasks outside of healthcare such as navigation of naval ships and control of airplanes [5, 7]. The application of DCog can improve understanding of temporal, physical and technological constraints on human team performance. Findings in non-medical studies have highlighted the importance of representational artifacts, physical location, and mechanisms for information flow (including storage and exchange) [5, 7, 8].

Clinical decision-making in acute care settings possesses many of the defining characteristics of distributed cognitive systems. Cognitive tasks and subtasks are distributed across agents (e.g., clinicians, staff, patients, and families), physical locations (e.g., patient rooms, nursing stations, pharmacies, and labs), and informational artifacts (e.g., paper or electronic medical records (EMRs), status boards, phones, and pagers). As prior work on DCog attests, errors emerge in complex processes distributed across people, artifacts, environments, and time [5, 7]. Consequently, DCog may provide a useful framework for understanding clinical decision-making and errors in acute care settings, including urgent care clinics, emergency departments (EDs), inpatient units, operating rooms (ORs), and intensive care units (ICUs) [9, 10, 11].

DCog analyses emphasize information representations, including *internal representations* (isolated to individuals or personal artifacts) and *external representations* (shared and accessible to others), to identify breakdowns in information flow and transformations that may contribute to error [5]. DCog analyses evaluate access to information, appreciating how physical space (i.e., the spatial layout), proximity to others' work and *horizons of* *observation* (i.e., what an individual can see or hear) can impact situational awareness and a team's ability to monitor for potential errors [5, 7, 12]. DCog analyses ~~also~~ view clinical decision-making as a process of human and artifact coordination in highly specific socio-cultural contexts, that may suggest alternative ways to prevent errors and improve the safety of healthcare delivery [12, 13]. DCog analyses also view cognitive abilities as belonging to an entire system though a phenomenon known as *emergence*. Thus, insights generated are larger than the sum of its parts [5, 7, 12].

The literature employing DCog analysis in healthcare settings is currently dispersed and a synthesis is lacking. Given the need for improved paradigms for investigating clinical decision-making and errors, we aim to conduct a scoping review to examine the extent, range, and nature of evidence collected in empirical studies applying DCog to clinical decision-making in acute care settings, to highlight gaps in the existing literature and delineate avenues for future study.

METHODS

We chose a scoping review methodology because the use of DCog in studies of acute clinical care is an emerging field with a heterogeneous body of literature [14]. We followed the five stages of a scoping review as described by Arksey and O'Malley [15]. We did not pursue expert consultation (Stage

6), as several team members (CS, DT, SD, MD) were already experts in DCog and other theories of cognition.

Stage 1: identifying the research question

Our review ~~sought to map the extent, range, and nature of research in this field~~aimed ~~to understand how DCog has been used to investigate clinical decision-making in acute care settings. We sought~~ to discover commonalities and gaps across empirical reports related to: (1) study settings, participants, and method~~ologie~~s; (2) distributed cognition elements (e.g., artifacts, interaction types, coordination, internal / external representations); (3) theory sophistication and strength of conclusions; and (4) emergent themes.

Stage 2: Identifying relevant studies (search strategy)

Our initial search and article selection process is reported followed established PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines [16]. The systematic review protocol was publicly registered in the PROSPERO database (https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020148836) before initiating this work. An experienced research librarian (WT) helped design the search algorithm (**SUPPLEMENTARY MATERIAL S1**). Given that DCog and related theories (e.g., Situated Cognition, Collaborative/Team Cognition, Cooperative Work, Activity Theory) are used at times interchangeably, our ~~preliminary~~ search was broadly inclusive. ~~Once we were confident that we had identified the appropriate studies, we narrowed our search to capture only those studies that explicitly employed DCog as their underlying theoretical approach.~~ We ran the search in Ovid Medline (ALL), Embase.com (including Embase Classic), Scopus, Web of Science Core Collection (Editions = A&HCI , BKCI-SSH , BKCI-S , CCR-EXPANDED , ESCI , CPCI-SSH , CPCI-S , SCI-EXPANDED , SSCI), CINAHL Complete (Ebsco), PsycInfo (Ebasco), ERIC (Proquest), and ProQuest Dissertations & Theses Global from each database's inception through December 17, 2019, with an update on September 29, 2020.

Deduplication was conducted in EndNote [17]. Citations were uploaded in DistillerSR (Evidence Partners, Ottawa, Ontario, Canada), a web-based data management tool, and then a second round of deduplication was performed. When we discovered conference papers and peer-reviewed articles that reported on identical data sets, we treated the conference papers as duplicates. ~~Working in pairs, a~~Two authors (EW, MD~~,~~ or EW, AR) independently screened titles, abstracts, and full texts. Discrepancies were resolved through discussion, with input from a third author (AR or MD) as needed, until consensus was reached. Interrater reliability was assessed using Cohen's Kappa.

Stage 3: Study selection

Following scoping review methodology [15], we revised our inclusion and exclusion criteria as we familiarized ourselves with the available evidence [18], arriving at the final inclusion and exclusion criteria shown in **TABLE 1**.

Criteria	**INCLUSION**	**EXCLUSION**
Theory	Study explicitly uses distributed cognition (DCog) to analyze cognitive processes dispersed among team members, environment, & artifacts in the clinical decision-making process.	Study does NOT use distributed cognition (DCog) as described in the "Inclusion Criteria"
Design	**Empirical research studies** (quantitative, qualitative, and mixed methods studies) including ***peer-reviewed journal publications, conference papers/proceedings*** or ***case studies*** **in which primary data collection and analysis were evident.**	***Reviews, commentaries, opinion pieces, anecdotes, book chapters, doctoral theses/dissertations***, and research studies and case studies that do **NOT** report primary data collection and analysis methods.
Setting	Study occurs in an **ACUTE medical/healthcare setting (which includes urgent care facilities, emergency departments, hospital units, intensive care units, and operating rooms)** where human agents and environmental artifacts/tools interact in tasks that function in the diagnosis and treatment of "patients" (as defined above).	Study does **NOT** occur in an **ACUTE medical/healthcare** setting as described in the "Inclusion Criteria." This *excludes studies occurring in simulated and virtual reality medical/healthcare environments and in health education settings. It also excludes telemedicine settings.*
Subjects	Must investigate interactions between ***at least 2 of the following entities:*** **[1] Patients** (defined as any individual receiving diagnostic or therapeutic care in a *REAL medical/healthcare setting*); **[2] Medical Practitioners** at any level of training, working in a *REAL medical/healthcare setting* where patient care is provided; **[3] Tools/ Artifacts** used in patient care in *REAL medical/healthcare settings*, including electronic medical records (EMRs), hand-written documentation/patient notes, whiteboards, radio systems, pagers, cell phones, and textual electronic communication; or, **[4] Between Practitioners** in different roles (e.g., physician and nurse).	Does **NOT** investigate **interactions among healthcare teams** AND/OR does **NOT** include at least 2 of the following entities: [**1] Patient, [2] Medical Practitioners, [3] Tools/Artifacts** or, **[4] Between Practitioners** in different roles (e.g., physician and nurse).as described in the "Inclusion Criteria." Note that our definition of **Medical Providers/Practitioners** *specifically excludes dentists, dental students, dental hygienists, and other individuals working in the field of dentistry.*
Language/ Country	**English language** research papers; conducted in **ANY country**	**Non-English language** research papers

