A Cognitive Systems Engineering Design Approach to Improve the Usability of Electronic Order Forms for Medical Consultation

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Highlights

- Cognitive systems engineering was applied to medical referral management.
- Physicians' cognitive needs shaped design guidelines for consultation order forms.
- Design prototypes were preferred over implemented computerized order entry system.
- Cognitive systems engineering produced useful, usable electronic consult order forms.

Conflict of Interests

There are no conflicts to declare.

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Abstract

Background: During medical referrals, communication barriers between referring and consulting outpatient clinics delay patients' access to health care. One notable opportunity for reducing these barriers is improved usefulness and usability of electronic medical consultation order forms. The cognitive systems engineering (CSE) design approach focuses on supporting humans in managing cognitive complexity in sociotechnical systems. Cognitive complexity includes communication, decision-making, problem solving, and planning.

Objective: The objective of this research was to implement a CSE design approach to develop a template that supports the cognitive needs of referring clinicians and improves referral communication.

Methods: We conducted interviews and observations with primary care providers and specialists at two major tertiary, urban medical facilities. Using qualitative analysis, we identified cognitive requirements and design guidelines. Next, we designed user interface (UI) prototypes and compared their usability with that of a currently implemented UI at a major Midwestern medical facility.

Results: Physicians' cognitive challenges were summarized in four cognitive requirements and 13 design guidelines. As a result, two UI prototypes were developed to support order template search and completion. To compare UIs, 30 clinicians (referrers) participated in a consultation ordering simulation complemented with the think-aloud elicitation method. Oral comments about the UIs were coded for both content and valence (i.e., positive, neutral, or negative). Across 619 comments, the odds ratio for the UI prototype to elicit higher-valenced comments than the implemented UI was 13.5 (95% CI = [9.2, 19.8]), $p < .001$.

Conclusion: This study reinforced the significance of applying a CSE design approach to inform the design of health information technology. In addition, knowledge elicitation methods enabled identification of physicians' cognitive requirements and challenges when completing electronic medical consultation orders. The resultant knowledge was used to derive design guidelines and UI prototypes that were more useful and usable for referring physicians. Our results support the implementation of a CSE design approach for electronic medical consultation orders.

Keywords: Referral and Consultation; Cognitive Systems Engineering; Usability Evaluation; Human Factors; Medical Order Entry Systems

1 INTRODUCTION

More than a third of patients in the United States are referred to a specialist each year, and more than half of outpatient visits are with specialists (Mehrotra, Forrest, & Lin, 2011). Although consultation is a core clinical process, it is a long-standing source of frustration for clinicians, due to communication breakdowns in the process. Some of these breakdowns include the consultation requests being directed to the wrong specialty or consulting service, delayed information from either the referring or consulting clinician, unclear information from the referrer, insufficient information in the consultation request, patients not attending the consultation, and the priority of requests not being communicated to the consultant (Gandhi et al., 2000; Saleem et al., 2011). Managing consultations requires coordination and avoiding communication breakdowns among referrers, consultants, ancillary staff, and patients.

In many health care systems, when clinicians decide to send their patients to consultants, they generate referrals by ordering consultations in electronic health record (EHR) systems. Referral-related communication between clinicians is often inadequate (e.g., Bodek, Ghori, Edelstein, Reed, & Macfadyen, 2006). As the first step in referral communication, the consultation order is also the first point of communication breakdowns. Both referrers and consultants make errors of omission that could be prevented by a well-designed consultation order form. For example, referrers might not communicate necessary information, like a clinical question, the reason for consultation, or level of urgency (Conley, Jordan, & Ghali, 2009). On the other hand, consultants might not communicate the recommendations or findings. In some cases, roles of referrers or consultants in clinical co-management are unclear (Forrest, 2009; Thorsen, Hartveit, & Baerheim, 2013). Therefore, issues with the consultation process can be described as sociotechnical (Berg, 1999; Sittig & Singh, 2010; Wu et al., 2016).

Technological support for communication and coordination plays a key role, but EHR systems also contribute to unexpected barriers in the consultation process. Since 2009, spurred by government incentives to promote patient safety and communication among clinicians, EHRs have been increasingly adopted and are now used widely (Adler-Milstein et al., 2014; Blumenthal & Tavenner, 2010). Despite increased use, EHRs have not yet improved communication adequately; both referrers and consultants agree that the current approach to referral and consultation is flawed, with poor EHR usability as a contributing factor (Mehrotra et al., 2011; O'Malley & Reschovsky, 2011). Across public and private health care systems, studies have noted information-transfer challenges, fragmented care, and delayed access to specialty care (Esquivel, Sittig, Murphy, & Singh, 2012; Hysong et al., 2011; O'Malley & Reschovsky, 2011; Saleem et al., 2011; Zuchowski et al., 2015). Therefore, the implementation of a design approach capable of addressing the complexities of coordination, communication, and decision-making across clinical teams, information systems, and health care facilities is warranted (Turner, Brownstein, Cole, Karasz, & Kirchhoff, 2015).

Cognitive systems engineering (CSE) is an approach to the design of technology, training, and processes intended to manage cognitive complexity in sociotechnical systems, such as a medical center (Clark et al., 2017; Hollnagel & Woods, 1983; Militello, Dominguez, Lintern, & Klein, 2010; Rasmussen, Pejtersen, & Goodstein, 1994; Thyvalikakath et al., 2014). Cognitive complexity includes activities such as identifying, judging, attending, perceiving, remembering, reasoning, deciding, problem-solving, and planning (Militello et al., 2010; Miller & Militello, 2015), all of which referring and consulting clinicians must manage in the consultation process. Although cognition, by definition, refers to an individual's mental process, from a systems view, it is valuable to consider the concept of joint cognitive systems focusing on how humans and technology interact to perform complex work (e.g., primary care physician interacting with a computerized consultation template; Hollnagel & Woods, 2005; Woods & Hollnagel, 2006).

CSE advocates for methods aimed at understanding the world of work with an emphasis on cognitive challenges (Militello & Klein, 2013; Rasmussen et al., 1994); however, specific methods are not prescribed. Rather, methods are tailored to each project depending on project goals and resource constraints. CSE methods are often used with participatory design and ecological interface design. Examples of the application of CSE include strategies to inform models of workflow (Turner et al., 2015), work products (Berry et al., 2016), and cognition (Aselmaa et al., 2017). For this project, we combined documentation reviews to identify the intent of the electronic consultation order, interviews to obtain first-person perspectives, and observations to explore cognitive work as it occurs across humans and technology. Previous studies of consultations focused on rates and types of failure (Conley et al., 2009; Gandhi et al., 2000; Saleem et al., 2011; Zuchowski et al., 2015) or on strategies for improving consultations processes and clinical practice (Esquivel et al., 2012; Salerno, Hurst, Halvorson, & Mercado, 2007). However, this study focused on creating a foundational description of complex cognitive activities, contextual elements that increase difficulty, and how information flows across humans and technologies throughout the consultation process (Militello et al., 2018).

The objective for this research was to implement a CSE design approach to develop a template that supports the cognitive needs of referring clinicians in appropriately requesting consultations, which is the first step in the consultation process. CSE methods have not been applied to the design of consultation user interfaces (UIs). With an interdisciplinary team, which included physicians, human factors engineers, informaticians, and graphic designers, we followed a CSE approach to deriving cognitive requirements, translating them into design of a new prototypes for consultation, and evaluating the prototypes. As predicted by paradigms of cognitive fit and task-technology fit, when a UI is aligned with users' mental representations and external workflow, usability—specifically, task performance—improves (Goodhue & Thompson, 1995; Vessey, 2006). This study details one portion of a larger project to identify barriers and facilitators to effective consultations and deliver recommendations for mitigating barriers. Within the overarching goal, this study demonstrates the use of CSE in early stages of an adapted, iterative, interdisciplinary design process that supported shorter interview sessions to align with physicians' busy work schedules. To achieve our objective, we outlined the following aims: 1) identify cognitive requirements, 2) translate requirements to design guidelines, 3) design UI prototypes, and 4) evaluate usability impact. Compared with the currently implemented UI, we predicted that the prototypes would elicit more positive comments about its usability. Based on our review, this is the first study to apply CSE design methods to electronic consultation orders to improve decision and communication support.

2 COGNITIVE SYSTEMS ENGINEERING DESIGN APPROACH

Figure 1 illustrates the phases of this study. We chose CSE methods that overlap with other design frameworks to illustrate the potential of knowledge/skill transfer and increase likelihood of adoption for future designs. In the following section, our CSE design approach is discussed. Subsequently, we present our evaluation methods. We conducted a scenario-based simulation that compared the usability of the UI prototype with the usability of a currently implemented UI. In addition, we incorporated measures of clinicians' reactions to estimate impact of the designs derived from the CSE approach. Approval for the study was obtained from the U.S. Department of Veterans Affairs Central Institutional Review Board (protocol 13-53).

