Cogn Tech Work
DOI 10.1007/s10111-011-0189-0

ORIGINAL ARTICLE

How do clinicians reconcile conditions and medications? The cognitive context of medication reconciliation

Geva Vashitz · Mark E. Nunnally · Yisrael Parmet · Yuval Bitan · Michael F. O'Connor · Richard I. Cook

Received: 17 April 2011 / Accepted: 22 August 2011

Abstract Medication omissions and dosing failures are frequent during transitions in patient care. Medication reconciliation (MR) requires bridging discrepancies in a patient's medical history as a setting for care changes. MR has been identified as vulnerable to failure, and a clinician's cognition during MR remains poorly described in the literature. We sought to explore cognition in MR tasks. Specifically, we sought to explore how clinicians make sense of conditions and medications. We observed 24 anesthesia providers performing a card-sorting task to sort conditions and medications for a fictional patient. We analyzed the spatial properties of the data using statistical methods. Most of the participants (58%) arranged the medications along a straight line ($p < 0.001$). They sorted medications by organ systems (Friedman's $\chi^2(54) = 325.7$, $p < 0.001$). These arrangements described the clinical correspondence between each two medications (Wilcoxon $W = 192.0$, $p < 0.001$). A cluster analysis showed that the subjects matched conditions and medications related to the same organ system together (Wilcoxon $W = 1917.0$, $p < 0.001$). We conclude that the clinicians commonly arranged the information into two groups (conditions and medications) and assigned an internal order within these groups, according to organ systems. They also matched between conditions and medications according to similar criteria. These findings were also supported by verbal protocol analysis. The findings strengthen the argument that organ-based information is pivotal to a clinician's cognition during MR. Understanding the strategies and heuristics, clinicians employ through the MR process may help to develop practices to promote patient safety.

Keywords Medical cognition · Medical expertise · Diagnostic reasoning · Patient safety · Card-sorting · Affinity diagram

1 Introduction

A common fragile point in health care is transition between provider and locale (Cook et al. 2000). A transition creates a risk for loss of information, abandonment of care plan, or discontinuity of treatment. Unintentional failures in medication prescribing are one of the most frequent causes of preventable harm in health care (Cornish et al. 2005; Budnitz et al. 2006). Discrepancies may arise from incomplete, opaque, or ambiguous findings, complex medication interactions, and time pressure. Patients frequently do not convey valid clinical data in such transitions because of medical illiteracy, memory limitations, embarrassment (e.g., lifestyle medications and psychiatric medications), or the perception that information is clinically unimportant (e.g., herbals and vitamins).

Electronic supplementary material The online version of this article (doi:10.1007/s10111-011-0189-0) contains supplementary material, which is available to authorized users.

G. Vashitz (✉) · Y. Parmet
Department of Industrial Engineering and Management,
Ben-Gurion University of the Negev, P.O. Box 653,
84105 Beer-Sheva, Israel
e-mail: gevava@bgu.ac.il

M. E. Nunnally · Y. Bitan · M. F. O'Connor · R. I. Cook
Cognitive Technologies Laboratory,
Department of Anesthesia and Critical Care,
University of Chicago Hospitals, Chicago, IL 60637, USA

Medication reconciliation (MR) can be broadly defined as the task of bridging discrepancies in a patient's medical history after a care setting changes. Linkages between conditions and medications should be explained. However, MR is commonly identified as vulnerable to failure (Clay et al. 2008; Jylha and Saranto 2008; Miller et al. 2008; Pippins et al. 2008; Wong et al. 2008; Brady et al. 2009; Frei et al. 2009; Gandara et al. 2009). Awareness to MR interlaces within the growing awareness to patient safety issues (Agrawal 2009; Cacciabue and Vella 2010; Landrigan et al. 2010). The Joint Commission, the accreditation body for US hospitals and other health care organizations, has identified MR as a national patient safety goal (JCAHO 2006). This focus led to diverse efforts to audit and improve the process of MR. Most of these efforts are prescriptive, such as the use of forms and emphasis on supervision by pharmacists (Pronovost et al. 2003; Boockvar et al. 2006; Hayes et al. 2007; Manning et al. 2007; Weingart et al. 2007; Coffey et al. 2009; Walker et al. 2009), or the use of information technology (IT) as a tool for data management (Poon et al. 2006; Kramer et al. 2007; Turchin et al. 2008; Agrawal 2009; Schnipper et al. 2009). However, the question of how MR relates to a clinician's cognition of a patient's medical history is currently unexplored in the literature.

