REVIEW ARTICLE

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The Role of Computerized Decision Support in Reducing Errors in Selecting Medicines for Prescription

Narrative Review

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Abstract

This narrative review includes a summary of research examining prescribing errors, prescription decision making and the role computerized decision support plays in this decision-making process. A reduction in medication prescribing errors, specifically a reduction in the selection of inappropriate medications, is expected to result from the implementation of an effective computerized decision support system. Previous research has investigated the impact of the implementation of electronic systems on medication errors more broadly. This review examines the specific characteristics of decision support systems that may contribute to fewer knowledge-based mistakes in prescribing, and critically appraises the large volume of information available on the decision-making process of selecting medicines for prescription. The results highlight a need for work investigating what decision strategies are used by doctors with different levels of expertise in the prescribing of medications. The nature of the relationship between decision support and decision performance is not well

understood and future research is needed to determine the mechanisms by which computerized decision support influences medication selection.

The growth in medications and their indications for use has led to a considerable increase in the complexity of medication-related work processes,[1] resulting in increased concerns about medication errors. There is little doubt that medication errors are a problem, but the frequency and types of medication errors found depend on the definitions of error adopted and the methods used to detect them.[2-4] Prescription is often cited as the point in the medication process where most errors occur.[1,5-7] Errors that occur at this decision point have also been shown to be strongly associated with an increased risk of adverse drug events.[8,9]

This review provides a summary of the research investigating prescribing errors. It then describes research examining the decision-making process of selecting medicines for prescription and what is known about the role of computerized decision support in this decision-making process. The aim of this review is to demonstrate how prescription decision making and computerized decision support have been investigated independently from one another in the past, and to highlight a need for naturalistic work investigating how decision support influences the complex process of drug selection. A narrative review format was adopted to ensure comprehensive coverage of two separate but related areas of research (i.e. 'computerized decision support' and 'decision making'). While systematic reviews on computerized decision support and prescribing errors have been conducted, limitations of this form of review are its inability to combine multiple literature bases and to review an area where no studies have been performed. This narrative review provides a unique perspective on a research area in need of future investigation.

1. What we Know about Medication Prescribing Errors

Errors can occur at any stage of the medication process (e.g. prescription, transcription, administration). Studies have investigated the incidence, prevalence and type of medication errors, and the factors associated with errors. Methods used have included analysis of incident reports,[6] interviews[10,11] and, most commonly, review of medication charts.[5,10,11]

Some studies have examined the types of and factors associated specifically with medication prescribing errors.[12-18] In most studies, pharmacists were recruited to identify errors in medication orders (prescriptions) and subsequently classified errors on a range of measures (e.g. the drug class, proximal causes, the potential severity of the error).[12,14-16,18,19] The majority of errors were found to occur when doctors selected a dose (i.e. overdoses and underdoses). Prescribing medications to which the patient was allergic, or inappropriate dosage forms, were also reportedly problematic. Prescribing errors made by doctors were judged by pharmacists to originate in both medication order writing and in the prescribing decision.[18]

The most common contributing factor associated with prescribing errors was medication knowledge deficiency.[12,15,16] Inadequate knowledge about drugs, drug therapy factors, patient characteristics and patient history (e.g. a failure to account for the patient's status when choosing a medication) were typical.

Following the identification of errors by pharmacists, several important studies employed semi-structured interviews to allow doctors to indicate what factors they believed to impact prescribing errors.[13,17,20] These interviews led to the identification of a range of system factors associated with error occurrence. The contributing factors consistently identified related to the work environment (e.g. workplace design, staffing, heavy workload), the individual (e.g. physical health, skills and knowledge) and teamwork (e.g. communication, responsibility, supervision).[13,17,20] Consistent with these findings, a recent literature review identified factors related to the work environment, the individual and the team, and also factors related to the task (e.g. non-standardized prescribing) and to the patient (e.g. complexity of disease).[21] The authors reported that 'knowledge-based mistakes' were the most common failures cited in the literature. Knowledge-based mistakes are decision errors that occur in relatively unique situations, where actions must be planned in real-time using stored knowledge.[22] In this case, prescribers selected inappropriate medications, doses, etc., because they did not know enough about the drug they were prescribing or the patient they were prescribing for.[21]

Some studies suggest that the majority of prescribing errors could have been prevented if prescribers had timely information and access to an adequate knowledge base.[12,16,23] That is, many errors were classified as likely to be prevented by the use of an appropriate computerized physician order entry (CPOE) system, computerized decision support system (CDSS), or both.