TABLE 1: Inclusion and exclusion criteria for full-text screening

Stage 4: Charting the data

An initial team meeting created a shared understanding of key review terms and definitions. A pilot data extraction form was developed in Google Sheets. All authors independently extracted data from two studies and met to revise the form. The final form (**SUPPLEMENTARY MATERIAL S2**) captured article identifiers, study objectives, findings, and conclusions. Study elements related to components of DCog were included, as were sources of error and sophistication of theory discussion [19]. Studies were assigned to author pairs (EW, MD~~, ~~; EW, AR~~, ~~; EW, DT~~, ~~; EW, SD~~, ~~; EW, CA; EW,~~, ~~ CS) for independent data extraction. Discrepancies were resolved through discussion, with involvement of a third author as needed. ~~As recommended for scoping reviews, study quality was not assessed.~~

Stage 5: Collating, summarizing, and reporting

Data from the extraction form was outlined in a narrative summary and it was also arranged into a series of figures to provide a visual summary of the findings. Using an interpretivist ~~approach~~paradigm, ~~A~~ a thematic analysis was performed by EW, MD, AR, and NG following Braun and Clarke's method [20, include Braun & Clarke , 2019; and 2021 see refs]. This was conducted deductively through the lens of DCog. Following familiarization with the data, an initial set of codes was generated. These codes were created by researchers who engaged in a collaborative and reflexive process ~~discussed iteratively by all team members~~ to arrive at a final list of codes, which were subsequently ~~collated~~ developed into themes. Themes were identified and refined as patterns of shared meaning by ~~then reviewed and refined by~~ the team~~, and discrepancies were resolved by discussion until final consensus was achieved~~.

RESULTS

A total of 6083 articles were identified. After deduplication, 3213 articles remained. After title and abstract screening, 2,892 were excluded (κ = 0.85, strong inter-rater agreement), leaving 321 articles for full-text evaluation. At this stage, 279 articles were excluded (κ = 0.88, strong inter-rater agreement) and complete consensus was achieved on included articles**.** Five articles were removed as “duplicates” at the full-text stage due to near-identical findings reported by the same authors. Thirty-seven articles were included in the final analysis. The PRISMA flow diagram is shown in **FIGURE 1** [21]. A summary of key data from all included articles is provided in **TABLE 2.**

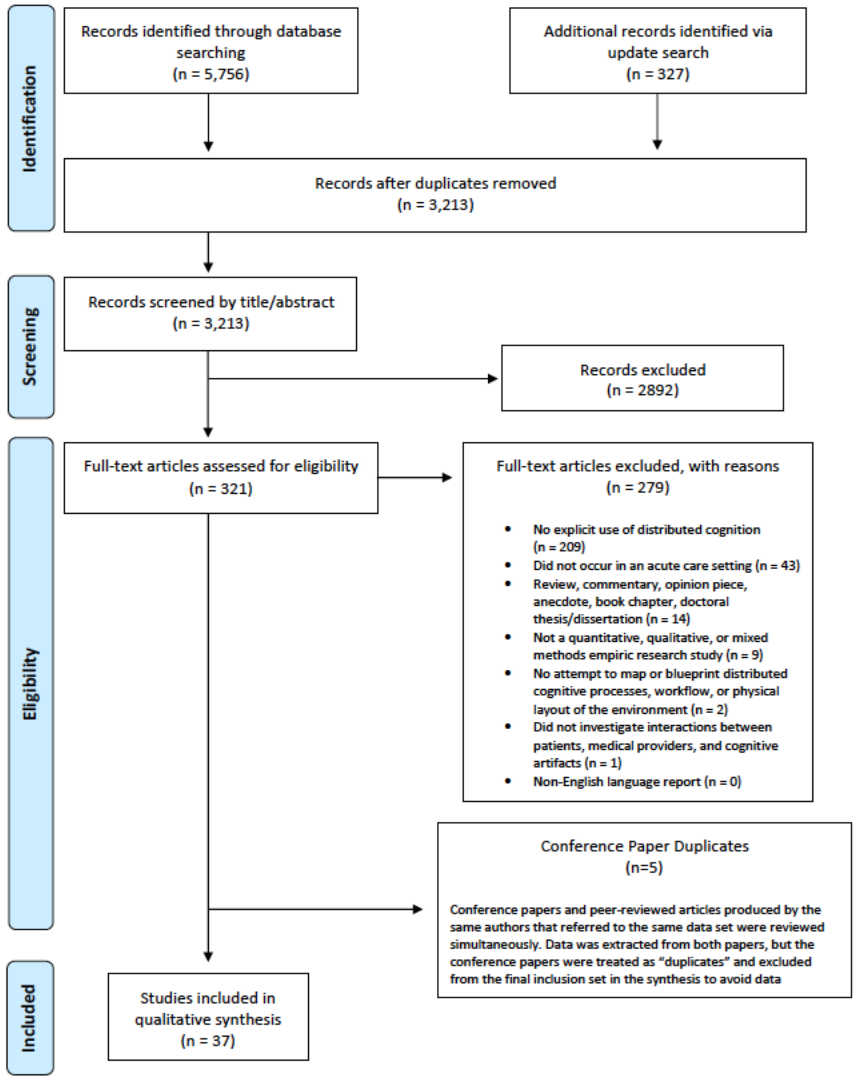

FIGURE 1: PRISMA flow diagram for included studies

Study settings, participants, and methodology

Most studies took place in the United States and Canada (n=22, 59.5%), eleven (29.7%) were European, and four (10.8%) were Australian **(TABLE 2)**. **FIGURE 2A** depicts the frequency of study settings, with most in ICUs (n=18, 48.7%), followed by ORs (n=7, 18.9%) and inpatient hospital units (n=7, 18.9%), and then EDs (n=5, 13.52%). More than fourteen distinct health professionals and trainees were included, with physicians (n=28) and nurses (n=27) most frequent, followed by residents (n=16), advanced practice providers (n=8 nurse practitioners, NPs; n=4 physicians assistants, PAs), and fellows (n=4) (**FIG 2B**). Most studies used qualitative approaches (n=30, 81.1%) including observations (n=35, 94,5%), interviews (n=26, 70.1%), and artifact analyses (n=16, 43.2%) (**Fig 2C,2D**). A few studies used a mixed-methods approach (n=7, 18.9%). No studies used an exclusively quantitative approach.