An extensive body of literature explored cognitive processes related to clinical diagnostic reasoning (Boshuizen and Schmidt 1992; Patel et al. 1997, 2002; Charlin et al. 2000; Round 2001; Elstein et al. 2002; Thomas et al. 2008; Vickrey et al. 2010). MR can be described as a cognitive problem-solving task, similar to popular memory or matching games. MR requires memory, reasoning, and prioritization based on incomplete, ambivalent, or redundant data. Such functions place an extensive cognitive load on the clinician, especially because MR is commonly performed under intense working conditions. MR may include typical characteristics of difficult problems, including time constraints, interactions between parts, uncertainty, and risk (Woods and Hollnagel 1987).

We previously demonstrated that clinicians performing a simulated MR task arranged medical conditions along a line ordered by organ systems (Vashitz et al. 2010). We were curious to further explore whether such patterns appear with medications as well and whether clinicians reconcile conditions and medications in particular patterns. Our specific aims were to (1) explore how the ordering patterns previously observed in medical conditions are reflected in the arrangement of medications and (2) to describe the relationship between conditions and medications and the way the relationship might help define MR in practice. Such exploration is important to learn how clinicians make sense of medication and condition history and how this may potentially improve patient safety.

2 Methods

2.1 The experiment

In a simulation experiment, participants were asked to make sense of hypothetical conditions and medications using a card-sorting task. Details of the experiment are described elsewhere (Vashitz et al. 2010). The card-sorting method is a validated method in the cognitive and social sciences for gathering user input (Coxon 1999). Analyses of card-sorting tasks yield affinity diagrams that spatially represent a subject's concepts, mental models, or perceptions of a problem.

Participants were clinicians in the Department of Anesthesia and Critical Care at the University of Chicago Medical Center, who practice MR daily. We abstracted patient records to produce a fictional case for preoperative assessment by an anesthesia provider. We chose the case to replicate typical clinical complexity. We printed the fictional patient's diagnoses and medications on simple paper cards. All participants faced the same initial card arrangement shown in Fig. 1. The patient was described as a 66-year-old woman scheduled for a wide local excision of a tongue lesion. We asked the participants to arrange the cards in a sensible way while "thinking aloud" and sharing their thoughts. Three cards (cerebrovascular accident, clopidogrel, and digoxin) were exposed later in the simulation to assess the response to new data. For the methods described below, we analyzed the final arrangement of all cards. A video camera captured hand movements and conversation.