2. What we Know about Medication Errors and Computerized Physician Order Entry/Computerized Decision Support Systems

It has been argued that the ordering of drugs with computer support is the most promising application of information technology to assist in reducing serious medication errors.[24] CPOE systems automate the medication ordering process and ensure standardized, legible, complete orders.[2] These are often used in combination with a CDSS – providing computerized advice regarding drug doses, routes and frequencies. More advanced CDSSs can perform drug allergy checks, drug laboratory checks and drug-drug interaction checks, and can provide reminders about corollary orders or drug guidelines.[2] CPOE and CDSS can potentially increase the efficiency of the medication process and at the same time eliminate some of the factors found to contribute to medication error.[25,26]

Several studies have investigated the impact of CPOE systems and CDSSs on patient safety. The majority of research comprises outcome-based evaluations, focusing on assessing the effects of the introduction of an electronic system (CPOE, CDSS or both) on a predefined outcome variable, such as patient mortality, adherence to guidelines or cost of healthcare (for reviews see Kaushal et al.,[2] Sintchenko et al.,[27] Hunt et al.[28] and Chaudhry et al.[29]). The results of these studies have been inconsistent. Most research reports improved outcomes[30,31] but some studies have reported unexpected negative outcomes – and so-called 'unintended consequences' of implementation.[32-34] Studies that have specifically examined the impact of CDSS or CPOE systems on prescribing have also reported mixed results,[35,36] with some studies reporting fewer prescription errors following system implementation[37] and others reporting no change in error rates[38] or adverse drug events.[8]

Very few studies have isolated the functions or features of the electronic system responsible (or contributing) to the clinical outcomes observed. It is often unclear what specific features of the system (e.g. the selection of a dose from a predefined list, or the use of a drug-drug interaction alert) resulted in fewer medication errors, and what specific error types were affected (e.g. errors in the medication order writing or in the decision to prescribe a drug). The lack of standardized outcome measures for measuring medication error is seen as a major obstacle to determining the effects of decision support on prescribing.[35] Although rare,[31,39,40] studies that specifically evaluate one function of a CPOE or CDSS and determine the impact of this feature on a particular error type can reveal much about what characteristics of an electronic system are needed to improve the medication process.

A lack of empirical work systematically evaluating CPOE and CDSS features has led researchers to review the literature in an attempt to identify the characteristics of a CDSS that make it effective in improving clinical practice.[27,41,42] These have concluded that systems that provide alerts and reminders (i.e. 'critiquing' decision support) are more effective than those that provide 'consultative' decision support (e.g. provision of evidence-based guidelines, assistance in drug dosing). Decision support has also been found to be more effective if it was provided automatically (instead of being sought out), was integrated into an order entry system (instead of being stand-alone), prompted clinicians to record a reason for not taking a recommended course of action, provided a recommendation (instead of just information) and if the advice offered by the system was provided at the point of care.[41] It has also been suggested that for alerts to be effective they must be appropriate, sensitive, useful and usable.[43]

This research evidence is important in determining whether or not such systems should be pursued and resources devoted to them. However, what is also needed is research that is able to answer questions about how systems are used in practice, how practitioners view systems, and identification of the complex mix of technical, organizational and cognitive factors that ultimately help us to answer the question regarding *why* some systems in some situations produce significant reductions in medication errors. Evaluations in medical informatics that focus on process (complementing those investigating outcome) can add value above and beyond traditional audit approaches.[44,45]

Interviews, focus groups and observations of people using electronic systems have allowed researchers to identify the specific types of errors that can emerge from using a CPOE/CDSS system and the impact the implementation of a system can have on workload, workflow and communication.[26,46,47] Surveys have allowed user satisfaction to be assessed (e.g. too many alerts are bad),[48-52] and analysis of incident reports has led to the identification of contributing factors associated with medication errors while using a system.[25]

Structured interviews have allowed researchers to consider what users believe to be the effective features of decision support alerts.[53,54] For example, prescribers reported they preferred alerts that contained high priority information, were brief, clearly written and easy to navigate. Alerts that provided options for alternative medicines and linked to additional supporting documentation were also viewed favourably.[53] Doctors have suggested that safety alerts should be customized to specialty (e.g. cardiologists should receive different warnings to surgeons) and to job status (discussed further below).[54]

Researchers have turned to human factors methods to provide a means of analysing the impact of electronic systems on work processes. In particular, task analyses have been adopted to examine how implementation of a system can change a worker's tasks, roles and decision-making processes.[24,55,56] Research in domains other than healthcare (e.g. transportation) can tell us much about how decision support might influence performance. For example, it has been shown that the use of computerized decision support can lead to errors of omission (failing to notice something because the decision aid failed to detect it) and commission (choosing to follow an automated directive in spite of contradictory information from other sources).[57,58] The use of decision support in medicine is relatively recent, therefore studies of these automation-related effects on medication prescription are in their infancy.