Distributed Cognition Elements

Most authors focused on the DCog elements that were most applicable to their research question and study environment. **Figure 2E** summarizes frequencies observed for elements of DCog. Information flow (n=31, 83.7%) and coordination (n=31, 83.7%) were the most frequently included. Internal/ external representations were also frequently investigated (n=19, 51.4%), while spatial layout (n=9, 24.3%), patient-provider communication (n=6, 16.2%), horizon of observation (n=3, 8.1%), and emergence (n=1, 5.4%) were less often addressed. **Figure 2F** shows the frequencies at which specific interaction subtypes were observed. Studies focused primarily on interactions between providers and artifacts (n=35, 94.6%) and between different providers (n=30, 81.1%). However, interactions between providers and patients (n= 11, 29.7%%) and between patients and artifacts (n=4, 10.8%) were also observed. Across the included studies, 7 articles (18.9%)

examined only a single interaction type, 20 articles (54.1%) examined two interaction types, 7 articles (18.9%) examined three interaction types, and only 3 articles (8.1%) included all four interaction types.

Figure 2G depicts frequencies for a broad range of artifacts examined in the studies. Medical records, both electronic (EMR, n=18, 48.6.%) and paper (PMR, n=15, 40.5%), were the most frequently investigated artifacts. Other artifacts reported include computers (n=9, 24.3%), medication administration systems (MAS, n=7, 18.9%), handoff documents (n=6, 16.2%), whiteboards and track boards (n=6, 16.2%), OR equipment (n=6, 16.2%), checklists (n=5, 13.5%), individually created artifacts (e.g. rounding lists and to-do sheets, n=5, 13.5%), patient tracking tools (e.g., tracking cards/stickers signaling patient location, n=5, 13.5%), pagers (n=4, 10.8%), and phones (n=4, 10.8%).

Theory Sophistication and Strength of Conclusions

To investigate the extent of Dcog theory use in the studies, we used a hierarchical classification of theory sophistication previously described by Kumasi, Charbonneau, and Walster [19]. In this system, theory discussion is categorized as minimal (Theory Dropping, Theory Positioning), moderate (Theory Diversification, Theory Conversation), and major (Theory Application, Theory Generation, Theory Testing) based on citation of foundational literature and the extent of theory validation or expansion beyond existing work. **FIGURE 2H** provides an overview of frequencies of studies in each of the three levels. Most studies met criteria for major theory use (n=30, 81.1%), with the Theory Application subcategory being most frequent (n=24, 64.9%). Minimal theory use was observed infrequently (n=4, 10.8%), as was moderate theory talk (n=3, 8.1%).

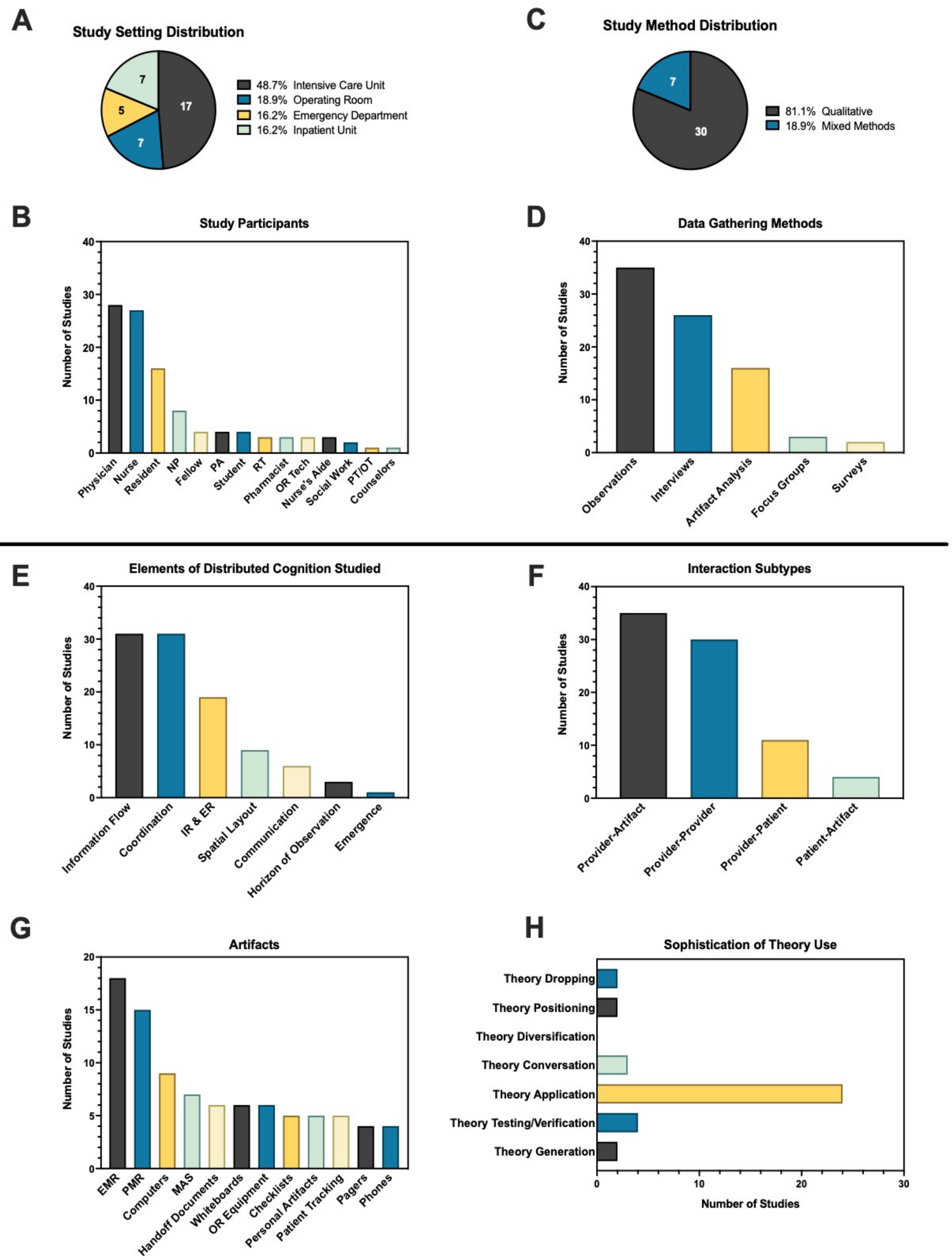

FIGURE 2: Graphical summary of study settings (**A**), participants (**B**), methodological approaches (**C**), data sources (**D**), DCog elements studied (**E**), interactions examined (**F**), artifacts investigated (**G**), and Sophistication of Theory Use according to Kumasi et al's hierarchy (**H**). Abbreviations: NP = nurse practitioner, PA = physician assistant, RT = respiratory therapist, PT = physical therapist, OT = occupational therapist, OR = operating room, IR = internal representations, ER = external representations, EMR = electronic medical record, PMR = paper medical record, MAS = medication administration system. "Personal artifacts" included any physical tool created by an individual, and electronic tracking artifacts monitored patients' physical location.