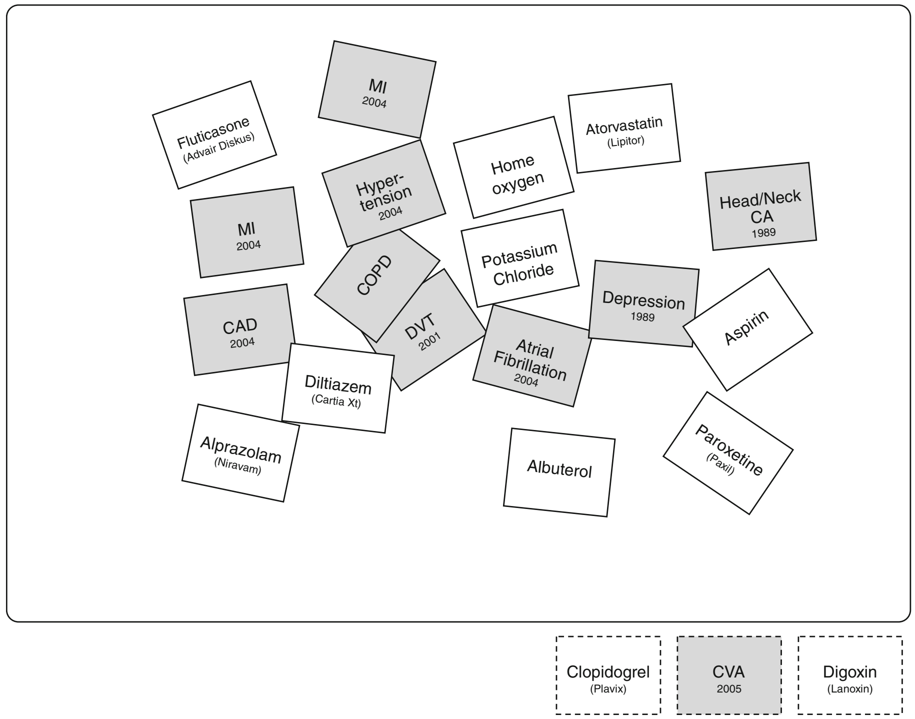
2.2 Data analysis

We used geometric and spatial cues such as card order, alignment, and clustering to explore the perceptions of the participants. We captured a graphic image of the final arrangements for each participant and coded the position of each card by its rectangular coordinates (x, y) in units of pixels. Using these coordinates, we calculated the Euclidean distance between each card pair. To make distances comparable across participants, we standardized the raw distances based on the longest distance in any particular arrangement.

2.2.1 Card alignment

An important spatial measure of card sorting is alignment, as it may represent some communal property or even priority between cards. A linear order exists if the variance of the coordinates projected on one of the axes (either X or Y) is smaller than the variance on the other axis. We used the Levene's test for equality of variance to compare the

Fig. 1 The simulated case. *CAD* coronary artery condition, *DVT* deep vein thrombosis, *COPD* chronic obstructive pulmonary condition, *CVA* cerebrovascular accident, *MI* myocardial infarction. Adapted from Vashitz et al. (2010) with kind permission from Springer Science+Business Media B.V



variances on *X*- and *Y*-axis projections. This test was applied to each participant separately. We then used a nonparametric binomial test to test the hypothesis of a line-like arrangement across all participants.

2.2.2 Proximity between cards

We were also interested in whether the cards were ordered in a meaningful pattern. One way to identify patterns in arrangement is to look at the proximity between cards. We used the Friedman test for ranking to compare the adjusted distances across participants. The Friedman test yields a mean rank for each card pair, which is the average of the pairs' ranks across all participants. The smaller mean rank for a card pair indicates that, across all participants, these cards were closer. We compared the mean ranks in the context of the clinical classification of the conditions and medications according to the organ systems treated. We used the nonparametric *k* independent samples test to correlate the Friedman's mean ranks with the classifications of senior clinicians. The classification was performed independently by two senior clinicians (MN, MO), who were unaware of the mean ranks. If two medications affected the same organ system (e.g., pulmonary and pulmonary, psychiatric and psychiatric), we referred to them as a "match". Such matches reflect the influence of clinical reasoning on card sorting. We compared the mean rank of each medication–medication pair, according to whether it was a "match" or not by the classification of the senior clinicians using a nonparametric two independent sample test.

2.2.3 Clustering conditions and medications

In our hypothesis, a shorter distance between a given medication and a condition suggested a clinical relation. We calculated the mean of the adjusted distances (MAD) of each condition–medication pair across all participants. We then ran a cluster analysis on the MADs using 4 clusters to replicate an ordinal scale: cluster 1, very close; cluster 2, close; cluster 3, far; and cluster 4, very far. Pairs in a same cluster might share clinical properties. We compared the MAD to the classification by the senior clinicians using a nonparametric two independent samples test.

2.2.4 Verbal protocols analysis

We aimed to explore 'how' clinicians reconcile the information by analyzing the think-aloud verbal protocols and the post-experiment interview. We sought to identify qualitative terms that may explain underlying cognitive process. The analysis focused on explanations about the way the cards were sorted, such as sorting criteria, order of cards, and spatial positioning.

3 Results

The participants sample has been described in detail previously (Vashitz et al. 2010). We recorded results from 24 participants: 6 attending physicians, 5 certified registered nurse anesthetists, 10 residents, and 3 third-year medical students. Ten participants were women and 14 were men.

3.1 Alignment and proximity between cards

The Levene's test for equality of variance showed that 14 participants (58%) arranged the medications along a straight line ($p < 0.001$). The 11 medications yielded 55 medication–medication pairs for each participant. Table 1 demonstrates the closest and farthest pairs and whether they are a clinical match. All pairs are available from the online appendix. Friedman's mean ranks were significantly different from each other (Friedman's $\chi^2(54) = 325.7$, $p < 0.001$). Lower mean ranks describe a pair of medications that were placed closely and presumably belong to a same organ system. The nonparametric two independent sample test showed that the mean rank in "matched" pairs (10.1) was significantly lower than the mean rank in "unmatched" pairs (37.4) (Wilcoxon $W = 192.0, p < 0.001$). In other words, the participants tended to sort medications treating similar organ systems together.

