Twenty Years of Cognitive Work Analysis in Health Care: A Scoping Review

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Improving patient safety, within the context of a complex system, forms one of the key challenges in health care today. Cognitive work analysis (CWA) is one way to analyze complex systems, and although it has been applied to health care for 20 years, little is known about its effectiveness or future research needs. This article presents a review of CWA studies in health care, addressing questions of use, usefulness, challenges, and opportunities. Results of the review make clear that the research agenda is largely confined to acute care. Of the 39 articles reviewed, 28 relate to this setting. There appears to be a growing interest in medical informatics, error investigation, and decision support. Conversely, work in physiological monitoring has slowed, associated with the uncertainties of modeling "biological" systems. Studies related to "organic" social systems are similarly challenged, although there is a recognition that important opportunities exist, such as studying work flow processes between teams. Other opportunities relate to new methods to enhance CWA; new technologies, such as auditory displays; and new applications, such as requests for proposals and incident investigation. Ultimately, the capacity to foster an understanding into the deep structures of a system may prove to be the greatest contribution of CWA to health care today.

Keywords: cognitive systems engineering, cognitive work analysis, health care systems, ecological interface design

INTRODUCTION

Today's health care systems face serious challenges. According to one observer, not only do "medical mistakes kill enough people [in the United States] each week to fill four jumbo jets," but "the medical community rarely learns from them. The same preventable mistakes are made over and over again" (Makary, 2012). The problem has spawned continuous discussion and debate as well as new branches of study in "patient safety" and "complex systems" within health care.

The Institute of Medicine (IOM) describes health care systems and their challenges as follows:

> In health care, a system can be an integrated delivery system, a centrally owned multihospital system, or a virtual system comprised of many different partners over a wide geographic area. However, an operating room or an obstetrical unit is also a type of system. Furthermore, any element in a system probably belongs to multiple systems. For example, one operating room is part of a surgical department, which is part of a hospital, which is part of a larger health care delivery system. *The variable size, scope, and membership of systems make them difficult to analyze and understand* [emphasis added]. (Kohn, Corrigan, & Donaldson, 2000, p. 52)

It is within this context that health care specialists are positioned today, facing vital safety concerns while grappling with inherent complexity. *Cognitive work analysis* (CWA) is an engineering framework used to analyze complex systems (Vicente, 1999). Although it has been applied to health care for two decades, there have been no reviews of its effectiveness or clear statements of research needs. Thus, the time is ripe for a historical review of CWA in health care to assess its value as well as to explore its potential to help meet some of the challenges we face.

This article presents a "scoping review" of 20 years of CWA in health care, in which the following guiding questions are addressed:

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1. How has CWA been applied to health care: at which levels of care, with which phases of analysis, and with what modifications?
2. Has CWA been considered useful in terms of its "impact" and "uniqueness" (Naikar, 2008)?
3. What challenges exist in applying CWA to health care?
4. What opportunities exist for future development?

After outlining basics of the CWA framework, a description of the scoping review methodology will be presented, followed by the results of the review.

CWA

The CWA framework, formulated in the 1970s, is based on studies of two contrasting systems: nuclear power and library science (see Vicente, 1999, for a historical overview). In the years since, the framework has been adopted for use in a variety of applications, from air traffic control (Ahlstrom, 2005) to military team building and training (Naikar, 2006). In the health care domain, CWA has been used for approximately 20 years. Although these domains vary considerably, they are all classified as "complex sociotechnical systems" by virtue of the subset of features they exhibit, as defined by Vicente (1999, p. 14). It is important to ensure a system is complex and sociotechnical because these kinds of systems in particular are considered best suited to an intricate CWA study. Features associated with such systems include the potential for hazards and the possibility of unanticipated events, which are often associated with systems that are dynamic and open to external influences. In the case of health care, These are also features that relate to two important concerns in health care: "medical error" and "unintended effects."

An Overview of the CWA Framework

Theoretically, the CWA framework revolves around the interactions between people, technologies, and workspaces. One way to consider these interactions is in terms of four layers. Within an *environmental context* lies an *organizational structure* that is populated by *individuals*. These individuals employ strategies, share information, and work toward goals while, in some fashion, interacting with a *technical system* that is designed to support system objectives. Five specific phases of analysis within CWA are employed to analyze these layers in a manner that reveals constraints upon the system. These constraints may involve laws of physics, regulations, financial caps, organizational structures, or human cognitive limitations. By highlighting constraints in a systematic manner, the results of the five phases show how options for action become progressively narrowed within a system (Vicente, 1999).

Another way to view these phases is by considering the set of questions and concerns they address, as outlined by Kilgore, St-Cyr, and Jamieson (2008). To begin, these concerns relate to the overall purpose of a system (Why?) and progressively narrow to the systemwide tasks to be performed (What?), the strategies within the organization to be invoked (How?), the roles and responsibilities for various "actors," be they human or machine, to fulfill (By whom?), and finally, the competencies necessary for an individual working within the system to utilize (By what means?).

Table 1 summarizes these phases as well as the general constraints and modeling tools associated with each phase. Use of these tools is often accompanied by ethnographic techniques, such as observation and interview. For detailed descriptions and demonstrations of the CWA phases and tools, see Rasmussen, Pejtersen, and Goodstein (1994); Vicente (1999); Bisantz and Burns (2008); and Jenkins, Stanton, Salmon, and Walker (2009).