Figure 1. *Overview of the phases of decision-centered design. Adapted from Working Minds: A Practitioner's Guide to Cognitive Task Analysis (p. 181), by B. Crandall, G. A. Klein, & R. R. Hoffman, 2006, Cambridge, MA: MIT Press. Adapted with permission.*

2.1 Interviews and Observations

2.1.1 Participants

Participants were clinicians and supporting staff at two medical centers and associated community-based outpatient clinics in the western United States. Participants were involved in managing consultations between primary care and subspecialty clinics. Clinicians were recruited from primary and specialty care teams with varying lengths of service. High-volume specialties requiring coordination with primary care were chosen such that they included a mix of procedural versus cognitive specialties, and medical versus surgical specialties. Specialty care providers were recruited from six services: mental health, oncology, orthopedics, rheumatology, cardiology, and ophthalmology. These vary in their reported ease of communication (Zuchowski et al., 2015). A collaborator at each site introduced the study during team meetings; the collaborator followed up with potential participants separately. Participants were purposively recruited to include key roles in referral and consultation: PCPs, nurses, and specialists. Target sample sizes for each role were 12 based on anticipated need to achieve data saturation (Saleem et al., 2011).

2.1.2 Semi-structured interviews

Data collection took place from December 2014 through February 2015. Interviews lasted approximately 30 minutes and were conducted in each participant's place of work. Six questions served as the foundation for the interviews (Table 1). Interviewers followed up with probing questions as needed, with a focus on how cognitive activities are accomplished across humans and technology, and what contextual factors add difficulty.

Table 1. Interview Questions for Primary and Specialty Care Providers.

Interview Group	Questions
Primary care	What challenges do you experience when entering a consultation request in the EHR system? For what reasons are some of your consultation requests cancelled by the specialist? What challenges do you experience in receiving a report or findings after the consultation has been completed? Independent of the EHR system, what aspects of coordination with specialty services are working well? Please explain. What aspects of coordination are challenging? What approaches have you or colleagues found helpful for improving the consultation management process? What further suggestions do you have for improving the consultation management process and information system support between primary care and specialty services?
Specialty care	How do you handle new consultation requests in your clinic? Does a staff member from your clinic triage new consultation requests for you, or do you handle them yourself from the EHR system? Please explain. What strategies do you have for meeting the organizational policy of seeing a patient within a limited time frame? Independent of the EHR system, what aspects of coordination with primary care are working well? Please explain. What aspects of coordination are challenging? What approaches have you or colleagues found helpful for improving the consultation management process? What further suggestions do you have for improving the consultation management process and information system support between primary care and specialty services?

2.1.3 Observation

To better understand consultation requests within clinical workflow, individual data collectors observed health care providers during clinical encounters. The observations were conducted in clinicians' clinics as half-day sessions lasting approximately four hours (Russ, Zillich, McManus, Doebbeling, & Saleem, 2012). At the beginning of encounters, written assent was obtained from patients. To minimize interruptions, observers waited for breaks to ask clarifying questions. Observers were instructed to document four types of events with their approximate time of occurrence: computer use, communication, barriers to productivity, and location changes. Data were manually recorded and later transcribed for analysis. Data collectors reviewed notes and assisted with the characterization of workflows and identification of key demonstrations of barriers, facilitators, and workarounds.

2.2 Analysis and Representation

Interviews. We conducted a qualitative thematic analysis (Green & Thorogood, 2009) of the transcribed interview data. Four research team members (non-clinicians) independently reviewed transcripts constructing categories to describe the data. The research team used an iterative consensus-based approach to create a coding list consisting of subcategories of the consultation process (e.g., decision to request a consultation, submission steps, and tracking). At the point that new thematic categories no longer emerged, conceptual saturation was reached. Next, the list of categories was used by five research team members, including one author with a clinical background, to code a randomly selected sample of transcripts. This process led to discussion and revisions to the codebook. The final codebook included codes related to the consultation process, the supporting technology, and patients' role. Next, four team members coded remaining transcripts, continuing to refine the categories to capture nuances in the consultation process, and reaching consensus for each code. For each transcript, two research team members independently coded the transcript, and met to compare codes; individual team members rotated coding partners for each coding assignment. Any discrepancies between the coding pair were resolved through discussion (Saldaña, 2015). Coding was conducted using NVivo 10 (QSR International Pty Ltd, Melbourne, Australia).

Team members reviewed the abstracted themes from each category, and wrote a summary for each. Observations were integrated across cases, a process that identified common themes and important insights. In many cases, themes were linked to a specific aspect of the consultation process. For example, one set of themes focused on barriers to the use of computerized consultation templates.

In the next stage of analysis, we looked across the abstracted themes to identify cognitive requirements. Specifically, we identified challenging aspects of the consultation process. We identified cognitive requirements and specific barriers associated with each (Militello & Klein, 2013). To ensure that these barriers were grounded in the data, we reviewed the data to determine which transcripts mentioned each barrier.

Observations. These data provided, for example, observed workflow in specific clinics, strategies used to manage uncertainty, details of team meetings to triage consultation requests, and processes for creating reports to aid in tracking consultations in a specialty clinic. We reviewed observation documents across participants, creating vignettes and workflow drawings from the observation notes. These provided context for interpreting the interview data.

2.3 Design

With an interdisciplinary team, we translated the resulting cognitive requirements and difficulties into design guidelines. The artifacts from the interviews and observations were used to prioritize design choices and develop concepts that address the difficulties highlighted by physicians. Using an iterative design scheme, our team of physicians, cognitive systems engineers, and human factors engineers developed UI prototypes to support order template search and form completion.

2.3.1 Participants' Characteristics

Across the two medical centers, 81 staff participated (52 female; 64%). At the first site, 21 participated in interviews, and 18 participated in observations. At the second site, 22 participated in interviews, and 20 participated in observations. Among participants who reported the length of their career in years, the median was 19 years (IQR = [10, 31.5]; *n* = 46). Among participants who reported their proportion of working time in clinics, the median was 88 percent (IQR = [65%, 100%]; *n* = 39).

2.3.2 Cognitive Requirements and Design Guidelines

In our participants' current system, when a decision is made to refer a patient to specialty care, a consultation order is written through the EHR. Ordering a consultation through the EHR requires three steps. First, using professional experience and local policy, the referrer identifies the intended consulting clinic. Next, the referrer finds and completes a form template that prompts for clinical details requested by the consulting clinic. Last, the clinician completes the remaining details of the order, including the provisional diagnosis and clinically indicated date, and submits the order.

Cognitive requirements are commonly used to guide the design of interventions intended to support cognitive performance in complex tasks (Militello & Klein, 2013). For this study, we present cognitive requirements from the primary care provider's perspective relative to requesting a consultation (Table 2). We identified four cognitive requirements relevant to requesting a consultation. First, **determining whether a consultation is warranted** requires experience and judgment. Challenges associated with this cognitive demand include the following.

- *Professional roles and responsibilities are unclear*. Criteria from the specialty clinic regarding what illnesses or conditions they will treat might not be clear. The primary care provider (PCP) and specialty consultant may disagree about what should be handled in primary care vs. specialty care. In some cases, resolution depends on the knowledge or expertise of the PCP. For example, a PCP who lacks expertise about treatment of lung cancer would need to refer patients who need that treatment.
- *Patient's consultation history is unclear*. In the studied health care system, only the first clinical encounter with a specialty clinic is considered a consultation. All subsequent specialty encounters corresponding to the consultation are considered follow-up care. For the PCP, determining whether the patient is being followed by a specialty clinic might be difficult, because medical documentation is sometimes vague about clinicians' roles and the follow-up care of patients.
- *Knowledge of consultation process varies*. Many referring clinicians are unfamiliar with institution- and software-specific procedures for referral and consultation, especially when clinicians are trainees or newly hired employees. Consensus about appropriate criteria for e-consultation, in which the consultant reviews medical records but does not interact with the patient, may be lacking.
- *Patients may exert pressure to be referred*. A patient may request a consultation despite a PCP's recommendations to the contrary (e.g., a patient may insist on consultation with an orthopedic surgeon even after the PCP explains that the

patient is not a good candidate for back surgery). Even when the consulting clinic understands that a request is based on a patient's preference, the consultant might determine that the consultation is not warranted.

Second, **determining which subspecialty** to consult can be challenging. In addition to the role ambiguity mentioned above, finding the request form for the correct clinic is not always easy. All consultation request forms are available through the EHR system, but the consultation menu hierarchy is not straightforward (e.g., "Pain Clinic" may be initially hidden, visible only under a submenu of "Physical Medicine and Rehabilitation"). In addition, the text displayed in the referral menus has abbreviations and acronyms, that may be unfamiliar to a referrer new to this health system.