The studies discussed above provide us with a good starting point for understanding how electronic systems impact on work processes, but additional work is needed to determine what specific system design features result in improved prescribing and clinical outcomes.[35,36] The effect of computerized decision support on the decision process of selecting medications remains to be effectively explored. Can decision support lessen the impact of factors found to contribute to medication error (e.g. knowledge deficiency), and therefore lead to a reduction in errors made in drug choice? It has been suggested that the major factor limiting sustainable impact of decision support in clinical practice is our lack of knowledge of clinicians' information processing characteristics and information needs.[27]

3. Medication Prescription: A Decision-Making Process

In order to appreciate how decision support systems might affect the decision-making process of selecting medicines, it is necessary to understand *how* prescribing decisions are made. Few studies have examined the cognitive processes used by physicians in making drug choices.[59,60] Some research involved asking physicians generally about factors that influence drug selection,[61-63] but the majority of studies that investigated decision making involved presenting physicians with case scenarios or common illnesses and instructing them to describe (via interview or questionnaire) what drug would be prescribed and why.[64-66] Several factors consistently emerged from these studies and literature reviews summarizing the work on drug selection.[67-69] Physicians appear to select drugs based on two main criteria: (i) the probability that the drug will be effective in controlling the disease (i.e. effectiveness); and (ii) the probability that adverse effects will result from using the drug (i.e. safety). Other factors such as drug cost, patient demand and hospital policy can also be influential,[61,70-72] but usually come into play when alternative drugs are deemed equivalent with respect to efficacy and safety.[73]

Most of the cognitive models of drug prescription that have emerged from interviews and questionnaires with doctors are based implicitly or explicitly on expectancy-value theory,[64] later expanded into the theory of reasoned action and then the theory of planned behaviour.[66,74] The expectancy-value theory states that a physician's drug choice is a function of two things: (i) his or her beliefs that certain outcomes will occur from various drug choices (e.g. the disease state will be controlled, the patient will be satisfied); and (ii) the values attached to those outcomes.[59] The later theories include additional weighted (valued) factors of opinions of fellow prescribers and perceived behavioural control. These theories assume that prescribers use compensatory decision-making processes in which multiple drug attributes and outcomes are considered before a choice is made.[59] However, it has been shown that as task complexity increases, people tend to use fewer analytical strategies (i.e. non-compensatory strategies) in order to simplify the decision task and reduce cognitive strain.[59] Compensatory strategies, such as those envisaged in the theories described in this review, are only adopted when the numbers of alternatives, attributes and task factors to consider are small.[75,76] People use a variety of strategies to make decisions (for reviews see Montgomery,[77] Chu and Spires[78] and Svenson[79]) and it has been proposed that the use of a decision-making strategy is dependent on many factors, including the task, the context and the individual.[63,80-82]

Some studies have gone further than asking physicians to explain retrospectively how drug choices were made, and used a process-tracing technique (i.e. verbal protocol) to determine the types of reasoning strategies used by physicians in making treatment decisions.[60,83-85] In these studies, doctors were presented with a difficult scenario and were asked to 'think out loud' as they came to a decision about the treatment that should be administered. It was found that decisions were made by breaking the overall decision into manageable pieces, and were made using limited information.[60,84] The doctors in these studies did not appear to use compensatory or non-compensatory strategies to make decisions. Instead, they used heuristics.[83,84]

Heuristics, rules of thumb used to compensate for information-processing limitations, emerge especially during periods of high workload or stress. Common heuristics include representativeness (probabilities are evaluated by the degree to which two items resemble one another), availability (people assess the probability of an event by the ease with which instances of the event come to mind) and habit persistence (a person selects the alternative that was chosen last time).[80,86] Heuristics are grounded in training, expert knowledge and experience, therefore they can be accurate most of the time,[58] but sometimes practitioners do not know the limits of the shortcut or fail to recognize situations where the simplification is no longer relevant.[87] Such sub-optimal decisions are known as biases. Research has identified a range of biases doctors make in treatment decision making.[88-91]

Mirroring work examining compensatory and non-compensatory decision strategies, most heuristics research has examined decision making in unnatural contexts (i.e. in laboratory settings). 'Naturalistic decision making' is the study of how people use their experience to make decisions in field settings.[92] This stream of research asserts that human decision making is different in its naturalistic context than in the laboratory because the underlying task and situation in which the decision is made determine how a decision is approached.[93] Examining and comparing behaviours in both experimental and real-world settings allow us to investigate the role of external factors in individuals' decision-making behaviours.[94,95]