Phases of Analysis

Typically, the first phase of analysis relates to a workspace or "work domain." During this phase, the analyst studies the overall purpose(s) of a system, progressively decomposing it for two reasons: first, to identify the system's deeper underpinnings, which may involve specifying constraints, such as physical laws and theories or regulatory rules and requirements; and second, to specify system information requirements, including the variables to be measured, calculated, estimated, or simulated to fulfill the overall purposes. Once a system's purposes are defined, the necessary tasks to achieve those purposes can be analyzed. The focus of the second phase, called

TABLE 1: Summary of Cognitive Work Analysis Phases

Question	Phase of Analysis	Constraints	Analytical Tools[b]
Why?	Work domain analysis (WDA)	Purposes, balances, priorities, processes	Abstraction hierarchy Part-whole decomposition
What?	Control task analysis (ConTA)	Activities	Decision ladder Chained decision ladder Contextual activity template (Naikar, Pearce, Drumm, & Sanderson, 2003)
How?	Strategies analysis (SA)	Strategies	Information flow map
By whom?	Organizational analysis (OA)[a]	Function allocation, communication	Information flow map Responsibility map (Rasmussen et al., 1990) Collaboration table
By what means?	Competencies analysis (CA)[a]	Cognitive capabilities	Skills-rules-knowledge (SRK) taxonomy

Note. Table adapted from Kilgore, St-Cyr, and Jamieson (2008) and Naikar (2006).
[a]The names and abbreviations adopted here are for clarity only and not intended to be associated with analyses from other frameworks.
[b]For background information regarding analytical tools, see Rasmussen, Pejtersen, and Goodstein (1994) unless otherwise noted.

"control task analysis," centers on what is necessary to achieve the system purposes rather than who will accomplish it or what technologies will support it. Thus, the emphasis in this phase lies on *what* is to be done rather than precisely *how* it will be done (Vicente, 1999). This question of how a task is achieved is addressed in the third phase of analysis, called the "strategies analysis." In this phase, each activity is deconstructed to understand how it may be accomplished. Even within a single information-processing activity, multiple strategies may exist. For example, problem solving might involve pattern recognition, "if-then" decision tables, or hypothesis-and-test approaches. Given the strategies adopted and the associated cognitive loads they carry, design implications follow. One example might relate to "function allocation," for instance (i.e., the division of labor between individuals and technologies), so that in situations of high cognitive load, an individual may be aided with appropriate decision support tools (Vicente, 1999).

This example of function allocation previews the fourth phase of CWA: the "social organization and cooperation analysis." In addition to identifying which "actor" (human or machine) will perform a task, this phase also identifies the organizational channels of coordination and communication necessary to accomplish that task. This information can, in turn, be mapped onto previous phases of analyses. For example, the division of labor between a surgeon and anesthesiologist during surgery can be mapped onto a work domain analysis (WDA) to better show how clinicians interact within a workspace (Vicente, 1999).

The final phase of CWA identifies the human competencies needed to perform a task at hand. These competencies involve cognitive capabilities and limitations, ranging from most cognitively efficient (like riding a bicycle for an avid cyclist) to most effortful (like calculating the bicycle's trajectory for most of the population). In situations of high (effortful) cognitive load, a system may be enhanced by integrating decision support tools or by introducing training modules into an organizational design. Alternatively, "cognitive offloading" may be an option whereby appropriate technical systems are in place so that an effortful activity is allocated to a machine rather than a human (Vicente, 1999).

Although the complete CWA framework consists of five phases of analysis, it is important to note that not every phase is suited to every circumstance. Often, only a subset of these will be performed. For instance, development of visual interfaces often involves the first and fifth analyses only, that is, WDA coupled with a competencies analysis, forming *ecological interface design* (EID; Bennett & Flach, 2011; Burns & Hajdukiewicz, 2004). However, other less formal combinations are also in use. Thus, the framework accommodates considerable variation in terms of which phases are applied as well as the order in which they are performed. Fundamentally, though, what the CWA framework is thought to offer is a deep study of the various constraints of a system and, chiefly, "a demonstration of the various dimensions of the problem" (Rasmussen, cited in Vicente, 1999, p. xi).

REVIEW METHODOLOGY

To answer the four guiding questions presented at the outset of this article, a scoping review methodology was adopted. The scoping review differs from a systematic review in its purpose and in some of its procedures. These differences are sketched out next, along with terminology in use and the specific methods that were applied for this study.

Scoping Review Framework

The methods in this study are based on a scoping review framework developed by Arksey and O'Malley (2005) in response to the challenges of applying a systematic review process to a relatively new field of research in housing and dementia. Scoping studies are suited to work that is early in development or for which no formal review has been conducted. They are typically qualitative rather than quantitative and intended to highlight "gaps in a body of literature" rather than answer narrowly circumscribed research questions (Armstrong, Hall, Doyle, & Waters, 2011, p. 148). Key differences between scoping studies and systematic studies are outlined in Table 2.

Although work involving CWA in health care began approximately 20 years ago, the majority of projects have taken place only in the past 10 years. It is not surprising, therefore, that no review study exists. Not only is there no review related to CWA in health care, but there is no formal review of CWA applications in any domain. Thus, the "lay of the land" and, consequently, the areas requiring further development (i.e., the gaps in the literature) remain obscured on many levels. Given this situation, the scoping study framework is appropriate to this task.

The six stages of the framework are as follows: identifying the research question; identifying relevant studies; selecting studies; charting the data; collating, summarizing, and reporting the results; and an optional consultation phase (Arksey & O'Malley, 2005). Implementation of each stage and the terminology in use is described below.

Research questions (Stage 1). The research questions guiding this study are listed in the introduction; however, to summarize, they involve the *use, usefulness, challenges*, and *opportunities* associated with applying CWA to health care. These questions were driven by the intention of not only understanding current use but also assessing value, uncovering matters of concern, and highlighting emerging possibilities.

Identifying and selecting studies (Stages 2 and 3). Given that work in this area is relatively recent, depth of search results was not expected; therefore, breadth was emphasized with an aim to include both peer-reviewed and non-peer-reviewed work. Both applied and theoretical articles were also considered, the latter to allow for deeper commentaries on CWA, which can shed light on important conceptual issues as well as considerations for future work.

The search process targeted identified articles published in English before July 2012, using health-related databases Embase, Pubmed, and PsychInfo; engineering databases Compendex and Inspec; and general databases Google Scholar and Google Web. Search terms *cognitive work analysis* and *ecological interface design* were entered into the health-related databases; *health* was added as a search term in the engineering databases and Google searches. Duplicates were eliminated. To supplement the database search, reference lists of relevant articles were scanned for additional material, and articles based on personal communication with experts in the field were accepted.