Third, **anticipating what the specialty clinic will need to know** is often difficult. Although the EHR consultation forms are intended to communicate what information is needed, the request forms are highly idiosyncratic. There is no standardization of consultation request forms across specialties. Some are onerous to complete, exhibiting poor usability—which distracts from sharing key clinical information about the patient (Savoy, Patel, Flanagan, Weiner, & Russ, 2017). Some request forms require information or even diagnostic tests or initial trials of treatments that are not relevant or appropriate for every patient. Referral request forms are not frequently updated, so at times a form may not fully reflect the current practice. In many settings, few opportunities exist for specialists and PCPs to interact and to improve their understanding of information needs in the other specialties.

A fourth challenge is **communication**. This was a consistent theme in our interviews. Consultation request forms constrain the information that can be easily communicated to the specialty clinic. To communicate outside the EHR-based consultation request, the PCP can contact the consulting clinic staff, or can contact the consulting clinician directly, if that person can be readily identified. Direct communication, however, is not always straightforward as clinicians are not generally available to respond to questions from other clinicians during clinic hours.

From the identified cognitive requirements, we derived associated design guidelines (Table 2).

Table 2. Cognitive requirements, difficulty, and design guidelines related to requesting a consultation.

Cognitive Requirements	Difficulty	Design Guidelines
1. Determine whether a consultation is warranted	• Roles ambiguity • Patient history not salient • Knowledge of consultation process varies • Patient pressures	1a. Display criteria from specialty clinic on consultation request form 1b. Make patient history salient 1c. Provide clinic-specific guidance about e-consultations 1d. Allow PCP to indicate consultation request motivated by patient desire to see specialty

2. Identify the appropriate target specialty	• Finding the request form for the right clinic	2a. Simplify consultation template list 2b. Make requirements of each specialty clinic available and accessible 2c. Provide a function to search for a template, or to match a clinical need to the appropriate consulting service
3. Anticipate what the consulting subspecialty will need to know	• Consultation request forms are idiosyncratic • Limited insight into consultants' needs and procedures.	3a. Standardize and simplify template forms 3b. Auto-populate the template with clinical information from the medical record whenever possible 3c. Provide a mechanism for the referrer to articulate important exceptions to the most common reasons for referral 3d. Communicate specialists' information needs and procedures
4. Communicate to consulting service	• Lack of contact information • Unknown preferred/effective mode of communication	4a. Create more flexible template forms, to support communication of key clinical details 4b. Provide mechanisms of interdisciplinary communication that maximize interaction and effectiveness while minimizing disruptions

2.3.3 UI Prototypes

Figures 2 and 3 illustrate the translation of design guidelines to design concepts. These design concepts are integrated into a template search and standardized consultation request form UI prototypes. We focused on three of the four cognitive requirements. Design concepts related to the first cognitive requirement, *Determine whether a consultation is warranted,* were not developed owing to its dependence on clinical assessment and diagnostic activities. The remaining cognitive requirements align with design guidelines related to template search and form UIs.

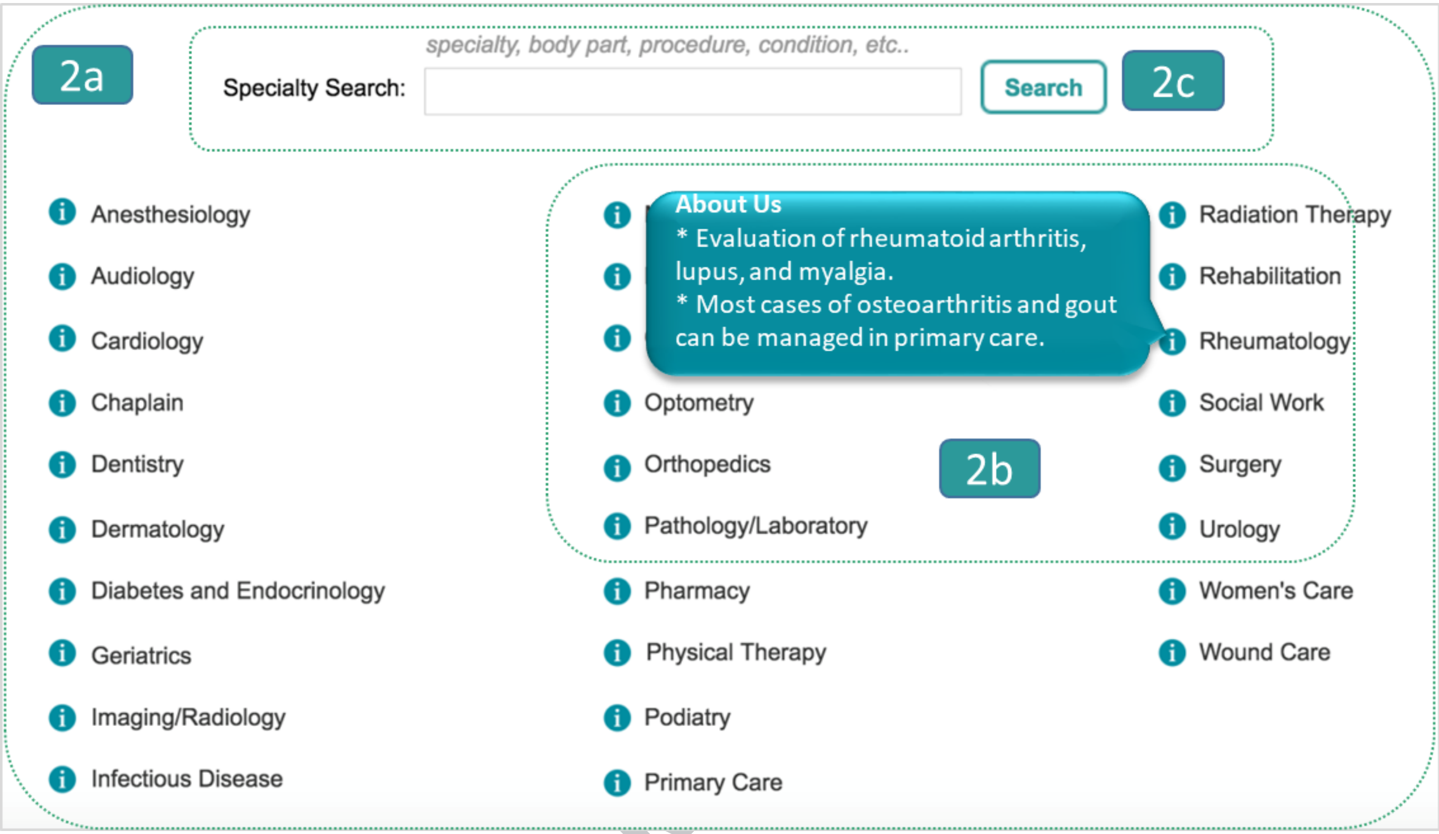

Figure 2. Form search interface.