Author	Country	Setting	Primary study objectives	Healthcare professionals	Artifacts studied	Interactions discussed	Research methods	Elements of DCog systems presented	Theory use	Strength of conclusion
Bång & Timpka [22]	Sweden	ED	To "build an understanding of the roles physical artifacts like paper-based patient records play in supporting cognition and collaboration in health care settings" (as a preliminary step towards using human systems design to construct EMRs.)	Physician, nurse, nurse's aide	Paper health/ medical charts, patient tracking cards/ stickers, desk in shared workspace	Provider - Artifact	Observations, Artifact Analysis	Information flow, coordination among team members, external representations	Theory Testing (Verification)	4
Berndt, Furniss & Blandford [23]	England	OR	To “understand the interactions of anesthetists, how the design of procedures and the environment supports work, and particularly how they used infusion devices…"	Physician, resident, OR techs	OR equipment (infusion devices, monitors, ventilators), telephones	Provider - Provider Provider - Artifact Patient - Provider Patient - Artifact	Observations, Interviews	Spatial layout, information flow, computation/ combination, coordination among team members, horizon of observation	Theory Application	3
Cohen et al. [9]	USA	ED	To “characterize the DCog that underlies patient care in a psychiatric emergency department in order to enhance the understanding of error in this context."	Physician, resident, social worker, nurse, substance abuse counselor	Whiteboards, patient charts, nursing notes, admissions notes, discharge notes, legal documents	Provider - Provider Provider - Artifact Patient - Provider	Observations, Interviews	Spatial layout, information flow, communication, coordination among team members, internal/ external representations	Theory Testing (Verification)	4
Collins et al. [24]	USA	ICU	To categorize the types of communication and information activities that occur and develop a theoretical model for interdisciplinary communication of ICU common goals in the context of EMR use.	Physician, fellow, resident, nurse, pharmacist, medical student, nursing student	EMR, paper health/ medical charts	Provider - Provider Provider - Artifact	Observations, Interviews, Focus Groups, Artifact Analysis	Information flow, coordination among team members, internal/ external representations	Theory Generation	3
Collins et al. [25]	USA	ICU	To describe the ICU activity system in the context of interdisciplinary communication of common goals; and to describe nurses’ and physicians’ perceptions of communication of common goals in the ICU.	Physician, resident, nurse, pharmacist, medical students, social worker, respiratory therapist, nutritionists	Personal notes, "to do" lists, EMR, paper health/ medical charts, pagers	Provider - Provider Provider - Artifact	Observations, Interviews, Focus Groups	Information flow, coordination among team members, internal/ external representations	Theory Application	3
Collins et al. [26]	USA	ICU	To analyze structure, functionality, and content of nurses’ and physicians’ handoff artifacts to inform the development of a handoff tool to support communication and coordination of care through integration with the EMR in a multi-disciplinary and highly specialized	Resident, physician assistant, nurse	Handoff Documents	Provider - Provider Provider - Artifact	Artifact Analysis	Coordination among team members, internal/external representations	Theory Application	3

Author	Country	Setting	Primary study objectives	Healthcare professionals	Artifacts studied	Interactions discussed	Research methods	Elements of DCog systems presented	Theory use	Strength of conclusion
			ICU setting.							
Dias et al. [27]	USA	OR	To elucidate the cognitive processes involved in surgical procedures from the perspective of different team roles; To provide a comprehensive compilation of intraoperative decision points, critical communications, pitfalls, problem-solving/ prevention strategies, and cognitive demands related to surgery; To present this comprehensive analysis in an interactive analytics dashboard.	Physician, perfusionist	OR equipment, checklists	Provider - Provider	Interviews, Cognitive Task Analysis	Coordination among team members	Theory Dropping	3
Furniss et al. [28]	England	Inpatient Hospital Unit	To "investigate the design and use of a modern inpatient glucometer, and how it is coupled with its context."	Biochemist, healthcare assistant/ nurse's aide, nurse practitioner, nurse	Glucometer and it's docking station, supply kit, trolley with supporting equipment, computers, paper health/ medical charts	Provider - Provider Provider - Artifact Patient - Provider Patient - Artifact	Observations, Interviews	Information flow, coordination among team members, communication	Theory Application	3
Furniss et al. [29]	England	Inpatient hospital Unit	To investigate how safety is constructed and compromised around infusions on a hematology ward, and to describe the socio-technical system in which infusion practice is organized & embedded.	Nurse practitioner/ nurse, healthcare assistant/ nurse's aide	Paper health/ medical charts, medication administration systems	Provider - Provider Provider - Artifact Patient - Provider	Observations, Interviews	Spatial layout, emergence, coordination among team members, communication, information flow	Theory Application	3
Furniss, Franklin & Blanford [30]	England	ICU	To gain an in-depth understanding of patterns of work that evolved in an ICU where a closed-loop IV medication administration system was implemented and of the consequent effects on patient safety.	Physician, nurse	EMR, patient track boards, medication administration systems linked to the electronic prescribing system	Provider - Provider Provider - Artifact Patient - Provider Patient - Artifact	Observations, Interviews	Spatial layout, information flow, coordination among team members, internal/ external representations	Theory Application	3
Gilardi, Guglielmetti, Pravettoni [31]	Italy	ED	To consider the critical aspects of collaborative teamwork in EDs that may have an impact on information flow...specifically, how ED team members gather, transfer, and integrate patient-specific information and how technological artifacts assist information flow.	Triagist, physician, nurse practitioner, nurse	Computers, checklists (electronic)	Provider - Provider Provider - Artifact	Observations, Interviews	Information flow, coordination among team members	Theory Application	4
Grundgeiger et al. [32]	Australia	ICU	"The goals of the study were to capture prospective memory (PM) tasks performed by ICU nurses, to classify the	Nurse practitioner, nurse	Personal notes, vital sign monitoring	Provider - Provider Provider -	Observations, Artifact Analysis	Information flow	Theory Application	3