TABLE 2: Comparison Between Systematic and Scoping Reviews

Criteria	Systematic Review	Scoping Review
Research question	"Focused with . . . narrow parameters"	Often broadly stated
Inclusion/exclusion	"Usually defined at the outset"	"Can be developed post hoc"
Quality filters	"Often applied"	"Quality not an initial priority"
Data extraction	'Detailed . . . extraction'	"May or may not involve data extraction"
Kind of synthesis	Often quantitative	Often qualitative
Purpose	To "formally assess the quality of studies and generate a conclusion relating to the focused research question"	To "identify parameters and gaps in a body of literature"

Note. Table adapted from Armstrong, Hall, Doyle, and Waters (2011, p. 148).

Studies were selected on the basis of first an abstract reading and then a full reading. Articles were excluded at the abstract stage if they focused on domains outside of health care (e.g., military systems, transportation, process control, pasteurization) and at the full reading stage if they referred to CWA or EID only in passing. Some articles were excluded because they could not be accessed from the library information system. (See Figure 1 for a complete breakdown of the selection results, patterned after Brien, Lorenzetti, Lewis, Kennedy, & Ghali, 2010.)

Charting the data (Stage 4). Initial charts comprised columns with the following information: the study "identification," including its level of care, authors, and title; study "description," including its purpose and participants; and "notes," including findings, comments on CWA analyses, and conclusions. Articles of a theoretical nature were grouped at the end of the chart. By taking this general approach, it was possible to survey the extent and nature of CWA use in the various health care subdomains and prepare for final reporting.

Collating, summarizing, and reporting results (Stage 5). In its final form, results to address the first research question regarding the use of CWA were both tabulated and discussed. The remaining questions of usefulness, challenges, and opportunities were ill suited to a tabulated format and were addressed descriptively.

Consultation (Stage 6). This optional stage consisted of informal consultations with systems engineering and health care specialists with experience using the CWA framework. First contact was made via e-mail to invite experts to share their opinions regarding the three final research questions of usefulness, challenges, and opportunities. Four experts responded. Communication was conducted via e-mail in two cases and in person in two others. Additional articles were also obtained via personal communication during this stage.

Terminology

Before turning to the results, it is important to explain the terms used to categorize the articles in this review. Articles may be largely theoretical or applied in nature. Theoretical articles include overviews, informal reviews, and analytical pieces. Applied articles are arranged thematically in terms of the following levels of care: "primary care," comprising general practice; "hospital care," comprising emergency/ambulatory, acute, continuing, and rehabilitation care; and "community care," comprising home and residential care as well as community mental health ("Types of Care," 2011). "Medical informatics" has been added as a distinct theme of its own. Although formal definitions related to informatics remain unclear (Hersh, 2009), for the purposes of this article, *informatics* refers to information technologies that

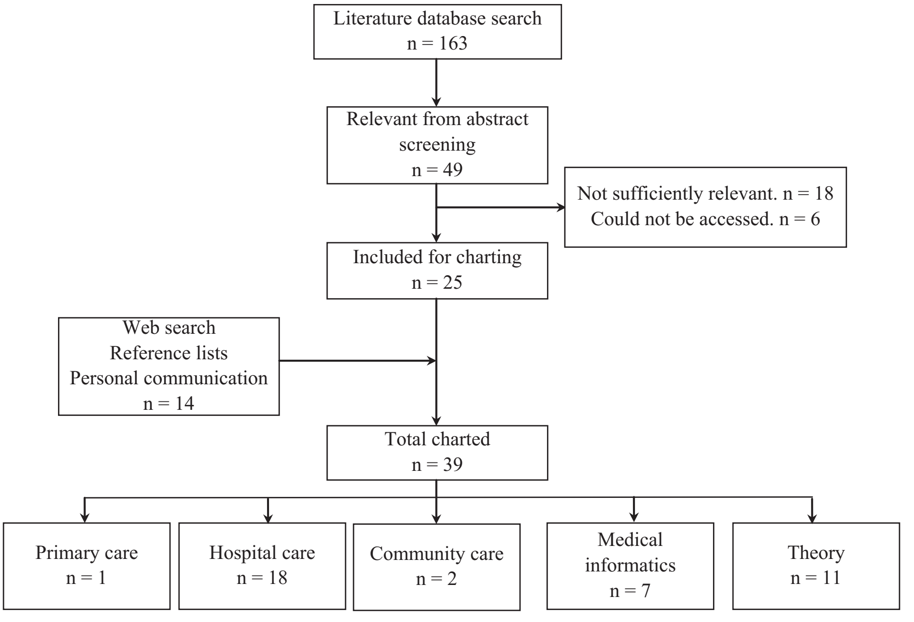

Figure 1. Results of the literature search.

support individual patient care, comprising telehealth, electronic health records (EHRs), and medication processing.

RESULTS

Search Results

After uncovering 163 articles in the database search, we identified 39 articles for inclusion in the review: 28 applied articles and 11 theoretical contributions. See Figure 1 for a breakdown of search results and Table 3 for the tabulated summary of CWA use in health care.

How Has CWA Been Applied to Health Care: At Which Levels of Care, With Which Phases of Analysis, and With What Modifications?

Despite a relatively modest number of application-based studies in total (28), several represent significant investments involving large-scale projects, such as trauma center redesign, nurse manager decision support tools, and cardiac care teletriage. In terms of the levels of care, it can be argued that 25 of 28 applied articles relate to hospital care, since informatics systems are typically hospital based (18 in hospital care; 7 in informatics). Although medical informatics is well represented in this CWA review, it is important to note that the corollary is not true: The use of CWA is not well represented in the field of health informatics as a whole. In terms of actors, nurses are most often represented in these applied studies, although surgical teams, emergency room teams, clinicians, and nonclinicians are also involved. Within the hospital care projects, intensive care unit (ICU), anesthesiology, and emergency medicine form the majority.