3.2 Clustering conditions and medications relations

The cluster analysis classified the relationships into four groups based on proximity, around centroids at MAD of 0.40, 0.48, 0.55, and 0.64 (Fig. 2). We expected that clinically associated conditions and medications would be placed in a similar cluster (i.e., condition–medication pairs that were related to a same organ system). We ratified these relationships statistically by comparing the MAD to the classification by senior clinicians using a nonparametric two independent sample test. Consistent with our hypothesis, the MADs correlated with the clinical match between conditions and medications (Wilcoxon $W = 1{,}917.0$, $p < 0.001$). All the pairs in cluster 1 (very close pairs) were matches, as were 59.3% in cluster 2 (close) and 39.5% in cluster 3 (far). There were no matches in cluster 4 (very far). Participants tended to match conditions and medications related to similar organ systems together. For example, cardiovascular conditions (atrial fibrillation, coronary artery condition, hypertension, myocardial infarction, and cerebrovascular accident) are treated by cardiovascular medications (aspirin, atorvastatin, clopidogrel, digoxin, diltiazem, and potassium). With some exceptions, the analysis put them into the same cluster, as it did with the psychiatric and pulmonary groups.

3.3 Verbal protocols analysis

Analyzing the verbal protocols, we looked at both the "think-aloud" portion of the task and the post-experiment reflections. Many subjects mentioned sorting the cards by organ systems (9 subjects). For example:

> …It's helpful for me to kind of think about it from either kind of an organ system approach (Subject 14).
> …I think my first inclination is to kind of group these in terms of anatomical location or patho-physiology (Subject 4).
> …I guess its kind of how we learned in medical school, first you have your history or your present illness… (Subject 7).

The subjects also mentioned pairing medications with conditions (6 subjects), for example:

> …I organize things according to the disease states…I feel it is incumbent upon the practitioner to make sure that a medication correlates with at least one diagnosis that we know the patient to have. I tend to lump things into systems, organ systems… (Subject 15).

Table 1 Order and proximity of medication pairs

	Mean rank	Classification by senior clinicians	Match
Top five pairs			
Fluticasone/albuterol	8.9	Pulmonary/pulmonary	Y
Alprazolam/paroxetine	10.4	Psychiatric/psychiatric	Y
Atorvastatin/diltiazem	12.9	Cardiovascular or neurological/cardiovascular	Y
Digoxin/diltiazem	15.2	Cardiovascular/cardiovascular	Y
Home oxygen/albuterol	16.1	Pulmonary/pulmonary	Y
Bottom five pairs			
Alprazolam/digoxin	38.6	Psychiatric/cardiovascular	N
Atorvastatin/paroxetine	38.7	Cardiovascular or neurological/psychiatric	N
Paroxetine/digoxin	38.7	Psychiatric/cardiovascular	N
Aspirin/paroxetine	38.9	Cardiovascular or neurological/psychiatric	N
Alprazolam/aspirin	39.0	Psychiatric/cardiovascular or neurological	N

For compact presentation, the table presents the top five and bottom five pairs of the 55 pairs. The mean rank of each card pair is the average of the pairs' adjusted distances across all participants. The entire table appears in Table 2 (online supplement)