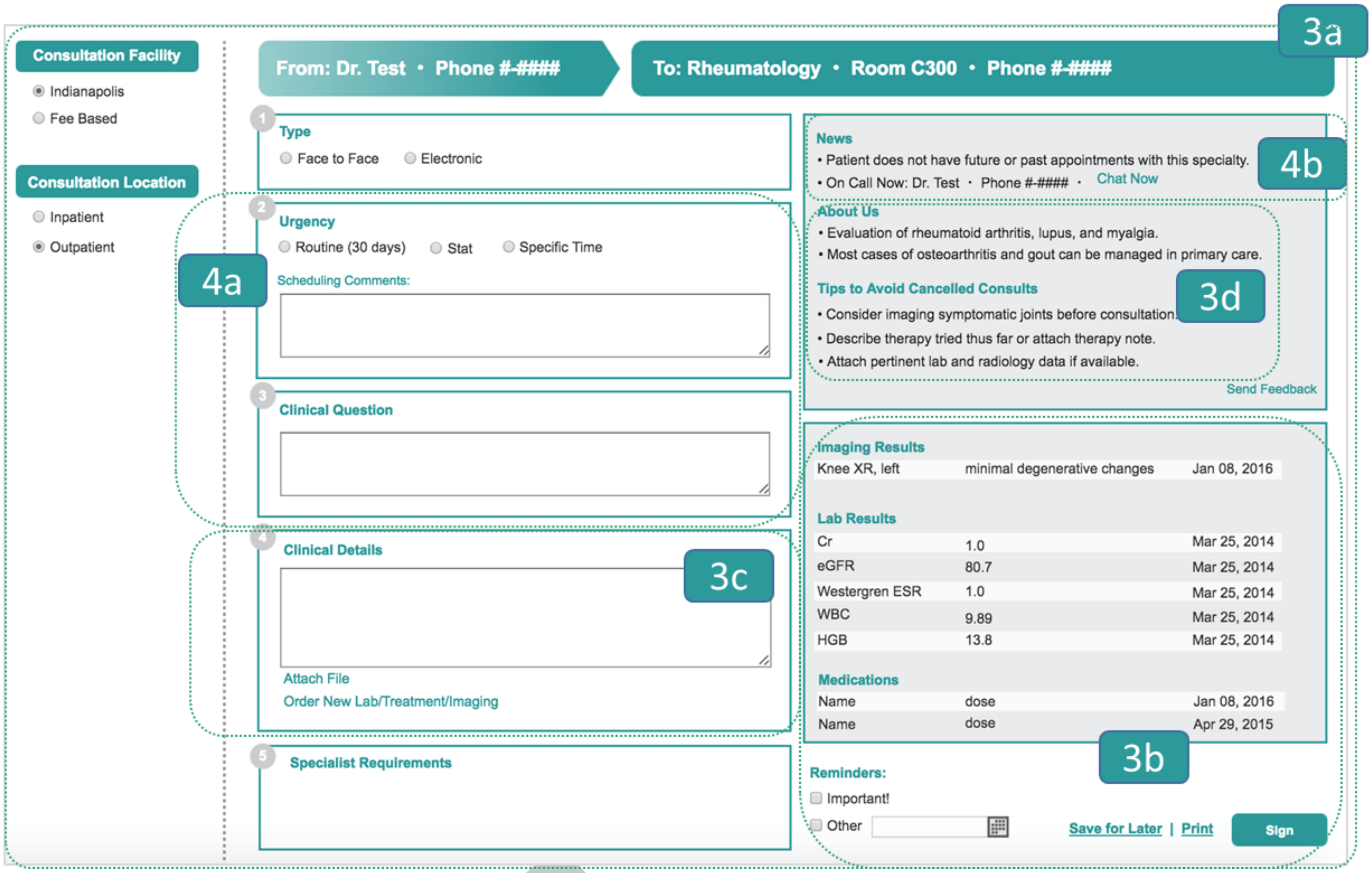

Figure 3. Consultation order form.

Key standard features of the consultation request form UI (Figure 3) included the following:

- Differentiators in the left column help to identify the desired location and setting for the consultation. The appropriate consultation request form appears in the main panel.
- Key headings would be standardized across all forms, but each specialty clinic would have the flexibility to specify what information should be included. For example, prerequisites for certain orthopedics issues might include imaging. For a mental health consultation, prerequisites might include responses to a depression screening.
- To facilitate communication, contact information for the specialty clinic would be included at the top of each form, including contact information for the consulting clinician who should be contacted with questions about the referral.
- Free-text fields are included, to increase the likelihood that important but non-routine information can be easily communicated when present.
- Recent and future appointments are displayed, to aid the referrer in determining which consulting clinics are following, or will be evaluating, the patient.

2.4 Evaluation Methods

After the prototype was designed, we conducted a comparative usability evaluation with physicians at a third site. The primary measurements for this evaluation were user satisfaction. Satisfaction with each UI was measured using a think-aloud (TA) method, where participants were instructed to verbalize their thought processes as they used the UI to complete their tasks. Their comments were audio-recorded and transcribed as part of a more comprehensive evaluation of usability. Next, we analyzed the number of negative, neutral, and positive verbalizations elicited by each UI (Lewis, 1995, 2002; Tullis & Albert, 2013).

2.4.1 Participants

Clinicians were recruited from an urban medical center in the Midwestern US. Participants were included if they worked in primary care and ordered consultations. No exclusion criteria were set. Email and in-person contact were used to recruit participants.

2.4.2 Study Setting and Design

This study was conducted in a laboratory arranged to simulate a clinical examination room (Russ, Weiner, et al., 2012). The prototype UI was a collection of interactive browser-based pages presented in a maximized window. The implemented UI was a simulated instance of the local EHR system, to enable us to compare the redesign with the way the current system functions (Figure 4 and Figure 5); that is, both designs were prototyped so that they could be tested at the same simulation fidelity level.

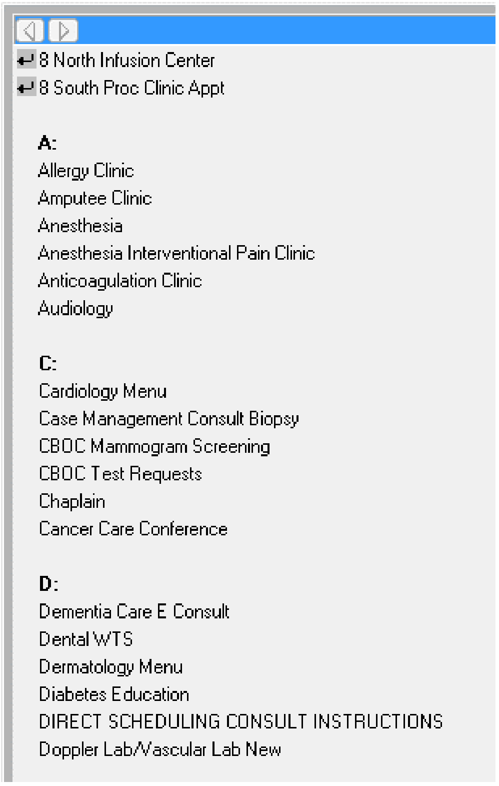

Figure 4. Partial list of specialty clinics and templates in the implemented EHR system.

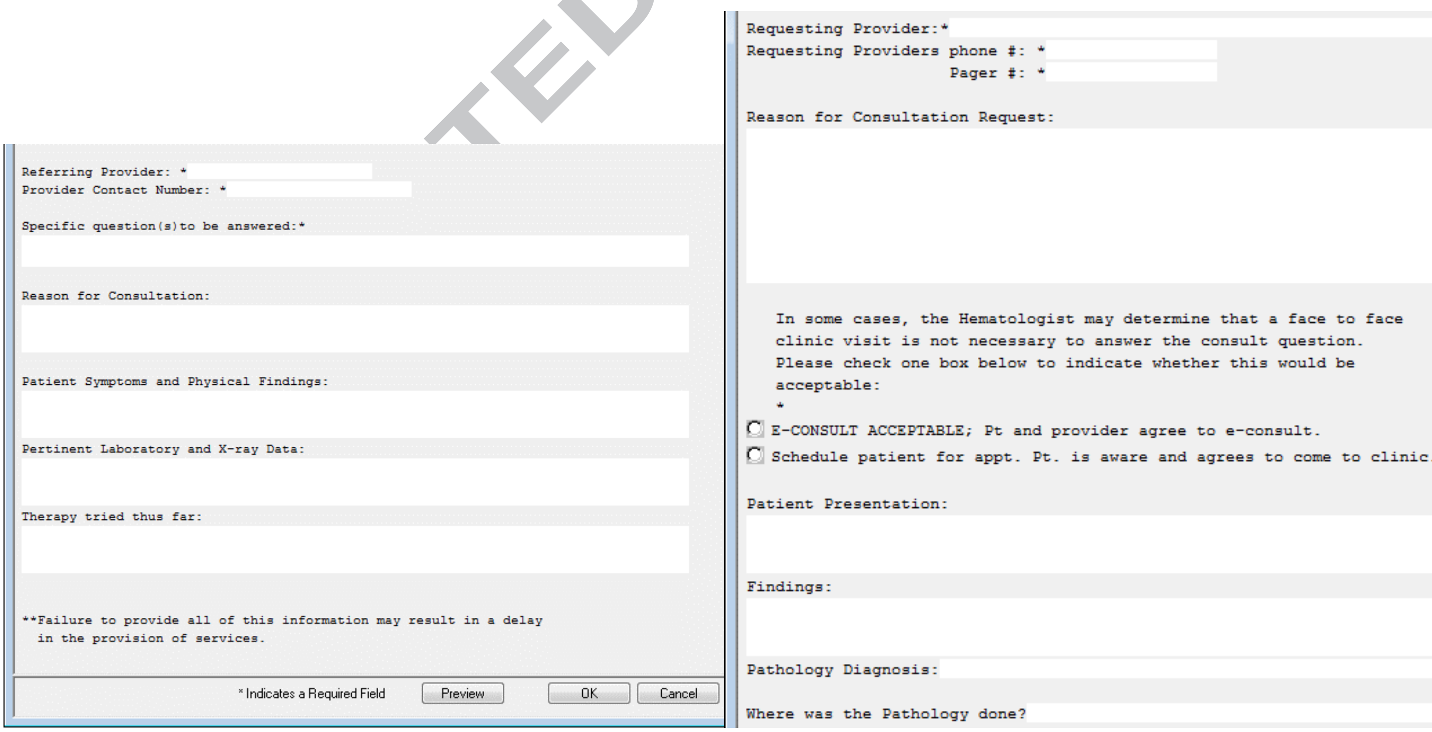

Figure 5. Two consultation order templates in the implemented EHR system.