Notably, it appears that some of the early applications of CWA, focusing on physiological monitoring in which the patient forms the "technical system" under study, appear to be in decline (see the subsection related to obstacles for a discussion of this result). Conversely, there seems to be a growing interest in analysis and error investigation (Lim, Anderson, & Buckle, 2008; Lopez, Gerling, Cary, & Kanak, 2010; Pingenot, Shanteau, & Sengstacke, 2009; Rogers, Cook, Bower, Molloy, & Render, 2004) and in development of decision-making support tools (Burns, Momtahan, & Enomoto, 2006; Effken, Brewer, Logue, Gephart, & Verran, 2011; Miller, Scheinkestel, & Steele, 2009; Morineau et al., 2009). However, this observation must be taken cautiously given the relative youth of the field and the size of the

TABLE 3: Cognitive Work Analysis in Health Care: A Summary of Results

Study: Author(s), Title, Country	Subdomain	WDA	ConTA	SA	OA	CA	Actors
Primary care: 1							
Thompson et al. (2003), "A Work Domain Analysis for Diabetes Management," Canada	Diabetes management	√					
Hospital care: 18							
Effken et al. (2011), "Using Cognitive Work Analysis to Fit Decision Support Tools to Nurse Manager's Work Flow," United States	ICU	√	√	√	√	√	Nurse managers/ directors/ executives, IT managers, quality managers (*n* = 20)
Effken et al. (2008), "Clinical Information Displays to Improve ICU Outcomes," United States	ICU	—	—	—	—	—	ICU nurses (*n* = 32)
Effken (2006), "Improving Clinical Decision Making Through Ecological Interfaces," United States	ICU	√	—	—	—	—	Novice nurses (*n* = 20); medical residents (*n* = 13)
Effken et al. (2001), "Using Cognitive Work Analysis to Design Clinical Displays," United States	ICU	√	√	√	√	√	ICU clinicians
Hall et al. (2006), "Fixation and Attention Allocation in Anesthesiology Crisis Management: An Abstraction Hierarchy Perspective," United States	Anesthesiology	√	—	—	—	—	Anesthesiology residents
Jungk et al. (1999), "Ergonomic Evaluation of an Ecological Interface and a Profilogram Display for Hemodynamic Monitoring," Germany	Anesthesiology						Anesthesiologists (*n* = 20)
Lopez et al. (2010), "Cognitive Work Analysis to Evaluate the Problem of Patient Falls in an Inpatient Setting," United States	Neurology	√	—	—	—	—	Administrators, nurse assistants, registered nurses (*n* = 33)

(continued)

TABLE 3: (continued)

Study: Author(s), Title, Country	Subdomain	WDA	ConTA	SA	OA	CA	Actors
Miller et al. (2009), "The Effects of Clinical Information on Physicians' and Nurses' Decision-Making in ICUs," United States/Australia	ICU	√	—	—	—	—	i. Nurses (*n* = 16); physicians (*n* = 4) ii. Physicians (*n* = 12)
Morineau et al. (2009), "Decision Making During Preoperative Surgical Planning," France	Surgery	—	—	—	—	√	Neurosurgeons (*n* = 6)
Pingenot et al. (2009), "Description of inpatient medication Management Using Cognitive Work Analysis," United States	Medication processing	√	√	√	√	√	Clinicians, health IT specialist, nurses, pharmacist (*n* = 11)
Rogers et al. (2004), "Barriers to Implementing Wrong Site Surgery Guidelines," United States	Surgery-ICU	—	—	√	√	—	Surgeons, anesthesiologist (*n* = 11)
Sarcevic et al. (2010), "Towards an Efficient Method for Studying Collaborative Practices of Emergency Care Teams," United States	Emergency medicine	—	√	√*	√*	√	Trauma team members
Sarcevic et al. (2008), "Quantifying Adaptation Parameters for Information," United States	Emergency medicine	—	—	√	√	—	Trauma team members
Sarcevic et al. (2008), "Transactive Memory in Trauma Resuscitation," United States	Emergency medicine	—	—	—	—	—	—
Sharp & Helmicki (1998), "The Application of the Ecological Interface Design to Neonatal Intensive Care Medicine," United States	Neonatal ICU	√	—	—	—	—	Physicians (*n* = 16)
Watson & Sanderson (2007), "Designing for Attention With Sound: Challenges and Extensions to Ecological Interface Design," Australia	Anesthesiology	√	—	—	—	√	—

(continued)

TABLE 3: (continued)

Study: Author(s), Title, Country	Subdomain	WDA	ConTA	SA	OA	CA	Actors
Wu et al. (2012), "Work Domain Analysis for Designing a Radiotherapy System Control Interface," Canada	Oncology	√	—	—	—	—	Radiotherapists
Zhang et al. (2002), "Effects of Integrated Graphical Displays on Situational Awareness in Anesthesiology," United States	Anesthesiology	—	—	—	—	—	ii. Students (*n* = 12)
Community care: 2							
Lim et al. (2008), "Analysing Care Home Medication Errors: A Comparison of the London Protocol and Work Domain Analysis," United Kingdom	Residential care	√	—	—	—	—	
Unruh & Pratt (2007), "Patients as Actors: The Patient's Role in Detection," United States	Outpatient oncology	—	—	—	—	√	Outpatients (*n* = 18)
Medical informatics: 7							
Burns et al. (2008), "A Cognitive Work Analysis of Cardiac Care Nurses Performing Teletriage," Canada	Telehealth	√	√	√*	—	—	Cardiac nurse coordinators (*n* = 7)
Burns et al. (2006), "Supporting Strategies of Cardiac Nurse Coordinators Using Cognitive Work Analysis," Canada	Telehealth	—	—	√	—	—	Cardiac nurse coordinators (*n* = 7)
Cam et al. (2008), "An Investigation on the Use of Computerized Patient Care Documentation," United States	EHRs	√	—	—	—	—	Administrators, nurses, physicians (*n* = 11)

(continued)

TABLE 3: (continued)