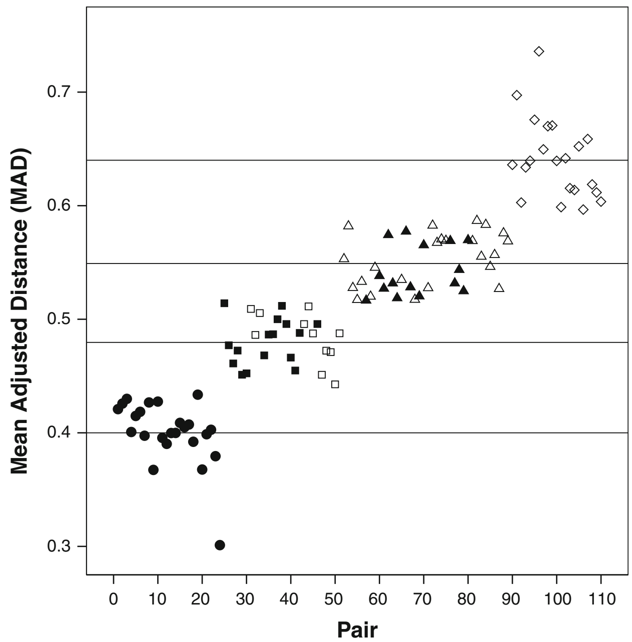


Fig. 2 Cluster analysis of relationship between conditions and medications. A cluster is a group of condition–medication pairs with an adjacent mean of adjusted distances (MADs). The *X*-axis depicts a nominal number assigned to the pair (from 1 to 110). The *Y*-axis depicts the MADs of each pair across all participants. Shorter MADs represent cards that are closer together. A "match" is a case in which the condition and medication belong to the same organ system (e.g., a pulmonary condition and a pulmonary medication). The *horizontal lines* represent the center of clusters (centroids). Legend: Cluster 1: *filled circle* matches, *open circle* non-matches. Cluster 2: *filled square* matches, *open square* non-matches. Cluster 3: *filled triangle* matches, *open triangle* non-matches. Cluster 4: *filled diamond* matches, *open diamond* non-matches

> …Then basically the main organizational scheme was just pairing the drugs with what condition they were likely to, to be… (Subject 24).
> …I've got it laid out so the diseases are over here and the medicines associated with them are over here, so there's kind of a correspondence between them… (Subject 17).

4 Discussion

Our initial quest was to describe how clinicians make sense of the MR task. Our previous findings (Vashitz et al. 2010) suggest a highly repetitive pattern of arranging medical conditions in an organ-based order. The current data replicate this finding with medications and moreover suggest linkages between the conditions and medications. The integration of our previous and current data depicts a pattern of separating conditions and medications into two groups, ordering elements of each group by organ system, and creating linkages based on in-group orders. If both conditions and medications are arranged by organ-based order, the linkages between conditions and medications should have a similar reasoning pattern. Data from the verbal protocols and the post-experiment interview support the findings from the quantitative analysis. These data suggest that many subjects sorted the cards by organ systems and matched medications with conditions.

4.1 Cognitive insights reinforced by findings

Each card had various attributes, such as priority, relevance to the forthcoming procedure, possible links with other cards, and time of occurrence. Such attributes may dictate the sorting strategy. Different clinicians may distinguish and weigh such attributes differently. The clinicians apparently used the attributes to classify cards by communal properties: it is clear that the clinicians sorted the cards into two groups (conditions and medications) and assigned an internal order within these groups according to organ systems. They also matched cards according to related criteria (conditions that are usually treated by certain medications, and medications that usually treat certain conditions). Such strategies are not obvious because other clinical, chronologic, causal, or contextual criteria could have been used. These relationships are based on a conceptual understanding of condition physiology. Such a consistent trend probably reflects disciplines learned in medical training, in which preclinical courses are often organ-based.

4.2 Correspondence with clinical reasoning and problem-solving literature

4.2.1 The "small worlds" concept

Clinicians making diagnoses use reasoning through a network of causal rules that appears to derive from the physicians' underlying knowledge base, adapted to goals of clinical tasks (Patel and Groen 1986; Charlin et al. 2000). Our findings suggest that medications and conditions share complex cognitive relationships, which clinicians use during clinical work. The cognitive literature offers several explanations for such mechanisms. For example, Kushniruk et al. (1998) showed that clinicians organize diagnostic knowledge by similarities between condition categories, forming 'small worlds' consisting of small subsets of conditions and their distinguishing features. The clinicians in our experiment apparently grouped together conditions and medications sharing communal features according to the presence of key medical findings.

4.2.2 *Family resemblance and representativeness*

Rosch and Mervis (1975) suggested that categories are not organized around strict definitions but rather according to a family resemblance. Objects belong to the same category because they are similar to each other and dissimilar to objects in contrasting categories. Ahn and Medin (1992) suggested that people first arrange data by a preferred criterion. If examples do not fit within the preferred criterion, people then adjust for differences between preferred and other criteria. Such an adjustment may represent a compromise between a structured concept and the necessity of mapping concepts into real-world examples. Variability in our data probably reflects such an adjustment. Some cards in our study fit several categories. For example, aspirin may be used to treat both cardiovascular and neurological conditions. Deep vein thrombosis (DVT) can be categorized as a cardiovascular or a hematologic condition. Hypertension is a risk factor for cardiovascular conditions, which can lead to myocardial infarction. Depression in the simulated case may have resulted from cancer or a heart condition. Less-connected cards potentially reflect uncertainty and may yield further noise.