For each UI, three clinical cases were presented, each with a different consulting clinic being targeted: oncology, mental health, and rheumatology. These clinics were chosen for their high volumes of patients and anticipated risk of inappropriate referral. Using their experiences, three physicians collaborated to develop the three case presentations. Each presentation included a short (1–2 paragraphs) narrative summary of a patient. The summary included the patient's age, gender, chief concern, history of present illness, and pertinent findings from recent laboratory tests, imaging, and physical examination. Participants completed three clinical cases with one UI, then three similar cases with the other UI; this approach prevented potentially disorienting effects of switching between UIs. To meet the requirements of the larger evaluation, which included measuring task time, the order of cases for each participant was matched between UIs. Nevertheless, to limit order-based effects, the order of cases was randomized across participants, and the order of UIs was block-randomized (i.e., counterbalanced) every 12 participants (Altman & Bland, 1999).

2.4.3 Procedure

Participants worked individually. Each case started with the participant reading the patient's presentation. After reading the narrative, the participant was directed to submit the appropriate consultation order for the patient. During most orders, a concurrent TA procedure was used to elicit procedural and evaluative comments about both UIs (Boren & Ramey, 2000). At the beginning of each sitting, the TA procedure was explained in a one-minute demonstration video (Nielsen, 2014). To permit undisturbed measurement of task time for the larger evaluation, TA was used for only the first two cases, since use of TA can interfere with task times for tasks that last longer than about a minute (Altom, 2006; Hertzum & Holmegaard, 2015). Therefore, time on task data were not used for analysis for the first two cases.

After three clinical cases with the first UI and some tasks related to the larger study, the participant was introduced to the second UI and its associated clinical cases as before. Including data collection for the larger study, each clinician's participation lasted approximately one hour.

2.4.4 Data Collection and Analysis

Evaluations were recorded and transcribed. From the transcripts, TA comments were coded using a rubric for evaluative utterances (Kushniruk & Patel, 2004). Coding was done using NVivo 10 (QSR International, Melbourne, Australia). The number of positive, neutral, and negative comments elicited by each UI was tallied within each category. Initial coding was done by top-down sorting of comments into the predefined codebook categories; secondary coding was emergent within these code categories. Initial coding was done by splitting the data between two independent pairs of coders. The four coders met to reach an initial consensus. Next, the coders continued to code transcripts, achieving consensus in pairs. They resolved discrepancies across coding pairs to complete the final dataset. The senior coder performed emergent coding by category. During coding, a category was added with the name Workflow to house comments about interpersonal communication that affected interaction with the UIs.

The relationship between positive and negative comments elicited by a UI can be used to measure satisfaction with the UI (Tullis & Albert, 2013). To test for differences in positive evaluative comments between the two UIs, proportional-odds cumulative logit regression was used to model the probability of the levels of evaluation occupying lower-ordered values (1 = positive, 2 = neutral, 3 = negative; Brown & Prescott, 2015). This model included a random intercept for each clinician to account for possible correlation of responses from the same clinician, and the model included fixed effects for comment category and UI. A cumulative logit model was also used to compare interfaces separately by category. This model excluded Consistency, because there were too few verbal comments related this category. To obtain model convergence, the random intercept was removed from models for Understanding of System Instructions and Error Messages and Overall Ease of Use.

2.5 Evaluation Results

2.5.1 Participants' Characteristics

Of 78 clinicians meeting the criteria for inclusion, 52 were contacted, 35 consented, and 30 completed all six cases. The median duration of clinical experience was 17 years, with 13 years in the current health care system (range 3–40 for both).

2.5.2 Evaluative Comments

Across the two UIs, 619 comments were recorded: 198 positive, 111 neutral, and 310 negative. Participants provided a median of 18 comments (range 8–50). Most comments about the prototype were positive (59%), whereas only 7.9% of comments about the implemented UI were positive (Table 3). Based on the cumulative logit model fit to the ordinal outcome (1 = positive, 2 = neutral, 3 = negative), the odds ratio for the prototype interface to elicit more positive comments (i.e., being in lower-ordered values) than the current UI was 13.5 (95% CI = [9.2, 19.8]), $p < .001$, while adjusting for category, $p = .001$. After adjusting for multiple comparisons, the prototype was significantly more likely to elicit more positive evaluation comments across all categories, except two: Meaning of Labels and Understanding of System Instructions or Error Messages.

Table 3. Positive, neutral, and negative comments from 30 clinicians regarding implemented and prototype interfaces overall and by category.

Category	Number of Clinicians (*N*)	Comment Valence	Interface: Implemented *N* (%)	Interface: Prototype *N* (%)	Adjusted OR [95% CI]	*p-value*
All	30					
		Positive	26 (7.9)	172 (59.3)	13.5 [9.2, 19.8]	**< .001**
		Neutral	53 (16.1)	58 (20)		
		Negative	250 (76.0)	60 (20.7)		
Navigation	21					
		Positive	3 (8.1)	12 (70.6)	86.8 [7.3, 1038]	**.002**
		Neutral	11 (29.7)	4 (23.5)		
		Negative	23 (62.2)	1 (5.9)		
Layout	28					
		Positive	2 (3.9)	74 (69.8)	28.9 [12.1, 69.6]	**< .001**
		Neutral	10 (19.3)	18 (17.0)		
		Negative	40 (76.9)	14 (13.2)		
Meaning of Labels	23					
		Positive	7 (28.0)	13 (32.5)	2.3 [0.6, 9.1]	.437
		Neutral	2 (8.0)	9 (22.5)		
		Negative	16 (64.0)	18 (45.0)		
Understanding	20					

		Positive	7 (20.0)	7 (26.9)	1.2 [0.4, 3.2]	.742‡
		Neutral	10 (28.6)	6 (23.1)		
		Negative	18 (51.4)	13 (50.0)		
Consistency	3					
		Positive	0 (0)	0 (0)	—	—
		Neutral	1 (14.3)	1 (100)		
		Negative	6 (85.7)	0 (0)		
Ease of Use	28					
		Positive	7 (7.1)	64 (77.4)	47.3 [20.6, 108.4]	**< .001‡**
		Neutral	6 (6.1)	9 (10.7)		
		Negative	86 (86.9)	10 (11.9)		
Workflow	22					
		Positive	0 (0)	1 (6.3)	22.9 [3.7, 142.6]	**.002**
		Neutral	13 (17.6)	11 (68.8)		
		Negative	61 (82.4)	4 (25.0)		

†*p*-value from cumulative logit models; *p*-values by category were adjusted for multiple comparisons with Bonferroni-Holm method.

‡*p*-value from cumulative logit model with random intercept term removed to obtain convergence.

Two unused categories are not presented: Response Time and Visibility of System Status. Participants' comments were not related to these categories.

2.5.3 Verbal Protocol Analysis

Identifying the Right Template. A positive aspect to the redesigned template forms was the ability to search easily for a specific template. In the current system, templates are not always organized intuitively. One participant stated, "I think that's my biggest complaint of [the implemented UI] is that you have to kind of know where things are. I mean, many times it's intuitive, but the rheumatology [form] is where it may not be intuitive." Regarding the new listing of templates, one participant noted, "It was much easier to find the [consultation] that you needed. It was listed where it was all alphabetical. It was logical and [more] reasonable than the [implemented UI]."

UI Preference. Most participants (26 of 30) reported that they preferred the UI prototype (i.e., redesigned consultation order UI) over the implemented UI. The reasons for this preference revolved around screen layout, ease of use, clarity of instructions, and ease of identifying the template of interest. One participant stated about this presentation of information:

"…everything was in the same screen [templated order form]." In addition to having the needed information on one screen, the presentation of the information was visually easy to navigate, and the amount of scrolling was reduced. One participant noted, "…everything was on one screen and much easier to read." Forms in the implemented UI can be lengthy and include many questions to complete. Participants also liked the clear display of consultants' telephone numbers and pager numbers. Typically, these contact numbers are not included in templates, and users must exit the template to search for them.