Study: Author(s), Title, Country	Subdomain	WDA	ConTA	SA	OA	CA	Actors
Edraki & Milgram (2004), "Designing an Information Querying Interface for a Rheumatoid Arthritis Patient Record System," Canada	EHRs	√	—	—	—	—	Rheumatologists, clinicians (n = 5)
Guarrera et al. (2012), "Engineering Better Health IT Systems: Cognitive Systems Engineering of a Novel Emergency Department Interface," United States	EHRs	√	—	—	—	—	Emergency department staff (n = 15)
Lin & Gennari (2007), "Designing CPOE Systems Using an Ecological Approach," United States	EHRs	—	—	—	—	—	Clinicians, nonclinicians, patients [Proposal]
Momtahan et al. (2007), "Using Personal Digital Assistants and Patient Care Algorithms to Improve Access to Cardiac Care Best Practices," Canada	Telehealth	—	—	—	—	—	Cardiac nurse coordinators (n = 7)
Theoretical, analytical, and overview articles: 11							
Ashoori & Burns (2012), "Team Cognitive Work Analysis: Structure and Control Tasks," Canada	Labor and delivery unit	√	√	—	—	—	—
Canfield & Petrucci (1993), "Interface Design for Clinical Information Systems: An Ecological Interface Design Approach," United States	EHRs	—	—	—	—	—	—
Effken (2002), "Different Lenses, Improved Outcomes: A New Approach to the Analysis and Design Of Healthcare Information Systems," United States	Acute care–ICU	—	—	—	—	—	—

(continued)

TABLE 3: (continued)

Study: Author(s), Title, Country	Subdomain	WDA	ConTA	SA	OA	CA	Actors
Hajdukiewicz et al. (2001), "Modeling a Medical Environment: An Ontology for Integrated Medical Informatics Design," Canada	Anesthesiology	√	√	√	—	—	Anesthesiologist, surgical team, patient
Little (2010), "Combining Ontologies and Cognitive Engineering to Innovate Electronic Health Records," United States	EHRs	—	—	—	—	—	—
McEwen et al. (2011), "Creating Safety in Primary Care Practice With Electronic Medical Records Requires the Consideration of System Dynamics," United States	EHRs/systems engineering; interview study	—	—	—	—	—	Clerical staff, medical assistants, nurses, office managers, physicians (n = 17)
Miller & Sanderson (2000), "Modeling 'Deranged' Physiological Systems for ICU Information System Design," Australia	Physiological monitoring	—	—	—	—	—	—
Momtahan & Burns (2004), "Applications of Ecological Interface Design in Supporting the Nursing Process," Canada	Nursing	—	—	—	—	—	—
Rogers et al. (2006), "Cognitive Work Analysis in Health Care," United States	Medication processing	√	—	√	—	√	Nurses
Sanderson (2006), "The Multimodal World of Medical Monitoring Displays," Australia	Anesthesiology	—	—	—	—	—	—
Wears (2009), "What Makes Diagnosis Hard?" United Kingdom	Emergency medicine	—	√	—	—	—	—
Total count = 39		19	7	8	5	8	

Note. WDA: work domain analysis; ConTA: control task analysis; SA: strategies analysis; OA: organizational analysis; CA: competencies analysis; ICU: intensive care unit; IT: information technology; EHRs: electronic health records.

sample. In informatics, development work in EHRs and one multiphase project in telehealth dominate. Only two projects involve community care, and one involves primary care.

One interesting point emerging from the results lies in the ways in which CWA is being applied, particularly to the non-work situation of patients' roles in cancer care (Unruh & Pratt, 2007); to non-technical applications, such as guideline evaluation (Rogers et al., 2004) and error analysis (Lim et al., 2008; Lopez et al., 2010; Rogers et al., 2004); and to knowledge translation efforts involving the development of cognitive aids to extend expert knowledge (Momtahan, Burns, Sherrard, Mesana, & Labinaz, 2007).

In terms of the phases of analyses, in general, the majority involve a WDA (19), with a relatively even distribution among the final four phases of analysis (7 involve control task analysis; 8, strategies analysis; 5, organizational analysis; and 8, competencies analysis). It is important to note that this tally represents a general picture of the phases in use rather than a definitive measure, since some analyses may have been undertaken but not reported, while others may have been only suggested but still counted. Thus, it is important to view this tally with caution. However, given the highly technical nature of the applied articles in this review, the emphasis on WDA is to be expected, although it contrasts with the relatively flat "phase profile" suited to social systems that is suggested by Vicente (1999, p. 347). This could be because subsequent phases of analysis, such as the social-organizational analysis, have yet to be leveraged to their full potential, as discussed later in this review.

WDA was applied conventionally, as a constraint-based analysis to map information needs (Edraki & Milgram, 2004), and also unconventionally, as both a means to document the communication of health professionals (Pingenot et al., 2009) and an "umbrella" method to structure qualitative and quantitative data from observations, focus groups, and surveys (Lopez et al., 2010). Notably, WDAs were considered unique to each situation and not transferable (Effken, Loeb, Johnson, Johnson, & Reyna, 2001), thus encouraging tailored modifications when necessary, such as incorporating an "environmental analysis" to understand regulatory constraints (Effken et al., 2011). Regarding the strategies analysis, not surprisingly, the end results varied from study to study. In physiological monitoring, if-then "decision tables" were found to be the most common strategy (Effken et al., 2011); in medication processing, it was hypothesize and test (Pingenot et al., 2009); in cardiac care teletriage, it was topographical search, hypothesis and test, and eliminating possibilities (Burns, Enomoto, & Momtahan, 2008).

Two studies described issues conducting a strategies analysis. In one, these issues involved how one addresses additional strategies, new strategies, changing strategies, and also distinguishing between strategies (Burns et al., 2008). In another, suggested improvements to the analysis included further developing elicitation methods, designing objective ways to categorize strategies, and better understanding the context around strategy use (Burns, Momtahan, & Enomoto, 2006). However, in general, this analysis was recommended (Burns et al., 2006) and, in one case, regarded as the most beneficial of all analyses, highlighting avenues for future decision support (Burns et al., 2008).