Decision makers in naturalistic settings can be novices, intermediates or experts, with each group differing in the quantity and quality of domain knowledge, and in the strategy adopted to make a decision. It has been suggested that proficient decision makers rarely make decisions in an analytical or rational way (i.e. they rarely compare alternatives).[69,93,96,97] Instead, they choose a course of action using experience and knowledge (expertise) and appear to 'know what to do', rather than 'figure out what to do'.[93] Many expert decisions are quick and largely automatic.[92,98] In these cases, an expert's ability to handle a decision depends on his or her skill at recognizing a situation as typical and familiar, not on the conscious generation of hypotheses.

As indicated above, medication knowledge deficiency (i.e. knowledge deficiency concerning the right medication for a particular condition as it is manifest in a particular patient) has been identified as the most common factor associated with prescribing errors, suggesting that the decision strategies adopted by some expert physicians may result in more accurate decisions than those strategies adopted by most novices. Research has shown that more experienced doctors generally adopt a more holistic approach to patient care,[99] although no research has specifically examined the differences in decision-making processes used by doctors of various levels of expertise to prescribe medications.

Although there appears to be a large amount of information available on the decision-making processes used by clinicians to prescribe medications, the bulk of this research has involved asking physicians to describe how a decision was made. It has been shown that physicians have difficulty looking back introspectively at their decision-making processes[83] and that they often report using more cues (e.g. patient age, drug cost, etc.) than they actually use.[100,101] Studies that have employed process-tracing techniques (i.e. 'thinking out loud') have examined treatment choices more generally (not specifically drug prescription) and have only done so in a laboratory setting with hypothetical cases. The majority of research was conducted some years ago (most was carried out in the 1970s and 1980s) and thus may not reflect modern medical education, delivery practices or organizational complexities. Medical education, training, products and procedures have changed considerably since that time, and information technology is now widely used in hospitals, making it necessary to re-evaluate current prescription processes naturalistically, and the role decision support plays in drug choice. It has been suggested that traditional decision research is inadequate in informing the development and implementation of effective decision support systems in healthcare.[102]

4. Decision Support and Decision Making: How are Errors Affected?

Little research has investigated how decision support actually influences decision performance, particularly in the medical setting. The nature of the relationship between decision support and decision performance is not well understood, although it is assumed that by expanding a decision-maker's information processing capabilities, a decision support system might reduce one's reliance on heuristics and therefore alleviate the effects of biases (and therefore errors).[76] Decision support may result in the adoption of more accurate decision strategies (by simplifying those strategies) or may influence decision-making efficiency by allowing the same strategy to be executed with less effort.[103]

It is generally believed that decision makers select a decision strategy based on an analysis of costs (usually defined as effort) and benefits (the anticipated decision quality).[78,80,104,105] People want to make the most accurate decision but also want to minimize the effort needed to make a decision. An effective decision support system might therefore function by reducing the costs required to implement a decision strategy.[105,106] Decision makers will adopt more effortful strategies, which generally lead to higher decision quality and therefore fewer errors, when a decision support system reduces the effort needed to use them.[105]

In order to determine the impact of CDSSs on the processes used by physicians to select medications, a more thorough understanding of doctors' decision-making processes is needed. So too is an examination of how decision support systems influence the adoption of different decision strategies by doctors with various levels of expertise. To do this, naturalistic investigations of decision making (e.g. thinking out loud in the field) are needed. An examination of decision strategies used by junior and senior doctors with and without the use of a decision support system will help establish how CDSS can change the way in which doctors decide what drugs to prescribe. Studies of this kind will also allow us to determine how the impact of decision support on prescribing is mediated by medical expertise. Do decision support systems alter the decision strategies used by both senior and junior doctors?

5. Conclusions

A reduction in prescribing errors, specifically a reduction in the selection of inappropriate medications, is expected to result from the implementation of effective CDSSs. Although previous research has investigated the impact of the implementation of electronic systems on medication errors, work examining what specific characteristics of a decision support system make it effective in targeting knowledge-based mistakes (i.e. poor drug choices) is required. Future work is also needed to investigate what decision strategies are used by doctors with different levels of expertise to prescribe medications, and to determine the role decision support plays in the decision-making process of selecting medicines for prescription.