Several studies (D'Zurilla and Goldfried 1971; Rath et al. 2004) suggested that problem-solving usually begins with a general orientation or "set", followed by various cognitive-behavioral steps, which ideally lead to effective problem resolution. The distinction between conditions and medications appears to underlie a general orientation, followed by arrangement by organ systems.

The categorization also may be derived from a representativeness heuristic (Tversky and Kahneman 1974). Cards may be classified into a category because they saliently represent it. For example, a deep venous thrombosis (DVT) is a hematologic representative, but it may be categorized into other groups as well. Whether such strategies were used, and their temporal order, should be further explored.

4.2.3 *MR as interplay between long-term and working memory*

MR is apparently an interplay between long-term conceptual models of anatomy and medications and a working-memory, problem-solving capability. Moreover, it is an interplay between external representations (e.g., diseases and medications) and internal representations (e.g., the clinical reasoning that matches between diseases and medications) (Richardson and Ball 2009). This insight would indicate what type of intervention could improve the effectiveness of the MR process and its reliability. As working memory is limited, we may suggest intervention that reduces working-memory workload, such as automated decision aids that map to observed cognitive processes.

4.3 Strengths and limitations

The simulated case was based on a real-life, complex preoperative evaluation that reflects a task clinicians face routinely. The experiment was conducted with minimal instructions to allow spontaneous behavior by clinicians who practice MR daily. The sample included a range of expertise, including senior attending clinicians, residents, advanced practice nurses, and medical students. We translated observed behaviors into quantitative data to uncover cognitive strategies.

We acknowledge several limitations of our findings. Our simulation was for one patient and included clinicians of the same specialty. Sample size limited the exploration of variability and different expertise levels. Although we think that the simulated case has a high fidelity to a real patient, performance in an experiment might be different from care of a real patient. Our observations do not address ambiguities and conflicts clinicians might encounter when performing MR. Exploring the findings with various clinical cases, specialties, and expertise levels may uncover ambiguities and conflicts at the heart of MR and advance its understanding.

4.4 Practical implications

The insights into the thought processes of clinicians during MR are a starting point for discussions about what makes medical care safe or vulnerable. The strategies identified here may serve to understand underlying cognitive processes. The results of the study can be reused for the purpose of providing clinicians with decision aids that support these patterns. Efforts to improve safety should strive to replicate the natural thought process of clinicians. Our findings support the argument that for MR safety, organ-based information should be considered pivotal to a clinician's cognition. We suggest that such tools should be aware of these strategies and assist clinicians with forming clinical linkages between conditions and medications. Such tool may follow previous concepts of graphic user interface with anatomical diagrams used to facilitate medical information gathering and entering (Stoicu-Tivadar and Stoicu-Tivadar 2006). MR should apparently be approached as a piece of a larger organizational, clinical, and cognitive process. Hence, it may be integrated in broad interventions to improve safety, including training, artifact design, and IT, for adaptive and resilient processes.

The methodology may be applicable to other disciplines, teams, technologies, and socio-technical contexts. The methodology is independent of the discussed context and is applicable to any other cognitive information gathering tasks.

5 Conclusions

We sought to explore whether ordering patterns previously observed in organizing conditions are replicated in the sorting of medications, and how clinical reasoning affects the cognitive relationship between conditions and medications. The majority of the clinicians performing a medication reconciliation task matched conditions and medications treating the same organ systems. The arrangements reflected a clinical reasoning between conditions and medications. These findings corroborate our previous findings and strongly suggest that medications and conditions share complex group relationships that are likely used by clinicians to build cognitive strategies, using their own conceptual understanding of condition physiology. The findings support the argument that organ-based information is central to a clinician's cognition while performing MR. These common strategies are a starting point for defining MR. Such exploration is important to learn how clinicians make sense of medication and condition histories. An understanding of such perceptions may produce organizational strategies that fit and support the process and potentially improve patient safety.

Acknowledgments This work was kindly supported in part by a Fulbright doctoral dissertation research scholarship to Geva Vashitz. We thank Christine Jette, MD, and Annette Martini, MD, for their help in constructing the experiment. GV was supported by a Fulbright doctoral dissertation research scholarship.