Regarding the individual competencies analysis, the modeling tool associated with this phase (specifically, the skills-rules-knowledge [SRK] taxonomy) was generally considered inadequate and restrictive (Burns et al., 2006), missing the dynamic shifts that people demonstrate in reality. In short, "the richness seem[ed] to be lost" (Burns et al., 2008, p. 172) with this tool.

One variation was to apply an entirely different "individual resources" analysis to the situation, adopting tenure, schooling, and continuing education for nurse managers as variables of competence rather than applying the typical SRK breakdown (Effken et al., 2011). Another variation was to supplement the taxonomy with Reason's (2000) model of human error (Unruh & Pratt, 2007), which similarly adopts a "systems" approach that involves considering human performance errors as well as related working environments, organizational procedures, and technical systems as part of the accident investigation.

In terms of the fruits of the analyses, one general outcome involved the importance of coordination and communication between actors, which was identified in terms of both its implications for design (Pingenot et al., 2009; Sarcevic, Lesk, Marsic, & Burd, 2008; Unruh &

Pratt, 2007) and its implications for care (Pingenot et al., 2009; Rogers et al., 2004; Sarcevic, Lesk, et al., 2008). Some within the medical community describe communication as "a potent source of error in medicine" (Murphy, 2009, p. 36), thus echoing the importance of such studies.

Finally, to supplement CWA, the following theories, perspectives, and models were applied: ontological theory (Little, 2010), transactive memory theory (Sarcevic, Marsic, Lesk, & Burd, 2008), Carper's ways of knowing (Effken, 2002), and Reason's model of human error as described earlier (Unruh & Pratt, 2007). Tools were also modified to incorporate an "environmental analysis" of regulatory constraints (Effken et al., 2011) rather than a typical WDA and a "resource analysis" (Effken et al., 2011) to assess individual background factors rather than a competencies analysis.

Has CWA Been Considered Useful in Terms of Its "Impact" and "Uniqueness"?

Although assessing a framework like CWA can prove difficult given the challenges in controlling for external factors (Vicente, 1999), Naikar (2008) evaluated such projects by investigating usefulness, which she defined in terms of "impact" and "uniqueness": *impact* meaning whether using the CWA analyses "influenced practice on each project" (Naikar, 2008, p. 70) and *uniqueness* referring to the singular contribution of the CWA framework. These definitions are employed here. Before addressing this question, however, it is important to note the paucity of full evaluation studies in this review, which generally renders the findings in this section preliminary.

Impact. Regarding influence (Naikar, 2008, p. 70), findings are somewhat positive. One pilot study offered a descriptive account of the advantages and disadvantages of a new patient record interface (Cam, Efthimiadis, & Hammond, 2008). Advantages involved enhancements to the system, enabling EHR input and review, alerts, and display options; however, disadvantages included usability and customization.

A second pilot study involved the effectiveness and satisfaction of a mobile decision support tool to help nurses advising pre- and postcardiac patients by phone. The device supports knowledge elicitation and decision making. Results regarding appropriateness of advice, patient satisfaction and nurse satisfaction were captured over a 3-month period. In that time, physicians agreed with 97% of the advice given, patients reported 92% satisfaction with the calls, and nurses rated their satisfaction as 4/5 using the device (Momtahan et al., 2007).

A third study entailed a simulation involving nurses' responses to various ICU scenarios, whereby CWA-based pictorial displays were compared to conventional bar graph displays. On measures of cognitive workload and event recognition speed, results for both displays were similar. On satisfaction, CWA displays scored higher. However, for treatment efficiency, results were mixed. For those interfaces that displayed seven variables, efficiency of CWA displays were lower compared to the traditional bar graph displays; for those with 12 variables, efficiency was higher. In all, the treatment efficiency results suggest a complex interplay of data visualization factors at work and a need to understand the mappings of data to display more deeply (Effken, Loeb, Kang, & Lin, 2008).

Finally, in a fourth study examining medication processing errors in residential care homes, the London protocol (Taylor-Adams, Vincent, Chapman, & Connolly, 2004), which is a generic incident investigation tool unique to health care, was compared to WDA (Lim et al., 2008). Although the protocol proved easier to apply, within a shorter time frame and with good short-term results, use of the WDA resulted in a greater number of recommendations. Using WDA, both local recommendations—related to training, communication, and policies—and also higher-level global recommendations—related to information availability, medication processes, and resident participation, all absent from the protocol results—were made visible. Results from the protocol were found to be relevant to the specific situation, whereas results from the WDA were also relevant systemwide. Researchers concluded that "to make a long term impact on system safety, WDA is recommended" (Lim et al., 2008, p. 453). Notably, this study demonstrates how analyzing a single instance can shed light on the deeper structure of a system. More broadly, error in health care is often described as "unintended consequences" or "side effects"; however, those who use this description overlook the notion that "there are no side effects—just *effects*. . . . [They] are not a feature of reality, but a sign that the boundaries of our mental models are too narrow" (Sterman, 2006, p. 505). "Side effects" may also be a signal that the deep structures of a system are not well understood and that different methods, functioning at various levels of abstraction, are needed.

Uniqueness. In terms of the "singular contribution" (Naikar, 2008) of CWA, there is also no straightforward answer. CWA was considered "useful in healthcare" (Effken et al., 2001), particularly in understanding context (Cam et al., 2008) and identifying constraints (Effken et al., 2011). With respect to WDA, the framework "provide[d] insights about the structure of the patient data not found in conventional patient record systems" (Edraki & Milgram, 2004, p. 1637), which is a general point regarding new insights echoed by several others (Hajdukiewicz, Vicente, Doyle, Milgram, & Burns, 2001; Lim et al., 2008).With respect to strategies analysis, CWA was also considered "most beneficial" (Burns et al., 2008).