Author	Country	Setting	Primary study objectives	Healthcare professionals	Artifacts studied	Interactions discussed	Research methods	Elements of DCog systems presented	Theory use	Strength of conclusion
			PM tasks using the taxonomy developed by Dismukes and Nowinski, and to investigate the extent to which the support for PM tasks was distributed..."		systems and alarms, medication administration systems, computers	Artifact				
Grundgeiger & Sanderson [11]	Australia	ICU	To test whether prospective memory theory can be used to study interruptions. To investigate which predictors help us understand the effects of interruptions in ICU nursing. To address the mismatch between healthcare interruption and lab studies in terms of the disruptive effects of interruptions.	Nurse practitioner/ nurse	Personal notes, vital sign monitoring equipment/ ventilators, patient monitoring alarm systems, medication administration systems, EMR	Provider - Provider Provider - Artifact	Interviews, Eye Movements, Observations	Internal/ external representations	Theory Application	3
Hakimzada et al. [33]	USA	ED	To characterize the factors that compromise patient safety at the point of patient registration in the ED	ED registration clerk, physician, resident, EMT/ paramedics	EMR, patient ID wristbands, computers, telephones, pagers, paper health/ medical charts	Provider - Artifact Patient - Provider Patient - Artifact	Observations, Interviews	Communication, information flow	Theory Application	4
Hazlehurst et al. [34]	USA	ICU	To shed light on how the ICU as activity system implements an order process and discuss what it may mean for the design or introduction of automated information systems such as computerized physician order entry."	Physician, nurse	EMR, paper health/ medical charts, medication administration systems	Provider - Provider Provider - Artifact Patient - Provider	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members, computation/ combination, internal/ external representations	Theory Application	3
Hazlehurst, McMullen, & Gorman [35]	USA	OR	To describe how cognitive and material resources in the activity system of the OR enable well-defined courses of action (through preparatory configuration) while dynamically accommodating unlikely events (through replanning).	Perfusionist, physician, physician assistant, nurse, OR Tech	OR Equipment (heart-lung machine, ventilator), checklists (tool/ instrument cheat sheets, inventory lists)	Provider - Provider Provider - Artifact	Observations, Artifact Analysis	Spatial layout, information flow, coordination among team members, internal/ external representations	Theory Testing (Verification)	4
Hazlehurst, McMullen, & Gorman [10]	USA	OR	To explore how achieving the goals of open-heart surgery requires coordination among team members and between the actors and the tools and technologies that support their work. To uncover how this coordination produces situation	Perfusionist, physician	OR Equipment (heart-lung machine, ventilator, table of OR surgical equipment)	Provider - Provider Provider - Artifact	Observations, Artifact Analysis	Spatial layout, information flow, coordination among team members, internal/ external representations	Theory Testing (Verification)	4

Author	Country	Setting	Primary study objectives	Healthcare professionals	Artifacts studied	Interactions discussed	Research methods	Elements of DCog systems presented	Theory use	Strength of conclusion
			awareness as a natural byproduct.							
Hussain, Dewey, & Weibel [36]	USA	ICU	To "explore fast and frugal heuristics that may be used to prioritize patient alarms, while continuing to monitor patient physiological state."	Nurse	Medication administration system, ventilator, drips, medication administration sheets	Provider - Artifact Patient - Provider	Observations, Interviews, Surveys	Spatial layout, horizon of observation	Theory Application	3
Hussain & Weibel [37]	USA	ICU	To describe how DiCoT principles led us to solutions to improving information flow in critical care. To study patient isolation procedures & discuss alternative solutions to improving information flow based on an analysis of the ICU system using Dcog.	Physician, nurse, pharmacist/ pharmacy tech, unit manager, patient care assistants, respiratory therapist	EMR, telephones, pagers, computers, isolation signs, masks	Provider - Artifact	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members, horizon of observation, internal/ external representations	Theory Application	5
Jensen & Bossen [38]	Denmark	Inpatient Hospital Unit	To highlight distinct and similar features of paper based and electronic paper records and to explore how these features support or hinder the establishment of clinical overview.	Physician	Personal notes, EMR, paper health/ medical charts	Provider - Artifact	Observations, Interviews	Information flow	Theory Generation	4
Kannampallil et al. [39]	USA	ICU	To “characterize the nature of physicians’ information seeking process, and the content and structure of clinical information retrieved during this process."	Physician, fellow, resident	EMR, paper health/ medical charts, computers	Provider - Provider Provider - Artifact	Observations	Information flow, coordination among team members, internal/ external representations	Theory Conversation	5
Liberati et al. [40]	England	Inpatient Hospital Unit	To “characterize what makes [a specific maternity unit] safe, attending both to features of context and intervention to generate an in depth understanding."	Physician, resident, midwives, risk managers	Whiteboards, maternity unit dashboard	Provider - Provider Provider - Artifact	Observations, Interviews, Focus Groups	Information flow, coordination among team members	Theory Conversation	4
Lin, Chaboyer, & Wallis [41]	Australia	ICU	To “better understand and identify vulnerabilities and risks in the ICU patient discharge process, which provides evidence for service improvement."	Physician, resident, nurse, registrar, ward medical staff, ward clerk, bed manager	EMR, computers, computerized hospital bed management program, discharge summaries	Provider - Provider Provider - Artifact	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members	Theory Application	5
Mamykina et al. [42]	USA	ICU	To “examine the apparent purpose of interruptions in a Pediatric Intensive Care Unit and opportunities to reduce their burden with informatics solutions."	Physician, resident, physician assistant/ nurse practitioner, nurse	EHMR, pagers, telephone, patient monitoring equipment	Provider - Provider Provider - Artifact Patient - Provider	Observations	Information flow, coordination among team members, communication	Theory Application	4
McLane & Turley [43]	USA	Inpatient	To "establish baseline functional requirements for an EMR-generated	Nurse	EMR, paper health/ medical	Provider - Artifact	Observations, Interviews,	Internal/ external representations	Theory Applicatio	3