Ease of Use. Regarding functionality, participants appreciated that the next available appointment time in the consultant's clinic would appear on the redesigned consultation template. Specifically, one participant stated, "It's nice that the next available appointment is right there, because then I can tell the patient while they're still in the clinic." Participants made positive statements about other new functions, too, including autocorrect, the option to text with the consulting clinic personnel, ability to order diagnostic tests or attach files, and auto-retrieval of (pre-populating forms with) relevant, available clinical information, such as diagnoses or diagnostic test results in the template form. Participants valued auto-retrieval: One participant noted about the new referral process, "It was faster. I didn't have to put in information that was automatically brought up." Participants noticed the additional flexibility in the redesigned templates, such as free-text fields allowed more text, and templates not requiring all fields to be completed.

Participants expressed positive comments about including in the redesigned templates tips to help the referrer avoid cancelled consultations. About this problem, one participant stated, "[Including] Tips to avoid cancelled [consultations] is nice. This is a big problem here. Sometimes it's a mystery why they'll cancel it. It's a moving target." After seeing these tips, another participant commented on the benefit of this feature, stating, "[What] I really liked about that one [redesign] is it clearly says on the top… what are things that will lead to the cancellation of the [consultation], so that kind of helps us with what are their expectations."

The redesigned template forms did have some drawbacks for users. The primary concern was that added labels (headings) were not defined. For example, the redesigned template form included three categories for the urgency of the consultation: stat ("immediately"), routine, and urgent. Participants were uncertain about the difference among these three. Typically, templates in the implemented UI include *stat* and *routine* for the scheduling time frame, which does not meet patients' needs for issues to be evaluated quickly (e.g., within 3-7 days) but not necessarily immediately (within just a few hours) Additionally, participants were uncertain about the distinction between clinical detail and clinical question.

3 DISCUSSION

Overview. This study provides a methodological contribution to the literature by demonstrating how a CSE approach can be implemented in the design of a study of electronic consultation orders within the rich context of a live clinical environment (i.e., a sociotechnical system), using knowledge elicitation techniques to derive key requirements for referring PCPs. Those key cognitive requirements were then transformed into design guidelines for an enhanced consultation management tool to improve support of PCPs. By systematically revealing cognitive requirements needed to complete the consultation ordering task, a CSE approach helps one design suitable information technology tools to support the cognitive complexity in the consultation management process. This approach differs from simply observing and interviewing end users by framing consultation management with the concept of "joint cognition" in context of teams (e.g. PCPs, specialist, and other staff in each clinic) working together, as well as within human-technology interactions. Design decisions were driven by this CSE perspective, and the corresponding designs were evaluated to estimate their impact.

Issues with Current Sociotechnical System. Designing from the technical aspect, CSE provided a framework and methods to elicit physician cognitive requirements and key decisions during the first step of the consultation process, ordering a consultation. Implementing a CSE approach, this study documents key challenges associated with consultation management from PCPs' perspective and contributes design concepts intended to aid the health care team in managing those challenges. During consultation processes across health care systems, computerized order entry UIs have usability issues that do not support effective and efficient communication (Savoy et al., 2017). These issues have presented unintended, adverse effects to patients and clinicians. Patients have experienced delays in access to care (Esquivel et al., 2012; O'Malley & Reschovsky, 2011; Zuchowski et al., 2015). Clinicians have experienced increased workloads due to repetitive order entries and workarounds to track consultations.

Technological Perspective, Design, and Implications. Due to CSE's emphasis on cognitive complexities, the results provided rationale for guidelines for design to support the physician information needs that were not overtly evident from traditional usability design guidelines and heuristics. Also highlighted by previous literature, existing forms do not support the referrers' decision making associated with consultation orders (Esquivel et al., 2012; Hysong et al., 2011; O'Malley & Reschovsky, 2011; Saleem et al., 2011; Zuchowski et al., 2015). Our results describe how challenges hinge on the lack of specialty clinic information and EHR features/tools that enable form completion and facilitate clinician communication. In addition to general human factors design principles, this study suggests an implementation emphasis on clear specialty clinic guidelines, simple UI navigation, and automated or assisted patient information retrieval. These indicate specific customizations that could become a standard for all consultation order forms.

The results of the comparative design evaluation strengthened the case for using a CSE design approach. In the implemented EHR, referrers characterized the currently implemented UI as problematic in terms of its ease of use, workflow fit, and visual layout, all of which impeded decision making and task completion. By contrast, referrers reported a relatively satisfactory fit between the UI prototype and their needs, particularly in the prototype's visual layout and its ease of use. Overall, relative to their currently implemented EHR's UI, the prototype was more than 13 times more likely to elicit a more positive comment. The results demonstrated preferences of the physicians and their perceived impact of the design choices. From the representative quotes presented in the Results section, there was a persistent, positive reaction to design choices that appeared to save physicians time when completing the consultation request. Many of the currently implemented referral forms captured numerous manually entered, specific clinical details, and determine conditions under which consultants may quickly cancel referrals; however, the shorter and more streamlined prototype may provide comparable clinical detail by auto-retrieving clinical information from the EHR, while saving the user time and mental effort. Auto-retrieving relevant clinical information might also improve accuracy and completeness of documentation of clinical details in the referral, and could decrease cancellations, delays, or additional workload due to incomplete referrals. These time savings can increase time for direct patient–clinician interaction and reduce redundancies in the clinical workflow. Simple design choices, like including the consultant's telephone number on the prototype, could have major workflow implications. During consultation activities, there is often a complex interplay between consultation-related issues and other aspects of care. For example, drugs or procedures prescribed by a consultant might conflict with drugs or procedures prescribed by the PCP or other health professionals involved in the patients' care. These situations would require resolution, sometimes requiring further communication and decision-making with the consultant. In other cases, the consultant's decision might depend on the patient's other issues as managed by the PCP, also prompting discussion, coordination, and shared decision-making. Thus, presenting the phone number eliminates the need for the referring clinicians to search multiple systems or create additional memory aids to facilitate direct discussion, which is often needed to clarify issues regarding the plans for evaluation, diagnosis, treatment, and follow-up of the patient.

Training and Organizational Design Implications. As an additional benefit, the highlighted challenges and considerations extended beyond the EHR's usability. They have implications for non-technological interventions to support consultation management, including both training and organizational design issues. This study identified and organized referrers' reactions to the consultation order prototype derived from the CSE design approach. Comments about the UIs also broached broader workflow problems relating to other steps in ordering and completing consultation. This indicates a need to assess, and possibly improve, the sociotechnical system surrounding consultations (Berg, 1999; Esquivel et al., 2012). The need to train both referring and consulting clinicians, to develop service agreements, and to develop organizational support for direct communication between clinicians is apparent but was outside the scope of this study. CSE should be used to complement other design and evaluation methods (Patel & Kannampallil, 2015). It helped our designers move beyond an oversimplified view of the consultation process to create prototypes that better support the complexity and uncertainty of ordering consultations.

Method Insights. Our study demonstrates a CSE approach implemented by an interdisciplinary team that placed emphasis on documentation review and observations to complement shorter interview sessions with physicians. CSE methods could be viewed as too resource-intensive (Woods & Hollnagel, 2006). The amount of time required by participants in the application of CSE methods is a limitation, which may have stalled the adoption and integration of CSE into systems engineering and design efforts. Initially developed in the context of complex engineered system such as troubleshooting maintenance engineers (Rasmussen & Jensen,1974), library system design (Pejtersen, 1989), and nuclear power plant control room design, CSE methods have traditionally been used to obtain a comprehensive understanding of a system from high-level system goals to very specific physical objects. As investigators began to apply CSE frameworks to more healthcare systems, there was a shift away from document review and observation to in-depth interviews to better understand a first-person perspective of cognitive challenges. This led to in-depth interviews and intensive observations (i.e., often including 2-hour interviews, lengthy ethnographic observation, video analysis, abstraction hierarchies, functional analysis, and discrete-event modeling; Militello & Hutton, 1998). With respect to clinicians' time, this could be a big hurdle to cross when using knowledge elicitation or usability evaluation methods that require more than forty-five minutes, based on our experience. The healthcare domain does not always afford this type of study as access to clinicians is limited and observations must be constrained to avoid negatively influencing patient-clinician interactions. We used a much shortened, targeted interview technique and focused observations. However, our study demonstrates that CSE methods can be adapted to fit clinicians' schedules. With the composition of the team and strategy to emphasize complementary methods, our 30-minute interview sessions were notably shorter compared with other CSE-related interview sessions (e.g., Berry et al., 2016; Crandall & Getchell-Reiter, 1993; Militello & Lim, 1995; Weir et al., 2007). With that, the resource demand of CSE on the front-end of the design process is smaller than the resources demanded for corrective action in systems that do not consider physician perspectives, workflow, and cognitive requirements (Militello et al., 2010). Without the adaptations to these methods, the knowledge of physicians' cognitive challenges would be limited. Thus, systems developed to assist physicians' workflow would be suboptimal and potentially yield negative consequences to workflow and patient safety.