For decision support tools, EHR interface design, and error investigation, in general, CWA was considered useful. However, this finding is not the case for every health care application; for physiological monitoring, the framework failed to offer a contribution. "Clearly, further basic research is needed to uncover the relationships among physiological variables to allow for more coherent presentation in displays" (Effken et al., 2008, p. 774), a point that is expanded upon in the next section.

What Challenges Exist in Applying CWA to Health Care?

Given that "the complexity of the patient far exceeds the complexity of any industrial process" (Sharp & Helmicki, 1998, p. 5), significant challenges to the use of CWA in some health care domains exist. For instance, in work on physiological monitoring, as introduced earlier, Effken et al. (2008) highlight gaps in our understanding of human biological sciences, which often renders a WDA incomplete. Moreover, a complete suite of sensors to support the information requirements is simply unavailable (Sharp & Helmicki, 1998). Thus, for situations such as anesthesiology and ICU monitoring, in which a fine degree of detail may be critical to the analysis, this indeterminacy may undermine the effectiveness of the WDA. In terms of design, these indeterminacies render a complete description of the information requirements of a system unrealizable. Miller and Sanderson (2000), however, consider the issue to run deeper, arguing that WDA suits well-understood physical systems in which maintaining control is paramount, such as nuclear power or aircraft systems, but proves ill suited to systems that are purposely let "out of control" or "deranged," such as anesthesiology. In addition, "individual differences" also significantly influence an analysis, contributing to uncertainty in patient monitoring. However, at issue may be our incomplete understanding of biological systems in general, rather than the "deranged" nature of anesthesiology systems in particular, given that even in anesthesiology, certain constraints, albeit looser ones, will still be maintained.

Notably, the fine level of abstraction that is critical to analyzing biological systems remains inaccessible regardless of the method of analysis. WDA is at no particular disadvantage compared to other analyses in this respect; rather, a complete understanding of biological relationships simply remains beyond reach at present.

Similarly, this argument can be extended from biological systems to "organic" systems, such as hospitals, where a rich understanding of human social relations remains equally underspecified, again, in contrast to "engineered" systems, such as aviation or nuclear power. Looking ahead, a deeper understanding of social relations, particularly involving multiple teams with overlapping or competing interests, will be important. Notably, this is a topic largely absent from the literature to date, likely because studies involving single-team dynamics are only beginning to emerge (Ashoori & Burns, 2012; Sarcevic, Lesk, et al., 2008; Sarcevic, Lesk, Marsic, & Burd, 2010).

In summary, the use of CWA for applications whereby the patient forms the system under study appears to have ceased in recent years, and early adoption of CWA for patient monitoring is generally declining, particularly with respect to visual displays. Epistemic gaps associated with biological systems form one key factor behind this development; however, another may involve a general shift in attention among some CWA practitioners from modeling "causal systems," which are governed by physical laws, toward "intentional systems," governed by human goals, beliefs, desires, and social structures (Dennett, 1971; Rasmussen et al., 1994).

In a general review of CWA applications across disciplines, Read, Salmon, and Lenné (2012) uncovered a total of 60 CWA projects, with the majority involving intentional domains rather than causal ones. In health care, a similar pattern is evident. Work in the past decade from medical informatics to decision support and error analysis all fall into this latter category, suggesting a growing recognition that CWA may be fruitfully applied toward intentional systems. This development may help explain the decline of studies related to patient monitoring.

Looking more broadly at the overall application of CWA within the trillion-dollar health care industry, it is clear that penetration—with 39 published articles in total—is virtually nonexistent. However, it is also important to keep this result in perspective. It is only in the past dozen years, with the publication of the American IOM report *To Err is Human* (Kohn et al., 2000), that the crisis within health care has come fully to light and in the past 30 years that even basic human factors guidelines and standards for medical devices have been developed (Israelski, 2012), let alone systems-based approaches adopted. Furthermore, CWA itself is in its infancy, with primary texts available in the 1990s (Rasmussen et al., 1994; Vicente, 1999) and an overall total, as reported in the aforementioned review article, of 60 applications (Read et al., 2012). Thus, neither the CWA tools nor the pressing need to implement those tools has been in place until recent years, so at this time, a sparse penetration is unsurprising. Still, use of the framework has not fallen away over recent years but has maintained a consistent, albeit minimal, presence.

What Opportunities Exist for Future Development?

Accompanying the challenges noted previously are several opportunities. These range from broadening the areas in which CWA can be applied to enriching the framework itself.

In terms of applications, a significant proportion of work has been conducted in acute care hospitals, leaving other levels of care barely studied. Thus, opportunities exist in primary, continuing, and rehabilitation care as well as in community care settings. Work in these settings is expected only to grow in importance, given recent shifts toward distributed health care (Unruh & Pratt, 2007) driven by shortened inpatient stays and "aging-at-home" strategies (see Govt of Ontario, 2010, for an example).

In terms of enrichments to the framework itself, most significant is the proposal by Ashoori and Burns (2012) regarding "team CWA," which extends the social/organizational phase of analysis by integrating traditional CWA tools with recent tool modifications. Specifically, the enriched framework draws together tools, such as responsibility maps, collaboration tables, and chained decision ladders (see Rasmussen et al., 1994; Rasmussen, Pejtersen, & Schmidt, 1990), with contextual activity templates (Naikar, Pearce, Drumm, & Sanderson, 2003) and newly devised decision wheels, which are built upon the existing decision ladder pattern. The objective of this extension is to render the collaborations, constraints, and temporal trajectories among actors visible, so that social structures can be more easily analyzed. In turn, these developments may offer analysts a way to move beyond studies of single-operator systems toward a deeper understanding of rich "organic" systems.