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References

1. Watcher RM. Understanding patient safety. New York (NY): The McGraw-Hill Companies, 2008
2. Kaushal R, Shojania KG, Bates DW. Effects of computerized physician order entry and clinical decision support systems on medication safety. Arch Intern Med 2003; 163: 1409-16
3. Lewis PJ, Dorman T, Taylor D, et al. Prevalence, incidence and nature of prescribing errors in hospital inpatients: a systematic review. Drug Saf 2009; 32 (5): 379-89
4. Franklin BD, Vincent C, Schachter M, et al. The incidence of prescribing errors in hospital inpatients: an overview of the research methods. Drug Saf 2005; 28 (10): 891-900
5. Bates DW, Boyle DL, Vander Vliet M, et al. Relationship between medication errors and adverse drug events. J Gen Intern Med 1995; 10: 199-205
6. Wilson DG, McArtney RG, Newcombe RG, et al. Medication errors in paediatric practice: insights from a continuous quality improvement approach. Eur J Pediatr 1998; 157: 769-74
7. Bates DW, Cullen DJ, Laird N, et al. Incidence of adverse drug events and potential adverse drug events. JAMA 1995; 274 (1): 29-34
8. van Doormaal JE, van den Bernt PMLA, Zaal RJ, et al. The influence that electronic prescribing has on medication errors and preventable adverse drug events: an interrupted time series study. J Am Med Inform Assoc 2009; 16: 816-25
9. van Doormaal JE, van den Bernt PMLA, Mol PGM, et al. Medication errors: the impact of prescribing and transcribing errors on preventable harm in hospital patients. Qual Saf Health Care 2009; 18: 22-7
10. Stanhope N, Vincent C, Adams S, et al. Applying human factors methods to clinical risk management in obstetrics. Br J Obstet Gynaecol 1997; 104: 1225-32
11. Leape LL, Bates DW, Cullen DJ, et al. Systems analysis of adverse drug events. JAMA 1995; 274 (1): 35-43
12. Bobb A, Gleason K, Husch M, et al. The epidemiology of prescribing errors. Arch Intern Med 2004; 164: 785-92
13. Dean B, Schachter M, Vincent C, et al. Causes of prescribing errors in hospital inpatients: a prospective study. Lancet 2002; 359: 1373-8
14. Folli HL, Poole RL, Benitz WE, et al. Medication error prevention by clinical pharmacists in two children's hospitals. Pediatrics 1987; 79: 718-22
15. Lesar TS, Briceland L, Delcoure K, et al. Medication prescribing errors in a teaching hospital. JAMA 1990; 263 (17): 2329-34
16. Lesar TS, Briceland L, Stein DS. Factors related to errors in medication prescribing. JAMA 1997; 277 (4): 312-7
17. Coombes ID, Stowasser DA, Coombes JA, et al. Why do interns make prescribing errors? A qualitative study. Med J Aust 2008; 188: 89-94
18. Dean B, Schachter M, Vincent C, et al. Prescribing errors in hospital inpatients: their incidence and clinical significance. Qual Saf Health Care 2002; 11: 340-4