Author	Country	Setting	Primary study objectives	Healthcare professionals	Artifacts studied	Interactions discussed	Research methods	Elements of DCog systems presented	Theory use	Strength of conclusion
		Hospital Unit	patient summary."		charts, personally created cognitive artifact		Scenarios		n	
Mylopoulos & Farhat [44]	Canada	OR	To "identify and elaborate [on] distributed cognitive processes that occur when an individual enacts purposeful improvements in a clinical context."	Physician, resident, fellow, nurse/ nurse practitioner, OR tech	OR equipment	Provider - Provider Provider - Artifact	Observations, Interviews	Information flow, coordination among team members	Theory Application	3
Nemeth et al. [45]	USA	OR	To describe the use of cognitive artifacts in healthcare and to consider implications for patient safety. To develop and use descriptive models of actual behavior and to examine how practitioner cognition can be understood using the analysis of cognitive artifacts to understand it.	Physician, resident, certified registered nurse anesthetist (CRNA), anesthesia coordinator, nurse, nurse coordinator	Schedules, OR graph (all paper-based), patient track boards, whiteboards	Provider - Provider Provider - Artifact	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members, internal/ external representations	Theory Application	4
Nemeth et al. [46]	USA	ICU	To "show that clinicians manage transitions between shifts using verbal hand-offs, or “sign outs,” to coordinate clinical work, authority, and responsibility."	Fellow	Handoff documents	Provider - Provider	Observations, Conversational analysis	Coordination among team members	Theory Positioning	3
Nemeth et al. [47]	USA	ICU	To "describe the process that our team and client followed to reveal the cognitive work in a burn intensive care unit (BICU) and to support it by developing an ecologically valid, coherent information technology (IT) system to facilitate individual and team decisions."	Physician, resident, nurse, physical therapist/ occupational therapist, respiratory therapist	EMR, telephones, email, handoff documents, daily wound care plan, vital signs printout, charge nurse checklist; wound tracking, fluid & nutrition software	Provider - Provider Provider - Artifact	Observations, Interviews, Surveys, Artifact Analysis	Information flow, coordination among team members, internal/ external representations	Theory Dropping	3
Parush et al. [48]	Canada	ICU	To determine the type of resources used and the frequency of their use during nursing handoffs.	Nurse	Paper health/ medical charts, handoff documents	Provider - Provider Provider - Artifact	Observations	Information flow, coordination among team members, internal/ external representations	Theory Application	3
Pelayo et al. [49]	France	Inpatient Hospital Unit	To explore medication administration in the context of a Computerized Provider Entry Order system, with a focus on the distribution of tasks among actors of the system. To use organizational analysis to describe variations in distribution of tasks between the actors of the	Nurse practitioner/ nurse, physician, pharmacist/ pharmacy tech	Paper health/ medical charts, medication administration systems	Provider - Provider Provider - Artifact Patient - Provider	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members	Theory Conversation	3

Author	Country	Setting	Primary study objectives	Healthcare professionals	Artifacts studied	Interactions discussed	Research methods	Elements of DCog systems presented	Theory use	Strength of conclusion
			medication use process, depending on the organization of the work system."							
Rajkomar & Blandford [50]	England	ICU	To improve understanding of the situated use of infusion pumps, which could help improve the safety and usability of the devices, while testing the utility and practicality of applying DiCoT to the study of a socio-technical healthcare system such as the ICU.	Physician, nurse, medical assistant, medical physicist	EMR, medication administration systems, computers	Provider - Provider Provider - Artifact Patient - Provider	Observations, Interviews, Artifact Analysis	Spatial layout, information flow, coordination among team members, communication, horizon of observation	Theory Application	4
Sarcevic, Marsic, & Burd [51]	USA	ED	To understand the causes of human errors unique to teamwork during trauma resuscitation.	Physician, resident physician, nurse	EMR, OR equipment, checklists, whiteboards	Provider - Provider Provider - Artifact	Observations, Interviews	Information flow, coordination among team members, internal/ external representations	Theory Application	4
Turki, Bosua & Kurnia [52]	Australia	ICU, ED	To "investigate the effects of using Electronic Patient Record (EPR) as a cognitive artefact for nursing handover."	Nurse	EMR, paper health/ medical charts, handoff documents	Provider - Provider Provider - Artifact	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members	Theory Application	3
Wilson, Galliers & Fone [53]	England	Inpatient Hospital Unit	To"present an argument for the importance of in use, in situ evaluation and to identify the kinds of use issues that can be revealed in such an evaluation as a step toward developing techniques that can be readily utilized by practitioners."	Physician, resident	Paper health/ medical charts, whiteboards, handoff documents, computers	Provider - Provider Provider - Artifact	Observations, Interviews, Artifact Analysis	Information flow, coordination among team members, internal/ external representations	Theory Application	4
Xiao et al. [54]	USA	OR	To study a public display board in an OR in a trauma center where coordination needs are exacerbated by unpredictability of incoming patients. To understand existing display boards, so that the development of technology can be guided by our understanding of the role these displays have in supporting collaborative work.	Physician, nurse, OR tech	Whiteboards, patient call strip	Provider - Artifact	Observations, Interviews, Photographing	Spatial layout, information flow, coordination among team members, internal/ external representations	Theory Positioning	3
Xiao et al. [55]	USA	ICU	To "adopt three perspectives in advancing our understanding of communication during rounds and in devising interventions: DCog, computer-supported cooperative work, and common ground."	Physician, resident, medical student, physician assistant/ nurse practitioner	EMR, paper health/ medical charts, computers, pre-rounding sheet	Provider - Provider Provider - Artifact	Artifact Analysis, Observations	Information flow, coordination among team members, communication	Theory Application	3

TABLE 2: Descriptive summary of findings from included studies. Abbreviations: OR = operating room, ICU = intensive care unit, ED = emergency department, DCog = distributed cognition, EMR = electronic medical record, DiCOT = distributed cognition for teamwork

Conclusion strength in articles was assessed using Hammick, Dornan, and Steinert's [56] Strength of Findings scale, which uses a 1-5 rating scale to evaluate the degree to which stated results support the authors' conclusions. Most studies were rated 3/5 (n=21, 56.8%, conclusions can probably be based on the results), and the remaining studies scored either 4/5 (n=13, 35.1%, results are clear and very likely to be true) or 5/5 (n=3, 8.1%, results are unequivocal) (**TABLE 2**).

~~Emergent Themes in Distributed Clinical Decision Making~~Findings of the Thematic Analysis

Seven themes ~~emerged~~ were developed ~~from the~~during the thematic analysis: information flow, task coordination, team communication, situational awareness, EMR design, systems-level error, and distributed decision-making.

(1) Information flow: ~~How is distributed information accumulated across representations?~~

Clinical decision-making requires rapid access to information collected at different points in space and time, and distributed across representations. This flow of information through the system is described ~~using DCog~~ in many of the studies. In one study, ED providers are "information gathers" who preserve information from patients in external artifacts like track boards and patient notes [9]. In OR settings, anesthesiologists were described as "information hubs" interacting bidirectionally with surgeons, medical monitors/devices, and the patient [23]. Communication was noted as limited because surgeons and anesthesiologists must wear masks [23]. This limitation can hinder surgeons' access to information, potentially adversely affecting clinical decisions in the OR.

Studies also examined the efficiency of information retrieval from key artifacts such as paper and EMRs. The findings point to obtaining high-quality, accurate information from pertinent artifacts as vital to maintaining the integrity of information flow within the system [39]. Artifacts prevent information loss by maintaining shared access over time; otherwise, information remains internal to the provider and exits the system when they do [9], hindering clinical decision-making. Notably, the information flow component from the Distributed Cognition for Teamwork (DiCoT) framework (developed by Furniss and Blandford) was employed across multiple articles [23, 28, 30, 37, 50].