Additionally, this project provides evidence that CSE's strength of explicit consideration of usual practice transfer to the redesign of electronic consultation orders. CSE's consideration of task complexity, joint cognitive systems, and tool use enabled the cogitation of patient safety (Hollnagel & Woods, 1983) (Bisantz, Burns, & Fairbanks, 2015). Also, CSE enabled the acknowledgment of consultation management's joint cognitive systems that are externally paced rather than self-paced. Delays in consultation ordering, scheduling, and outcomes have downstream effects not only on the patient but on other patients' scheduling. Limitations of the evaluation include focusing on individual users in one group (referrers) and on a specific timepoint (the consultation order) rather than teams working through an entire case.

Study Limitations. Although the study was conducted within the Veterans Health Administration (VHA), which is the largest integrated health care system in the U.S., we have no evidence that the general findings about our approaches to redesign would be limited to only one health care system. The VHA operates a vast system of health facilities, coordinating consultations within VHA facilities, across VHA facilities, and between VHA facilities and non-VHA health care systems. As of 2017, the VHA uses an open-source EHR platform, and it funds and promotes the dissemination of informatics research. This setting encourages both a critical perspective and a culture of openness and innovation in EHR development and implementation. Thus, the VHA offers a unique opportunity to examine potential barriers and explore solutions (Meeks et al., 2014). The details and degree of impact will vary based on the usability of current EHR systems, but the need for enhanced usability is widespread (Kim, Coiera, & Magrabi, 2017; Middleton et al., 2013; Payne et al., 2015). Although the simulation was limited to a single site, the design concepts were derived from multiple sites within the institution. In addition, the control templates included various customizations from different sites; many commercial EHR systems, too, enable local customization. During the early stages of design, users' reports were the most accessible measurements of the usefulness and usability impacts from the cognitive-emphasized designs (Nielsen, 1993). Participants were not video recorded. However, they adapted well to the think-aloud method, and the transcripts provided illustrative references and descriptive recounts of the sessions. Future studies could use screen and other video recordings to assess usability further. Lastly, there are many aspects to investigate in the sociotechnical perspective of consultation management as it relates to overall care management and coordination. This study limited its focus on the consultation process to demonstrate the benefits of CSE methods to obtain foundational knowledge of clinicians' cognitive needs and their translation into supportive EHR user interfaces. Future studies are warranted to further investigate additional sociotechnical aspects, including dependencies between consult management, patients' overall care management, and care coordination that might complicate the pending iterations of design guidelines or prototype evaluation.

4 CONCLUSION

With a CSE approach, redesigned consultation order templates can improve usefulness and enhance usability. This study provides a compelling case for the value of cognitive research and specifically, a cognitive systems engineering approach in relation to systems design and redesign for electronic consultation orders. Our results provide qualitative and quantitative evidence to support the implementation of a CSE research and design methodology. With this study, cognitive challenges were explained and translated into design guidelines for consultation order UIs. Physicians' reactions indicated improved ease of use over the currently implemented consultation order UI. The UI prototypes derived from the CSE approach better supported the cognitive needs of referring physicians. As the number of patients seeking care across multiple health institutions increases along with EHR adoption, we expect the use of EHR-mediated cross-institution referrals to increase. As such, this study informs the design of EHR-facilitated consultation orders, clinician communication, and information exchange both within and across health care systems.

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6 COMPETING INTERESTS

The authors have no competing interests to declare.

7 REFERENCES

Adler-Milstein, J., DesRoches, C. M., Furukawa, M. F., Worzala, C., Charles, D., Kralovec, P., . . . Jha, A. K. (2014). More than half of US hospitals have at least a basic EHR, but Stage 2 criteria remain challenging for most. *Health Affairs, 33*(9). doi:10.1377/hlthaff.2014.0453

Altman, D. G., & Bland, J. M. (1999). How to randomise. *BMJ : British Medical Journal, 319*(7211), 703-704.

Altom, T. H. (2006). *The effect of think-aloud on timed performance in usability testing.* (Master of Science), Indiana University, Indianapolis, IN.

Aselmaa, A., van Herk, M., Laprie, A., Nestle, U., Götz, I., Wiedenmann, N., . . . Goossens, R. H. M. (2017). Using a contextualized sensemaking model for interaction design: A case study of tumor contouring. *Journal of Biomedical Informatics, 65*, 145-158. doi:10.1016/j.jbi.2016.12.001

Berg, M. (1999). Patient care information systems and health care work: A sociotechnical approach. *International Journal of Medical Informatics, 55*, 87-101. doi:10.1016/S1386-5056(99)00011-8

Berry, A. B. L., Butler, K. A., Harrington, C., Braxton, M. O., Walker, A. J., Pete, N., . . . Haselkorn, M. (2016). Using conceptual work products of health care to design health IT. *Journal of Biomedical Informatics, 59*, 15-30. doi:10.1016/j.jbi.2015.10.014

Bisantz, A. M., Burns, C. M., & Fairbanks, R. J. (2015). *Cognitive systems engineering in health care*.

Blumenthal, D., & Tavenner, M. (2010). The “meaningful use” regulation for electronic health records. *New England Journal of Medicine, 363*(6), 501-504. doi:10.1056/NEJMp1006114

Bodek, S., Ghori, K., Edelstein, M., Reed, A., & Macfadyen, R. J. (2006). Contemporary referral of patients from community care to cardiology lack diagnostic and clinical detail. *International Journal of Clinical Practice, 60*(5), 595-601. doi:10.1111/j.1368-5031.2006.00902.x

Boren, M. T., & Ramey, J. (2000). Thinking aloud: Reconciling theory and practice. *IEEE Transactions on Professional Communication, 43*(3), 261-278. doi:10.1109/47.867942

Brown, H., & Prescott, R. (2015). Mixed models for categorical data. In *Applied Mixed Models in Medicine* (3rd ed., pp. 153-182). Chichester, United Kingdom: Wiley.

Clark, L. N., Benda, N. C., Hegde, S., McGeorge, N. M., Guarrera-Schick, T. K., Hettinger, A. Z., . . . Bisantz, A. M. (2017). Usability evaluation of an emergency department information system prototype designed using cognitive systems engineering techniques. *Applied Ergonomics, 60*(Supplement C), 356-365. doi:10.1016/j.apergo.2016.12.018

Conley, J., Jordan, M. R., & Ghali, W. A. (2009). Audit of the consultation process on general internal medicine services. *Quality and Safety in Health Care, 18*, 59-62. doi:10.1136/qshc.2007.025486

Crandall, B., & Getchell-Reiter, K. (1993). Critical decision method: A technique for eliciting concrete assessment indicators from the intuition of NICU nurses. *Advances in Nursing Science, 16*(1), 42-51.

Esquivel, A., Sittig, D. F., Murphy, D. R., & Singh, H. (2012). Improving the effectiveness of electronic health record-based referral processes. *BMC Medical Informatics and Decision Making, 12*, 107. doi:10.1186/1472-6947-12-107

Forrest, C. B. (2009). A typology of specialists' clinical roles. *Archives of Internal Medicine, 169*, 1062. doi:10.1001/archinternmed.2009.114

Gandhi, T. K., Sittig, D. F., Franklin, M., Sussman, A. J., Fairchild, D. G., & Bates, D. W. (2000). Communication breakdown in the outpatient referral process. *Journal of General Internal Medicine, 15*, 626-631. doi:10.1046/j.1525-1497.2000.91119.x

Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS Quarterly, 19*(2), 213-236. doi:10.2307/249689

Green, J., & Thorogood, N. (2009). *Qualitative methods for health research*. London, United Kingdom: Sage.

Hertzum, M., & Holmegaard, K. D. (2015). Thinking aloud influences perceived time. *Human Factors, 57*(1), 101-109. doi:10.1177/0018720814540208

Hollnagel, E., & Woods, D. D. (1983). Cognitive systems engineering: New wine in new bottles. *International Journal of Man-Machine Studies, 18*(6), 583-600. doi:10.1016/S0020-7373(83)80034-0

Hollnagel, E., & Woods, D. D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*. Boca Raton, FL: CRC Press (Taylor & Francis).