19. Coombes ID, Pillans PI, Storie WJ, et al. Quality of medication ordering at a large teaching hospital. Aust J Hosp Pharm 2001; 31: 102-6
20. Nichols P, Copeland T, Craib IA, et al. Learning from error: identifying contributory causes of medication errors in an Australian hospital. Med J Aust 2008; 188: 276-9
21. Tully MP, Ashcroft DM, Dorman T, et al. The causes of and factors associated with prescribing errors: systematic review. Drug Saf 2009; 32: 819-36
22. Reason J. Human error. Cambridge: Cambridge University Press, 1990
23. Lederman RM, Parkes C. Systems failure in hospitals: using Reason's model to predict problems in a prescribing information system. J Med Syst 2005; 29 (1): 33-43
24. Horsky J, Kaufman DR, Oppenheim MI, et al. A framework for analyzing the cognitive complexity of computer-assisted clinical ordering. J Biomed Inform 2003; 36 (1-2): 4-22
25. Zhan C, Hicks RW, Blanchette CM, et al. Potential benefits and problems with computerized prescriber order entry: analysis of a voluntary medication error-reporting database. Am J Health Syst Pharm 2006; 63: 353-8
26. Koppel R, Metlay JP, Cohen A, et al. Role of computerized physician order entry systems in facilitating medication errors. JAMA 2005; 293 (10): 1197-203
27. Sintchenko V, Magrabi F, Tipper S. Are we measuring the right thing? Variables that affect the impact of computerised decision support on patient outcomes: a systematic review. Med Inform Internet Med 2007; 32 (3): 225-40
28. Hunt DL, Haynes B, Hanna SE, et al. Effects of computer-based clinical decision support systems on physician performance and patient outcomes: a systematic review. JAMA 1998; 280 (15): 1339-46
29. Chaudhry B, Wang J, Wu S, et al. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. Ann Intern Med 2006; 144: 742-52
30. Bates DW, Leape LL, Cullen DJ, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA 1998; 280 (15): 1311-6
31. Terrell KM, Perkins AJ, Dexter PR, et al. Computerized decision support to reduce potentially inappropriate prescribing to older emergency department patient: a randomized controlled trial. J Am Geriatr Soc 2009; 57: 1388-94
32. Han YY, Carcillo JA, Venkataraman ST, et al. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. Pediatr 2005; 116: 1506-12
33. Nebeker JR, Hoffman JM, Weir CR, et al. High rates of adverse drug events in a highly computerized hospital. Arch Intern Med 2005; 165: 1111-6
34. Campbell EM, Sittig DF, Ash JS, et al. Types of unintended consequences related to computerized provider order entry. J Am Med Inform Assoc 2006; 13 (5): 547-56
35. Schedlbauer A, Prasad V, Mulvaney C, et al. What evidence supports the use of computerized alerts and prompts to improve clinicians' prescribing behavior? J Am Med Inform Assoc 2009; 16 (4): 531-8
36. Reckmann MH, Westbrook J, Koh Y, et al. Does computerized provider order entry reduce prescribing errors for hospital inpatients? A systematic review. J Am Med Inform Assoc 2009; 16 (5): 613-23
37. Donyai P, O'Grady K, Jacklin A, et al. The effects of electronic prescribing on the quality of prescribing. Br J Clin Pharmacol 2007; 65 (2): 230-7
38. Judge J, Field TS, DeFlorio M, et al. Prescribers' responses to alerts during medication ordering in the long term care setting. J Am Med Inform Assoc 2006; 13 (4): 385-90
39. Paterno MD, Maviglia SM, Gorman PN. Tiering drug-drug interaction alerts by severity increases compliance rates. J Am Med Inform Assoc 2009; 16: 40-6
40. Galanter WL, Didomenico RJ, Polikaitis A. A trial of automated decision support alerts for contraindicated medications using computerised physician order entry. J Am Med Inform Assoc 2005; 12 (3): 269-74
41. Kawamoto K, Houlihan CA, Balas A, et al. Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success. BMJ 2005; 330 (7494): 765-8
42. Pearson S, Moxey A, Robertson J, et al. Do computerised clinical decision support systems for prescribing change practice? A systematic review of the literature (1990-2007). BMC Health Serv Res 2009; 9: 154
43. van der Sijs H, Aarts J, Vulto A, et al. Overriding of drug safety alerts in computerized physician order entry. J Am Med Inform Assoc 2006; 13 (2): 138-47
44. Kushniruk AW, Patel VL. Cognitive evaluation of decision making processes and assessment of information technology in medicine. Int J Med Inform 1998; 51 (2-3): 83-90
45. Kaplan B. Evaluating informatics applications – some alternative approaches: theory, social interactionism, and call for methodological pluralism. Int J Med Inform 2001; 64 (1): 39-56
46. Ash JS, Berg M, Coiera EW. Some unintended consequences of information technology in health care: the nature of patient care information system-related errors. J Am Med Inform Assoc 2004; 11 (2): 104-12
47. Beuscart-Zephir MC, Pelayo S, Anceaux F, et al. Impact of CPOE on doctor-nurse cooperation for the medication ordering and administration process. Int J Med Inform 2005; 74: 629-41
48. Larum H, Ellingsen G, Faxvaag A. Doctors' use of electronic medical records systems in hospitals: cross sectional survey. BMJ 2001 Dec 8; 323 (7325): 1344-8
49. Lee F, Teich JM, Spurr CD, et al. Implementation of physician order entry: user satisfaction and self reported usage patterns. J Am Med Inform Assoc 1996; 3: 42-55
50. Glassman PA, Simon B, Belperio P, et al. Improving recognition of drug interactions: benefits and barriers to using automated drug alerts. Med Care 2002; 40 (12): 1161-71
51. Magnus D, Rodgers S, Avery AJ. GP's views on computerized drug interaction alerts: questionnaire survey. J Clin Pharm Ther 2002; 27: 377-82
52. Murff HJ, Kannry J. Physician satisfaction with two order entry systems. J Am Med Informs Assoc 2001; 8 (5): 499-511
53. Feldstein A, Simon S, Schneider J, et al. How to design computerized alerts to ensure safe prescribing practices. Jt Comm J Qual Saf 2004; 30: 602-13