References

Agrawal A (2009) Medication errors: prevention using information technology systems. Br J Clin Pharmacol 67:681–686

Ahn WK, Medin DL (1992) A two-stage model of category construction. Cogn Sci 16:81–121

Boockvar KS, LaCorte HC, Giambanco V, Fridman B, Siu A (2006) Medication reconciliation for reducing drug-discrepancy adverse events. Am J Geriatr Pharmacother 4:236–243

Boshuizen HPA, Schmidt HG (1992) On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. Cogn Sci 16:153–184

Brady AM, Malone AM, Fleming S (2009) A literature review of the individual and systems factors that contribute to medication errors in nursing practice. J Nurs Manag 17:679–697

Budnitz DS, Pollock DA, Weidenbach KN, Mendelsohn AB, Schroeder TJ, Annest JL (2006) National surveillance of emergency department visits for outpatient adverse drug events. JAMA 296:1858–1866

Cacciabue PC, Vella G (2010) Human factors engineering in healthcare systems: the problem of human error and accident management. Int J Med Inform 79:e1–e17

Charlin B, Tardif J, Boshuizen HP (2000) Scripts and medical diagnostic knowledge: theory and applications for clinical reasoning instruction and research. Acad Med 75:182–190

Clay BJ, Halasyamani L, Stucky ER, Greenwald JL, Williams MV (2008) Results of a medication reconciliation survey from the 2006 Society of Hospital Medicine national meeting. J Hosp Med 3:465–472

Coffey M, Cornish P, Koonthanam T, Etchells E, Matlow A (2009) Implementation of admission medication reconciliation at two academic health sciences centres: challenges and success factors. Healthc Q 12(Spec No Patient):102–109

Cook RI, Render M, Woods DD (2000) Gaps in the continuity of care and progress on patient safety. BMJ 320:791–794

Cornish PL, Knowles SR, Marchesano R, Tam V, Shadowitz S, Juurlink DN, Etchells EE (2005) Unintended medication discrepancies at the time of hospital admission. Arch Intern Med 165:424–429

Coxon APM (1999) Sorting data: collection and analysis. Sage, Thousand Oaks

D'Zurilla TJ, Goldfried MR (1971) Problem solving and behavior modification. J Abnorm Psychol 78:107–126

Elstein AS, Schwartz A, Schwarz A (2002) Clinical problem solving and diagnostic decision making: selective review of the cognitive literature. BMJ 324:729–732

Frei P, Huber LC, Simon RW, Bonani M, Luscher TF (2009) Insufficient medication documentation at hospital admission of cardiac patients: a challenge for medication reconciliation. J Cardiovasc Pharmacol 54:497–501

Gandara E, Moniz T, Ungar J, Lee J, Chan-Macrae M, O'Malley T, Schnipper JL (2009) Communication and information deficits in patients discharged to rehabilitation facilities: an evaluation of five acute care hospitals. J Hosp Med 4:E28–E33

Hayes BD, Donovan JL, Smith BS, Hartman CA (2007) Pharmacist-conducted medication reconciliation in an emergency department. Am J Health Syst Pharm 64:1720–1723

Joint Commission on Accreditation of Healthcare Organizations (JCAHO) (2006) Using medication reconciliation to prevent errors. Jt Comm J Qual Patient Saf 32:230–232

Jylha V, Saranto K (2008) Electronic documentation in medication reconciliation—a challenge for health care professionals. Appl Nurs Res 21:237–239

Kramer JS, Hopkins PJ, Rosendale JC, Garrelts JC, Hale LS, Nester TM, Cochran P, Eidem LA, Haneke RD (2007) Implementation of an electronic system for medication reconciliation. Am J Health Syst Pharm 64:404–422

Kushniruk AW, Patel VL, Marley AA (1998) Small worlds and medical expertise: implications for medical cognition and knowledge engineering. Int J Med Inform 49:255–271

Landrigan CP, Parry GJ, Bones CB, Hackbarth AD, Goldmann DA, Sharek PJ (2010) Temporal trends in rates of patient harm resulting from medical care. N Engl J Med 363:2124–2134

Manning DM, O'Meara JG, Williams AR, Rahman A, Myhre D, Tammel KJ, Carter LC (2007) 3D: a tool for medication discharge education. Qual Saf Health Care 16:71–76