(2) Task Coordination: ~~How are distributed tasks coordinated to meet urgent timelines?~~

Given the urgency of clinical decision-making in acute care settings, studies often address the coordination of tasks across practitioners to produce and share needed information to meet urgent timelines. The centralization of shared workspaces and artifacts (e.g., track boards, computers, medical documents) was found to enhance coordination in EDs and trauma centers [9, 54]. In ORs, coordination of surgical tools and supplies facilitated the distribution process among OR staff. Standardized access to tools supported a more universal understanding of their use and increased coordination [35]. Similarly, organizing patient records on a centrally located table supported work coordination among ED providers [22]. These studies recommend universal frameworks for tools and centrally located workspaces to meet the needs of multiple practitioners. Sharing resources and space under time demand requires explicit, self-evident, and planful physical arrangements to support clinical decision-making.

(3) Team Communications: ~~How do team members interact about case information?~~

Communication practices and preferences were frequently addressed in the selected articles. The medium (i.e., face-to-face versus via phone or electronic messaging), timing (i.e., scheduled versus opportunistic), and formality of communication were investigated. One study with ICU providers identified "information exchange patterns," including scheduled discussions (e.g., handoff, rounds), impromptu updates on patient status, and remote information exchange through EMRs [26]. A study of cardiothoracic surgeons identified six unique communication exchanges between surgeons and perfusionists that facilitate the clinical decision-making process [10]. Providers preferred verbal communications over non-verbal when concerned about outdated information in artifacts (e.g., EMR) [25]. Other studies similarly report a key role for technological artifacts in information exchange, along with social dynamics among providers in different roles (e.g., nurses and physicians) [31].

(4) Situational awareness: ~~What can team members observe about others' distributed tasks?~~

Research studies employing DCog ~~also~~ emphasized spatial layouts as promoting awareness of other activities in the workspace. Physical layouts may promote perception, understanding and anticipation of other ongoing distributed tasks [5, 57]. This situational awareness is important in clinical decision-making because sharing information about resources, practitioners, and patients may contribute to successful decision-making in clinical settings. In one study, shared awareness was maintained through physical movement of patient charts across a desktop [22]. In DCog, *horizon of observation* refers to the scope of distributed activity observable by an individual team member. Studies noted this helps to create a shared mental model within the team. ~~In one study, shared awareness was maintained through physical movement of patient charts across a desktop [22].~~ In studies of ORs, physical arrangements of providers and equipment afforded observation of their interactions. Situational awareness facilitates precise communication and coordination of activities across practitioners even when horizons of observation are limited (such as during procedures) [10, 35].

DCog provides an explanation of how co-location improves clinical decision-making and may reduce error.

(5) Electronic medical record design: ~~How do archival artifacts support real-time decision-making?~~

Several articles applied the DCog framework to EMR efficacy (e.g., computerized physician order entry and electronic medication administration records) [22, 24, 25, 34, 38, 39, 43, 49]. These studies noted that many EMR platforms are not designed ~~for efficient use~~to support decision-making during clinical practice; instead, EMRs serve archival record-keeping functions. Consequently, systems fail to support providers' easy access, manipulation, or sharing of information as needed [22, 24, 39, 52]. Practitioners created customized workarounds (e.g., personal notes) to record needed information outside of EMRs – particularly at key transitions such as handoffs [~~32~~52]. Findings across studies support EMR designs with positive features like temporary status, transportability, shareability, and visibility within the work environment [24, 25, ~~32~~52]. Further, EMRs must provide integrated access by multiple providers [22]. Workarounds increase cognitive effort as practitioners respond to problems in EMR design [~~32~~52]. Studies focusing on workarounds during clinical decision-making may identify ways to improve system support [38].

(6) Systems-level error: ~~Where does distributed cognition break down?~~

Some studies found DCog well-suited for investigating the evolution and propagation of error at the systems level [33, 34, 36, 37, 38, 40, 41, 42]. Several articles found errors arising from interruptions, distractions, multitasking, information loss, and workarounds [11, 24, 29, 37, 41, 52]. Physicians received no notification when a computed tomography (CT) was available, so they had to actively look for it in the system [49]. A study of ICU nurses found that interruptions and physical changes in the workplace were associated with more lag time before resumption [11]. This added demand on working memory created a reliance on contextual reminders which may increase error. Another source of error explored in the studies was information loss occurring at intake, handoff, and discharge [26]. Errors arise because of communication or documentation deficits, and studies found errors were particularly prevalent in ICU and ED settings [9, 33, 41]. Similarly, a study of trauma resuscitations demonstrated how interruptions and communication breakdowns led to errors and suggested technology supports for trauma bay layouts [51]. While studies focused on the development of technological interventions [36, 42, 51], conclusions about error reduction strategies for clinical decision-makers were limited.

(7) Distributed decision-making: ~~Where are diagnostic decisions made in distributed teams?~~ Diagnostic and management decisions are made at varied points on distributed teams.

Some studies identified team members as “decision hubs” in acute care settings [9, 23]. One study identified prospective memory tasks as a more specific form of DCog where an individual plans and creates reminders for future time points supported by external cues [32]. Custom artifacts in the work environment serve as triggers for prompt task execution over time and agents [7]. However, there was a paucity of findings addressing *how* clinical decisions are made. While acute care decisions require a distributed system, most studies focused on observable events (information shared through track boards or verbal exchanges) rather than the progress of clinical decision-making across teams and its relationship to clinical outcomes. Only one study specifically emphasized DCog as a negative factor in clinical decision-making. In this study, conversational analysis revealed signs of physician uncertainty during handoff preparation, and this was ascribed to the distribution of clinical decision-making over time [46]. Sharing an uncertain understanding requires capturing incomplete decision representations awaiting further information.

DISCUSSION

We examined the extent, range, and nature of evidence in empirical studies using a DCog framework [5] to explore clinical decision-making in acute care settings. Our findings demonstrate that DCog has been utilized to examine the work of a wide range of health professionals, in numerous contexts. Information flow and task coordination were the most frequently investigated elements of DCog, and significant attention has been given to provider-artifact and provider-provider interactions. Other elements of DCog, such as spatial layouts, horizon of observation, and emergence, as well as patient-provider and patient-artifact interactions, have been less well-explored to date.

Our findings highlight key strategies for enhancing information flow, communication, and coordination within teams including: (1) adding representations of intermediate steps in decision-making; (2) optimizing artifacts to improve coordination (e.g., track boards, EMRs); and (3) increasing situational awareness through centralized workspaces.

Our findings also suggest that the EMR ~~should~~ might be redesigned to better support clinical decision-making by teams dispersed across space and time, rather than serving predominately as an archival record. This mismatch, of EMR use as record versus use as a tool to support decision-making, contributed to information loss, lack of coordination, and faculty communication. Consequently, information existing within the distributed system was not routinely employed as needed in decision-making. DCog provides a means to determine *where* needed information is located compared to *where it should be* located to support clinical decision-making, which can inform EMR re-design. The ability to access, share and analyze information at the point of care using an interconnected system of portable devices (tablets, phones, small and large screens in nursing stations and patient rooms) linked with support decision systems, would be critical to redistribute and enhance the use of EMR in the workplace.