54. van der Sijs H, Aarts J, Gelder TV, et al. Turning off frequently overridden drug alerts: limited opportunities for doing it safely. J Am Med Inform Assoc 2008; 15 (4): 439-48
55. Weir CR, Nebeker JJR, Hicken BL, et al. A cognitive task analysis of information management strategies in a computerized provider order entry environment. J Am Med Inform Assoc 2007; 14 (1): 65-75
56. Shachak A, Hadas-Dayagi M, Ziv A, et al. Primary care physicians' use of an electronic medical record system: a cognitive task analysis. J Gen Intern Med 2009; 24 (3): 341-8
57. Skitka LJ. Automation: decision aid or decision maker. Washington, DC: National Aeronautics and Space Administration, 1998
58. Mosier KL, Skitka LJ. Human decision makers and automation decision aids: made for each other? In: Parasuraman R, Mouloua M, editors. Automation and human performance: theory and applications. Mahwah (NJ): Lawrence Erlbaum Associates, 1996: 201-20
59. Chinburapa V, Larson LN, Brucks M, et al. Physician prescribing decisions: the effects of situational involvement and task complexity on information acquisition and decision making. Soc Sci Med 1993; 36 (11): 1473-82
60. Kuipers B, Moskowitz AJ, Kassirer JP. Critical decisions under uncertainty: representation and structure. Cogn Sci 1988; 12 (2): 177-210
61. Schumock GT, Walton SM, Park HY, et al. Factors that influence prescribing decisions. Ann Pharmacother 2004; 38: 557-62
62. Pearson S, Rolfe I, Smith T. Factors influencing prescribing: an intern's perspective. Med Educ 2002; 36: 781-7
63. Campo K, Staebel OD, Gijsbrechts E, et al. Physicians' decision process for drug prescription and the impact of pharmaceutical marketing mix instruments. Health Mark Q 2006; 22 (4): 73-107
64. Segal R, Hepler CD. Drug choice as a problem-solving process. Med Care 1985; 23 (8): 967-76
65. Becker MH, Stolley PD, Lasagna L, et al. Differential education concerning therapeutics and resultant physician prescribing patterns. J Med Educ 1972; 47 (2): 118-27
66. Denig P, Haaijer-Ruskamp FM, Zijsling DH. How physicians choose drugs. Soc Sci Med 1988; 27 (12): 1381-6
67. Worthen DB. Prescribing influences. Br J Med Educ 1973; 7: 109-17
68. Hemminki E. Review of literature on the factors affecting drug prescribing. Soc Sci Med 1975; 9 (2): 111-6
69. Bradley CP. Decision making and prescribing patterns: a literature review. Fam Pract 1991; 8: 2762-87
70. Anderson N, Fuller R, Dudley N. 'Rules of thumb' or reflective practive? Understanding senior physicians' decision-making about anti-thrombotic usage in atrial fibrillation. QJM 2007; 100 (5): 263-9
71. Nutescu EA, Park HY, Walton SM, et al. Factors that influence prescribing within a therapeutic drug class. J Eval Clin Pract 2005; 11 (4): 357-65
72. Reichert S, Simon T, Halm EA. Physicians' attitudes about prescribing and knowledge of the costs of common medications. Arch Intern Med 2000; 160: 2799-803
73. Denig P, Haaijer-Ruskamp FM, Wesseling H, et al. Towards understanding treatment preferences of hospital physicians. Soc Sci Med 1993; 36 (7): 915-24
74. Lambert BL, Salmon JW, Stubbings J, et al. Factors associated with antibiotic prescribing in a managed care setting: an exploratory investigation. Soc Sci Med 1997; 45 (12): 1767-79
75. Ford JK, Schmitt N, Schechtman SL, et al. Process tracing methods: contributions, problems, and neglected research questions. Organ Behav Hum Decis Process 1989; 43 (1): 75-117
76. Silver MS. Systems that support decision makers: description and analysis. West Sussex: John Wiley & Sons Ltd, 1991
77. Montgomery H. Decision rules and the search for a dominance structure: towards a process model of decision making. In: Humphreys P, Svenson O, Vari A, editors. Analysing and aiding decision processes. Budapest: North-Holland Publishing Company, 1983
78. Chu PC, Spires EE. The joint effects of effort and quality on decision strategy choice with computerized decision aids. Decis Sci 2000; 31 (2): 259-92
79. Svenson O. Process descriptions of decision making. Organ Behav Hum Perform 1979; 23: 86-112
80. Payne JW, Bettman JR, Johnson EJ. The adaptive decision maker. Cambridge: Cambridge University Press, 1993
81. Hogarth R. Judgement and choice: the psychology of decision. 2nd ed. Chichester: John Wiley & Sons, 1980
82. Tamayo-Sarver JH, Dawson NV, Cydulka RK, et al. Variability in emergency physician decision making about prescribing opioid analgesics. Ann Emerg Med 2004; 43 (4): 483-93
83. Mancuso CA, Rose DN. A model for physicians' therapeutic decision making. Arch Intern Med 1987; 147: 1281-5
84. Moskowitz AJ, Kuipers B, Kassirer JP. Dealing with uncertainty, risks, and tradeoffs in clinical decisions: a cognitive science approach. Ann Intern Med 1988; 108: 435-49
85. Backlund L, Skaner Y, Montgomery H, et al. GPs' decisions on drug treatment for patients with high cholesterol values: a think-aloud study. BMC Med Inform Decis Mak 2004; 4: 23
86. Tversky A, Kahneman D. Judgement under uncertainty: heuristics and biases. Science 1974; 185: 1124-31
87. Cook RI, Woods DD. Operating at the sharp end: the complexity of human error. In: Bogner MS, editor. Human error in medicine. Hillsdale (NJ): Lawrence Earlbaum Associates, 1994
88. Bornstein BH, Emler AC. Rationality in medical decision making: a review of the literature on doctors' decision-making biases. J Eval Clin Pract 2001; 7: 97-107
89. Christenson C, Heckerling PS, Mackesy-Amiti ME, et al. Pervasiveness of framing effects among physicians and medical students. J Behav Decis Mak 1995; 8: 169-80
90. Cohen H, Robinson ES, Mandrack M. Getting to the root of medication errors: survey results. Nursing 2003; 33 (9): 36-46
91. Aberegg SK, Arkes HR, Terry PB. Failure to adopt beneficial therapies caused by bias in medical evidence evaluation. Med Decis Mak 2006; 26 (6): 575-82