Miller SL, Miller S, Balon J, Helling TS (2008) Medication reconciliation in a rural trauma population. Ann Emerg Med 52:483–491

Patel VL, Groen GJ (1986) Knowledge based solution strategies in medical reasoning. Cogn Sci 10:91–116

Patel VL, Groen CJ, Patel YC (1997) Cognitive aspects of clinical performance during patient workup: the role of medical expertise. Adv Health Sci Educ: Theory Pract 2:95–114

Patel VL, Kaufman DR, Arocha JF (2002) Emerging paradigms of cognition in medical decision-making. J Biomed Inform 35:52–75

Pippins JR, Gandhi TK, Hamann C, Ndumele CD, Labonville SA, Diedrichsen EK, Carty MG, Karson AS, Bhan I, Coley CM et al (2008) Classifying and predicting errors of inpatient medication reconciliation. J Gen Intern Med 23:1414–1422

Poon EG, Blumenfeld B, Hamann C, Turchin A, Graydon-Baker E, McCarthy PC, Poikonen J, Mar P, Schnipper JL, Hallisey RK et al (2006) Design and implementation of an application and associated services to support interdisciplinary medication reconciliation efforts at an integrated healthcare delivery network. J Am Med Inform Assoc 13:581–592

Pronovost P, Weast B, Schwarz M, Wyskiel RM, Prow D, Milanovich SN, Berenholtz S, Dorman T, Lipsett P (2003) Medication reconciliation: a practical tool to reduce the risk of medication errors. J Crit Care 18:201–205

Rath JF, Langenbahn DM, Simon D, Sherr RL, Fletcher J, Diller L (2004) The construct of problem solving in higher level neuropsychological assessment and rehabilitation. Arch Clin Neuropsychol 19:613–635

Richardson M, Ball L (2009) Internal representations, external representations and ergonomics: towards a theoretical integration. Theor Issues Ergon Sci 10:335–376

Rosch E, Mervis CB (1975) Family resemblances: Studies in the internal structure of categories. Cogn Psychol 7:573–605

Round A (2001) Introduction to clinical reasoning. J Eval Clin Pract 7:109–117

Schnipper JL, Hamann C, Ndumele CD, Liang CL, Carty MG, Karson AS, Bhan I, Coley CM, Poon E, Turchin A et al (2009) Effect of an electronic medication reconciliation application and process redesign on potential adverse drug events: a cluster-randomized trial. Arch Intern Med 169:771–780

Stoicu-Tivadar L, Stoicu-Tivadar V (2006) Human-computer interaction reflected in the design of user interfaces for general practitioners. Int J Med Inform 75:335–342

Thomas RP, Dougherty MR, Sprenger AM, Harbison JI (2008) Diagnostic hypothesis generation and human judgment. Psychol Rev 115:155–185

Turchin A, Hamann C, Schnipper JL, Graydon-Baker E, Millar SG, McCarthy PC, Coley CM, Gandhi TK, Broverman CA (2008) Evaluation of an inpatient computerized medication reconciliation system. J Am Med Inform Assoc 15:449–452

Tversky A, Kahneman D (1974) Judgment under uncertainty: heuristics and biases. Science 185:1124–1131

Vashitz G, Nunnally M, Bitan Y, Parmet Y, O'Connor M, Cook RI (2010) Making sense of diseases in medication reconciliation. Cogn Tech Work 13:151–158

Vickrey BG, Samuels MA, Ropper AH (2010) How neurologists think: a cognitive psychology perspective on missed diagnoses. Ann Neurol 67:425–433

Walker PC, Bernstein SJ, Jones JN, Piersma J, Kim HW, Regal RE, Kuhn L, Flanders SA (2009) Impact of a pharmacist-facilitated hospital discharge program: a quasi-experimental study. Arch Intern Med 169:2003–2010

Weingart SN, Cleary A, Seger A, Eng TK, Saadeh M, Gross A, Shulman LN (2007) Medication reconciliation in ambulatory oncology. Jt Comm J Qual Patient Saf 33:750–757

Wong JD, Bajcar JM, Wong GG, Alibhai SM, Huh JH, Cesta A, Pond GR, Fernandes OA (2008) Medication reconciliation at hospital discharge: evaluating discrepancies. Ann Pharmacother 42:1373–1379

Woods DD, Hollnagel E (1987) Mapping cognitive demands in complex problem-solving worlds. Int J Man Mach Stud 26:257–275