Such initiatives are not only well supported in the health care literature, where the importance of studying social and organizational interactions has been emphasized (Healey & Vincent, 2007; Shiell, Hawe, & Gold, 2008), but are also well suited to the complex "system of systems" nature of health care described in the opening quote of this article (Kohn et al., 2000). Given this nature, a more targeted opportunity lies in the study of team-based work processes and specifically in the prioritizing, monitoring, and reprioritizing of cases in an emergency department. Although studies of trauma teams are underway (see Sarcevic et al., 2010), those studies focus on events within an operating room, rather than in a ward, leaving an important area of study concerning work flow still open. Other focused developments in CWA have arisen from work in anesthesiology, where researchers have suggested the EID framework be extended to support development of auditory displays (Sanderson, 2006; Watson & Sanderson, 2007) in a manner that both preserves semantic content and addresses attentional demand. For example, a "display" may incorporate a tempo sound to indicate heartbeat, combined with specific acoustic properties to direct attention (Watson & Sanderson, 2007). Such an extension would develop EID in important ways, beyond its current focus on visual perception.

An opportunity highlighted by Sanderson (2006) relates to a new arena of application for WDA, involving "research and development in instrumentation engineering" (p. 506). Thus far, there is little evidence to suggest that identifying information requirements, which are among the fruits of conducting a WDA, have been leveraged in this manner, so this opening would represent a new avenue for manufacturers to explore.

Finally, other openings for work, as suggested previously by Naikar (2008), involve determining training needs and requirements and conducting request-for-proposal evaluations. Although these suggestions were made with respect to industrial applications, both apply equally to health care. Moreover, health care researchers Shiell et al. (2008) highlight a need for such evaluations, arguing that "outcomes [for health care interventions] should be measured at multiple levels within the complex system, with tools designed specifically for this purpose" (p. 1282). CWA may offer suitable tools for such a task.

Expert consultation. The informal consultation with four CWA experts involved in health care revealed a few common threads. In terms of challenges to CWA, two felt that interest in applying CWA in industry is sparse because of its lack of exposure within the design community, the substantial investment of time and resources necessary to complete an analysis, and the current reliance on basic human factors methods that emphasize iterative design. However, it was noted that industry adoption is similarly low for other approaches, such as situational awareness and cognitive task analysis, so CWA is not unique in this respect. Moreover, even the degree to which human factors is being applied to health care systems is considered minimal, with universal standards developed only very recently (Israelski, 2012).

Other important issues that were raised involve the challenges associated with modeling the patient (as described earlier), since physiological processes "are either unknown, out of the user's control, or too complex to be relevant." (Participant 2, personal communication, Feb 1, 2012) Conversely, a WDA that remains at a high level of abstraction may not be sufficiently detailed to foster design innovation. Furthermore, issues related to control of biological systems as opposed to control of process systems, as described previously, render use of CWA problematic. Aside from these limitations, it was felt that CWA has been successfully applied in health care.

In applying the phases of analysis, it was noted that allowing the phenomenon to define the level of analysis, rather than blindly or rigidly applying tools and techniques, was important. It was also emphasized that the later phases of analysis, which often get ignored, may prove most beneficial, particularly related to understanding the strategies in use and facilitating sharing and transfer of expertise. However, broadening the CWA framework to suit highly social systems, such as health care, may require a deeper understanding of both individual intentional systems—associated with beliefs, goals, and expectations—and the social constraints that limit them.

Some felt that CWA is useful because it helps organize one's thoughts and decompose a complex problem into its constituent "blocks," which can help highlight the constraints of a system. Few approaches offer these advantages. Highly emphasized was the notion that committing to a full analysis helps uncover the deep structure of a phenomenon and that it is this particular aspect that gives CWA its power. Whereas human factors, for example, focuses on interfaces, and user-centered design focuses on mental models, CWA focuses on correspondence with reality. It involves "designing for medicine, rather than MDs" (Participant 3, personal communication, March 14, 2012).

Limitations of the Review

Limitations of this review are methodological. In general, scoping reviews do not assess the quality of articles found. Furthermore, synthesizing findings within a scoping review remains a challenging exercise with little guidance on constructing a cohesive narrative (Arksey & O'Malley, 2005). Other limitations are specific to this study, such as the absence of a second reviewer to assist with study selection (Levac, Colquhoun, & O'Brien, 2010), which lay beyond the resource limits of this project. Thus, it is likely that articles have been missed, particularly, gray literature, such as unpublished technical reports that often come to light from an author's professional network of contacts. Some articles were missed because of restrictions associated with the library information system in use; and others, likely because of search criteria that did not capture them.

CONCLUSIONS

At the outset of this article is the startling news that weekly fatal medical errors can be counted by the plane load (Makary, 2012). Although this situation would be catastrophic in aviation, in health care, it remains an everyday fact, even a decade after this information first came to light (Kohn et al., 2000). Difficult challenges continue to beset complex systems in health care.

CWA is one approach to study complex systems, but despite 20 years of use, little has been known about its value or its potential to help meet health care challenges. Consequently, the aim of this scoping review was to better understand the use, usefulness, obstacles, and opportunities associated with applying CWA within the health care domain.

Results of the review make clear that the research agenda is largely confined to acute care hospitals. Use is generally considered beneficial, particularly in the areas of electronic health records, decision support tools, and incident investigation, although the same cannot be said for physiological monitoring, which is hampered by the uncertainties associated with biological systems. Similar challenges relate to the study of "organic" social systems, in which there is also uncertainty, especially in contrast to "engineered" systems that are typically well understood. Also challenging are assessments of feasibility (Naikar, 2008), which are important but absent from this study, given the difficulties associated with accessing that information on the basis of the literature available. One can surmise that given the costs associated with developing, implementing, and maintaining a health care system, upfront analysis would be well worth the investment; however, no proof of feasibility based on the literature reviewed was presented.

Regarding opportunities for CWA, many exist. There is potential for new technologies associated with auditory displays, for example; for new methods associated with enhancements to the conventional CWA framework; and for new applications, including training, request for proposal, and incident investigation as well as future potential for inter-team work flow processes. In addition, a broadening of the research agenda to include settings beyond hospital care would be beneficial, particularly given the increasing shift toward community-based care. After 20 years of use, however, perhaps the greatest single contribution of CWA to health care lies in fostering a deeper understanding of a system into the "various dimensions of [a] problem" (Rasmussen, cited in Vicente, 1999, p. xi), which may prove critical in supporting patient safety within a culture of complexity.

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