92. Flin R, Salas E, Strub M, et al., editors. Decision making under stress: emerging themes and applications. Aldershot: Ashgate, 1997
93. Zachary WW, Ryder JM. Decision support systems: integrating decision aiding and decision training. In: Helander M, Landauer TK, Prabhu P, editors. Handbook of human-computer interaction. 2nd ed. Elsevier Science, 1997: 1235-58
94. Westbrook J, Woods A, Rob M, et al. Association of interruptions with an increased risk and severity of medication administration errors. Arch Intern Med 2010; 170 (8): 683-90
95. Westbrook J, Coiera EW, Dunsmuir W, et al. The impact of interruptions on clinical task completion. Qual Saf Health Care 2010; 19 (4): 284-9
96. Lipshitz R. Converging themes in the study of decision making in realistic settings. In: Klein GA, Orasanu J, Calderwood R, et al., editors. Decision making in action: models and methods. Norwood (NJ): Ablex Publishing Corporation, 1993: 103-37
97. Spring B. Health decision making: lynchpin of evidence-based practice. Med Decis Mak 2008; 28 (6): 866-74
98. Klein GA, Calderwood R, MacGregor D. Critical decision method for eliciting knowledge. IEEE Trans Syst Man Cybern 1989; 19 (3): 462-72
99. Higgins MP, Tully MP. Hospital doctors and their schemas about appropriate prescribing. Med Educ 2005; 39 (2): 184-93
100. Harries C, Evans JSBT, Dennis I. Measuring doctors' self-insight into their treatment decisions. Appl Cogn Psychol 2000; 14 (5): 455-77
101. Evans J, Harries C, Dennis I, et al. General practitioners' tacit and stated policies in the prescription of lipid lowering agents. Br J Gen Pract 1995; 45: 15-8
102. Patel VL, Kaufman DR, Arocha JF. Emerging paradigms of cognition in medical decision-making. J Biomed Inform 2002; 35 (1): 52-75
103. Todd P, Benbasat I. Evaluating the impact of DSS, cognitive effort, and incentives on strategy selection. Inform Syst Res 1999; 10 (4): 356-74
104. Beach LR, Mitchell TR. A contingency model for the selection of decision strategies. Acad Manage Rev 1978; 3 (3): 439-49
105. Todd P, Benbasat I. An experimental investigation of the impact of computer based decision aids on decision making strategies. Inform Syst Res 1991; 2 (2): 87-115
106. Sintchenko V, Coiera EW. Which clinical decisions benefit from automation? A task complexity approach. Int J Med Inform 2003; 70: 309-16

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