While some DCog studies documented errors, further research is needed to identify how these arise in distributed cognitive systems. For example, studies comparing sites or through ABA designs can identify properties of distributed systems that promote (and mitigate) errors. Given the dearth of attention to distributed clinical decision-making, future studies are needed applying DCog to map when, where, and how intermediate decisions are made and how they accumulate to produce diagnostic outcomes. Focused functional analysis, such as tracking when and how consults occur across cases, may identify ways to build in more efficient processes during clinical decision-making.

Contributions from DCog Studies in Acute Care Settings

Our review explored contributions of the DCog framework going beyond previous findings about decision making in acute care, such as handoffs as pain points [26]. While there is much room for further progress in DCog systems analyses, our findings describe new contributions to research on decision making in acute care settings.

One contribution is the importance of “workarounds” created by team members to share, preserve, or move information outside of standard processes. Individuals distribute their own work over time, resulting in the need to anticipate and remind themselves of intentions. To fill this need, clinicians created personal artifacts such as to-do lists. The documented need for prospective memory [58] supports providing these external cues within the system [7, 32]. Standardized artifacts in the environment may be useful triggers to prompt task execution across time and agents [7] in ways like shared status boards.

The DCog framework also raised new questions about how to better support awareness of agents in the system, particularly regarding the spatial layout of workspaces and collocation of team members. Shared workspaces may have advantages through “overhearing” others’ work [5]. Presence in the same physical space provides a greater horizon of observation because information is (often unintentionally) accessible to other team members. A shared understanding of clinical cases evolves over time as individuals change their execution based on perceptions of what other team members know (or should know). These coordinating processes are highly dependent on subtle features of spatial and physical arrangements of team members and technology, suggesting situational awareness should be a primary concern in clinical space design.

Finally, DCog provides a means to identify how clinical decision-making differs across cases. The typical and the actual information flow in a case may be different due to variations in the timing of information arrival, its format or completeness, and its coordination in later tasks. Comparing typical progress with unusual cases may point to other ways to standardize processes, improving system robustness [5]. How can patterns in distributed cognitive tasks (delay, repetition, interruption) signal the need for system improvements? Feedback on collective performance may also motivate team members to contribute beyond their assigned tasks. Providing system feedback to all team members (number and kinds of cases, tasks, problems, and discharges by shift) may inculcate a collectivist view of clinical decision making as distributed cognition.

Future Opportunities for Applying DCog in Acute Care Settings

The findings of this review demonstrate how frameworks like DCog can be useful for understanding complex interactions among healthcare providers and tools. Further, it suggests some directions for the design and development of more efficient healthcare technologies, workspaces, and processes to address gaps in the study of system-level error in clinical decision making.

(1) Error detection and mitigation

While most studies mention errors, efforts to develop strategies to mitigate error were sparse. More effective error reduction interventions in U.S. healthcare are sorely needed [59, 60], and existing error interventions from Root Cause Analysis (as employed by most US hospitals) do not appear to effectively reduce errors [61]. The DCog framework offers a novel approach for identifying errors in *interactions* among tools and actors working in complex environments. Thus, it may provide an optimal framework for developing error reduction interventions.

(2) Initiation in distributed systems

One focus of the selected studies was task coordination, and how exchanges between team members moved the process ahead. For future studies, there is a need to understand *initiation* in clinical decision-making. Given the complexity of distributed tasks, it is likely that nonoptimal lags in progress were caused by the absence of notifications and reminders to return to "paused" tasks [49]. Studies using EMR entries and time points of access may identify information trajectories, suggesting places where additional tools may assist practitioners in rapid action.

(3) System feedback

DCog frameworks could enhance the identification of key performance metrics within acute care systems. While the overall outcome of a clinical case may be considered for quality improvement purposes, it may be challenging to identify the role of each distributed task in contributing to successes and shortcomings. This is a systems-level, rather than a case-level, question. In studying complex systems of collective behavior, signals were identified that inform individuals so they can decide correctly, moment-by-moment, what task to perform and how to perform it [60]. Future work may identify the key factors needed to inform distributed teams about what works and what doesn't.

(4) Improving clinical decision-making

A final opportunity in future studies is combining analyses of individual clinical decision-making and distributed cognitive systems. Without pairing the distributed system with the decision-making processes, it is not possible to identify where errors arise or how to best mitigate them. While standard case evaluations compare what is documented in an EMR about a case and a healthcare provider’s decisions about it, the key factors of distribution of incoming information over space, time, and cases are not typically considered. To determine whether and what types of errors are arising, it is important to consider the decision-making process within the context of the DCog system supporting it. For example, if a clinical case involved key evidence (e.g., a pregnancy test outcome), a decision analysis might conclude it was critical to the case, while a DCog analysis might identify where and when that information was available in the distributed system, and how it failed to propagate to the clinical decision-maker. DCog analyses have the potential to trace representation change from initial to final assessment across artifacts and individual understandings to better support clinical decision-making.

Limitations

Because most studies were qualitative and labor-intensive, they focused on macroscopic (information coordination) rather than microscopic elements (errors during specific tasks, information flow to a decision-maker) requiring richer data collection. While superficial interactions between actors and artifacts could be broadly categorized, this “birds-eye view” may miss more nuanced interactions ultimately driving system success, such as shared team history [62]. ~~Our review is also limited by the small number of empirical studies applying DCog in acute care settings. Additional studies may identify other findings and novel insights.~~ The studies took place in a wide variety of clinical settings across varied medical procedures; consequently, describing common themes across studies may omit important properties of DCog application in individual studies. Further, our focus on acute care settings may emphasize urgent decision-making requiring concurrent diagnostic activities. Care settings with less need for expediency may demonstrate less need for coordination; however, distribution may arise from specialization (of providers and technological artifacts) as well urgency.

CONCLUSION

A primary gain from theory is pointing researchers in the right direction. The distributed cognition framework directs attention beyond individual healthcare providers to the system: How is information collected, represented, propagated, and transformed during the distributed clinical decision-making processes? New technologies, such as EMR systems, change the trajectories of information with consequences to clinical decision-making that are rarely anticipated by designers. The application of the DCog framework to clinical decision-making in acute care settings identifies the importance of these situated processes as enacted in the independent activities of real persons interacting with real artifacts and with each other.

Abbreviations: DCog = Distributed Cognition, ED = emergency department, OR = operating room, ICU = intensive care unit, PRISMA-ScR = Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews, NP = nurse practitioner, PA = physician’s assistant, EMR = electronic medical record, PMR = paper medical record, MAS = medication administration system, DiCOT = Distributed Cognition for Teamwork, CT = computed tomography.

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Competing interests

Authors state no conflict of interest.

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