Hysong, S. J., Esquivel, A., Sittig, D. F., Paul, L. A., Espadas, D., Singh, S., & Singh, H. (2011). Towards successful coordination of electronic health record based-referrals: A qualitative analysis. *Implementation Science, 6*, 84. doi:10.1186/1748-5908-6-84

Kim, M. O., Coiera, E., & Magrabi, F. (2017). Problems with health information technology and their effects on care delivery and patient outcomes: A systematic review. *Journal of the American Medical Informatics Association, 24*(2), 246-250. doi:10.1093/jamia/ocw154

Kushniruk, A. W., & Patel, V. L. (2004). Cognitive and usability engineering methods for the evaluation of clinical information systems. *Journal of Biomedical Informatics, 37*(1), 56-76. doi:10.1016/j.jbi.2004.01.003

Lewis, J. R. (1995). IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. *International Journal of Human–Computer Interaction, 7*(1), 57-78. doi:10.1080/10447319509526110

Lewis, J. R. (2002). Psychometric evaluation of the PSSUQ using data from five years of usability studies. *International Journal of Human–Computer Interaction, 14*(3-4), 463-488.

Meeks, D. W., Smith, M. W., Taylor, L., Sittig, D. F., Scott, J. M., & Singh, H. (2014). An analysis of electronic health record-related patient safety concerns. *Journal of the American Medical Informatics Association, 21*(6), 1053-1059. doi:10.1136/amiajnl-2013-002578

Mehrotra, A., Forrest, C. B., & Lin, C. Y. (2011). Dropping the baton: Specialty referrals in the United States. *The Milbank Quarterly, 89*, 39-68. doi:10.1111/j.1468-0009.2011.00619.x

Middleton, B., Bloomrosen, M., Dente, M. A., Hashmat, B., Koppel, R., Overhage, J. M., . . . Zhang, J. (2013). Enhancing patient safety and quality of care by improving the usability of electronic health record systems: Recommendations from AMIA. *Journal of the American Medical Informatics Association, 20*(e1), e2. doi:10.1136/amiajnl-2012-001458

Militello, L. G., Dominguez, C. O., Lintern, G., & Klein, G. (2010). The role of cognitive systems engineering in the systems engineering design process. *Systems Engineering, 13*(3), 261-273. doi:10.1002/sys.20147

Militello, L. G., & Hutton, R. J. B. (1998). Applied cognitive task analysis (ACTA): a practitioner's toolkit for understanding cognitive task demands. *Ergonomics, 41*(11), 1618-1641. doi:10.1080/001401398186108

Militello, L. G., & Klein, G. (2013). Decision-centered design. In J. D. Lee & A. Kirlik (Eds.), *The Oxford Handbook of Cognitive Engineering* (pp. 261-271). Oxford, United Kingdom: Oxford University Press.

Militello, L. G., & Lim, L. (1995). Patient assessment skills: Assessing early cues of necrotizing enterocolitis. *The Journal of Perinatal & Neonatal Nursing, 9*(2), 42-52.

Militello, L. G., Savoy, A., Porter, B. W., Flanagan, M. E., Wu, J., Adams, J. M., . . . Weiner, M. (2018). Hidden complexities in information flow between primary and specialty care clinics. *Cognition, Technology & Work*. doi:10.1007/s10111-018-0486-y

Miller, A., & Militello, L. G. (2015). The role of cognitive engineering in improving clinical decision support. In A. M. Bisantz, C. M. Burns, & R. J. Fairbanks (Eds.), *Cognitive Systems Engineering in Health Care*. Boca Raton, FL: CRC Press.

Nielsen, J. (1993). *Usability Engineering*. San Francisco, CA: Morgan Kaufmann.

Nielsen, J. (2014, September 1). Demonstrate thinking aloud by showing users a video. Retrieved from https://www.nngroup.com/articles/thinking-aloud-demo-video/

O'Malley, A. S., & Reschovsky, J. D. (2011). Referral and consultation communication between primary care and specialist physicians: Finding common ground. *Archives of Internal Medicine, 171*(1), 56-65. doi:10.1001/archinternmed.2010.480

Patel, V. L., & Kannampallil, T. G. (2015). Cognitive informatics in biomedicine and healthcare. *Journal of Biomedical Informatics, 53*(Supplement C), 3-14. doi:10.1016/j.jbi.2014.12.007

Payne, T. H., Corley, S., Cullen, T. A., Gandhi, T. K., Harrington, L., Kuperman, G. J., . . . Zaroukian, M. H. (2015). Report of the AMIA EHR-2020 Task Force on the status and future direction of EHRs. *Journal of the American Medical Informatics Association, 22*(5), 1102-1110. doi:10.1093/jamia/ocv066

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive systems engineering*. New York, NY: Wiley.

Russ, A. L., Weiner, M., Russell, S. A., Baker, D. A., Fahner, W. J., & Saleem, J. J. (2012). Design and implementation of a hospital-based usability laboratory: Insights from a Department of Veterans Affairs laboratory for health information technology. *Joint Commission Journal on Quality and Patient Safety, 38*(12), 531-540.

Russ, A. L., Zillich, A. J., McManus, M. S., Doebbeling, B. N., & Saleem, J. J. (2012). Prescribers' interactions with medication alerts at the point of prescribing: A multi-method, in situ investigation of the human–computer interaction. *International Journal of Medical Informatics, 81*(4), 232-243. doi:10.1016/j.ijmedinf.2012.01.002

Saldaña, J. (2015). An introduction to codes and coding. In *The Coding Manual for Qualitative Researchers* (3 ed.). Los Angeles, CA: Sage.

Saleem, J. J., Russ, A. L., Neddo, A., Blades, P. T., Doebbeling, B. N., & Foresman, B. H. (2011). Paper persistence, workarounds, and communication breakdowns in computerized consultation management. *International Journal of Medical Informatics, 80*(7), 466-479. doi:10.1016/j.ijmedinf.2011.03.016

Salerno, S. M., Hurst, F. P., Halvorson, S., & Mercado, D. L. (2007). Principles of effective consultation: An update for the 21st-century consultant. *Archives of Internal Medicine, 167*(3), 271-275. doi:10.1001/archinte.167.3.271

Savoy, A., Patel, H., Flanagan, M. E., Weiner, M., & Russ, A. L. (2017). Systematic heuristic evaluation of computerized consultation order templates: Clinicians' and human factors engineers' perspectives. *Journal of Medical Systems, 41*(129), 1-9. doi:10.1007/s10916-017-0775-7

Sittig, D. F., & Singh, H. (2010). A new sociotechnical model for studying health information technology in complex adaptive healthcare systems. *Quality and Safety in Health Care, 19 Suppl 3*, i68-74. doi:10.1136/qshc.2010.042085

Thorsen, O., Hartveit, M., & Baerheim, A. (2013). The consultants' role in the referring process with general practitioners: partners or adjudicators? A qualitative study. *BMC Family Practice, 14*(1), 153. doi:10.1186/1471-2296-14-153

Thyvalikakath, T. P., Dziabiak, M. P., Johnson, R., Torres-Urquidy, M. H., Acharya, A., Yabes, J., & Schleyer, T. K. (2014). Advancing cognitive engineering methods to support user interface design for electronic health records. *International Journal of Medical Informatics, 83*(4), 292-302. doi:10.1016/j.ijmedinf.2014.01.007

Tullis, T., & Albert, B. (2013). Behavioral and physiological metrics. In T. Tullis & B. Albert (Eds.), *Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics* (2 ed., pp. 163-186). Boston, MA: Morgan Kaufmann.

Turner, A. M., Brownstein, M. K., Cole, K., Karasz, H., & Kirchhoff, K. (2015). Modeling workflow to design machine translation applications for public health practice. *Journal of Biomedical Informatics, 53*, 136-146. doi:10.1016/j.jbi.2014.10.005

Vessey, I. (2006). The theory of cognitive fit: One aspect of a general theory of problem solving. In P. Zhang & D. Galletta (Eds.), *Human–Computer Interaction and Management Information Systems: Foundations* (pp. 141-183). Armonk, NY: M.E. Sharpe.

Weir, C. R., Nebeker, J. J. R., Hicken, B. L., Campo, R., Drews, F., & LeBar, B. (2007). A cognitive task analysis of information management strategies in a computerized provider order entry environment. *Journal of the American Medical Informatics Association, 14*(1), 65-75. doi:10.1197/jamia.M2231

Woods, D. D., & Hollnagel, E. (2006). *Joint cognitive systems: Patterns in cognitive systems engineering*. Boca Raton, FL: CRC Press (Taylor & Francis).

Wu, J., Militello, L. G., Flanagan, M. E., Barker, B., Rehman, S., Porter, B. W., . . . Weiner, M. (2016). *Barriers and facilitators to using electronic health records for referrals between primary and specialty care clinics.* Paper presented at the AMIA 2016 Annual Symposium, Chicago, IL.

Zuchowski, J. L., Rose, D. E., Hamilton, A. B., Stockdale, S. E., Meredith, L. S., Yano, E. M., . . . Cordasco, K. M. (2015). Challenges in referral communication between VHA primary care and specialty care. *Journal of General Internal Medicine, 30*, 305-311. doi:10.1007/s11606-014-3100-x