

Toward An Action Based Taxonomy of Human Errors in Medicine

Jiajie Zhang¹, Vimla L. Patel², Todd R. Johnson¹, & Edward H. Shortliffe²

¹ School of Health Information Sciences
University of Texas at Houston
7000 Fannin, Houston, TX 77030
{Jiajie.Zhang, Todd.R.Johnson}@uth.tmc.edu

² Department of Medical Informatics
Columbia University
622 West 168th Street, New York, NY 10032
{Patel, Shortliffe}@dmi.columbia.edu

Abstract

One critical step in addressing and resolving the problems associated with human errors is the development of a cognitive taxonomy of such errors. In the case of errors, such a taxonomy may be developed (1) to categorize all types of errors along cognitive dimensions, (2) to associate each type of error with a specific underlying cognitive mechanism, (3) to explain why, and even predict when and where, a specific error will occur, and (4) to generate intervention strategies for each type of error. Based on Reason's (1992) definition of human errors and Norman's (1986) cognitive theory of human action, we have developed a preliminary action-based cognitive taxonomy of errors that largely satisfies these four criteria in the domain of medicine. We discuss initial steps for applying this taxonomy to develop an online medical error reporting system that not only categorizes errors but also identifies problems and generates solutions.

1. Introduction

The medical error report from the Institute of Medicine (Kohn, Corrigan, & Donaldson, 1999) has greatly increased people's awareness of the frequency, magnitude, complexity, and seriousness of medical errors. As the 8th leading cause of death in the US with 98,000 preventable deaths per year, ahead of motor vehicle accidents, breast cancer, or AIDS, medical errors need immediate attention from academic, healthcare, and government institutions and organizations. To achieve the goal of reducing medical errors by 50% in five years set by the former Clinton Administration, we need to understand the fundamental causes of medical errors such that medical errors can be prevented or greatly reduced systematically at a large scale. In our opinion, cognitive factors are fundamental in medical errors. This can be seen from the view of the healthcare system hierarchy and the view of action chains.

Cognitive factors are critical at various levels of the healthcare system hierarchy of medical errors (Figure 1). At the lowest core level, it is individuals who trigger errors. Cognitive factors of individuals play the most critical role here (Reason, 1992). At the next level, errors can occur due to interactions between an individual and technology. This is an issue of human-computer interaction where cognitive properties of interactions between human and technology affect and sometimes determine human behavior (Helander, Landauer, & Prabhu, 1997; Zhang, 1997;

Zhang & Norman, 1994). At the next level, errors can be attributed to the social dynamics of interactions between groups of people who interact with complex technology in a distributed cognitive system. This is the issue of distributed cognition and computer-supported cooperative work (Baecker, 1993; Hutchins, 1995a, 1995b; Zhang, 1997). At the next few levels up, errors can be attributed to factors of organizational structures (e.g., coordination, communications, standardization of work process), institutional functions (e.g., policies and guidelines), and national regulations. At these higher levels, cognitive factors also play some roles. Although the properties at the six levels can be to some extent studied independently, a cognitive foundation for the system is essential for a complete and in-depth understanding of medical errors.

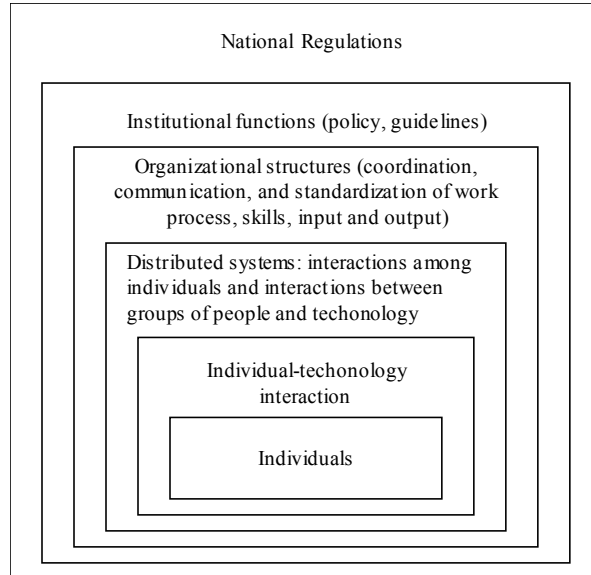


Figure 1. The system hierarchy of human errors in medicine

From the view of action chains, the critical roles of cognitive factors in medical errors are also clear. Figure 2 shows the chain of events and factors that lead to an error in a system. It is clear that individuals are at the last stage of the chain, although the individuals may not be the root cause of the error. If the chain of events can be stopped at the in-

dividual's stage through cognitive interventions, errors could be potentially prevented.

Medical errors are human errors in healthcare. By definition (Kohn et al., 1999; Reason, 1992), human errors are errors in human actions. Human actions are primarily cognitive activities. It is not surprising to see that human errors occur primarily due to inadequate information processing in cognitive tasks (Bogner, 1994; Norman, 1981; Reason, 1992; Woods, Johannesen, Cook, & Sarter, 1994). In order to prevent or greatly reduce medical errors, it is critical to understand the underlying cognitive mechanisms of medical errors.

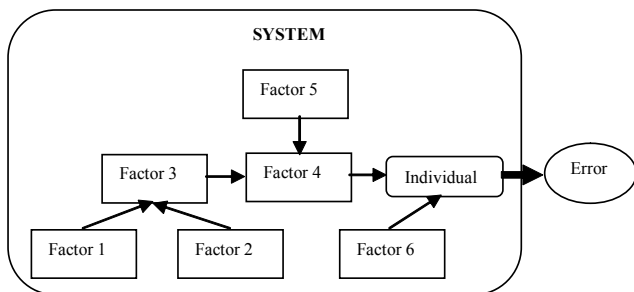


Figure 2. The chain of events leading to an error

2. Theoretical Background

To understand the cognitive mechanisms underlying medical errors, we first need to develop a cognitive taxonomy of medical errors that can (1) categorize all types of medical errors along cognitive dimensions, (2) associate each type of medical error to a specific underlying cognitive mechanism, (3) explain why and even predict when and where a specific error will occur, and (4) generate intervention strategies for each type of error.

The purpose of this paper is to develop an action based cognitive taxonomy that can be potentially expanded to include all four features listed above.

2.1. Reason's definition of human error

Reason's (Reason, 1992) definition of human error is the most widely accepted: an error is a failure of achieving the intended outcome in a planned sequence of mental or physical activities. According to Reason, human errors are divided into two major categories: (1) slips that result from the incorrect execution of a correct action sequence and (2) mistakes that result from the correct execution of an incorrect action sequence. In comparison with mistakes, slips have been extensively studied and better understood (for reviews, see Norman, 1986; Reason, 1992).

2.2. Norman's action theory

To be comprehensive, descriptive, predictive, and generalizable, a cognitive taxonomy should be based on a

sound cognitive theory that has explanatory and predictive power. Since human errors are defined as errors in human actions, a cognitive theory of human actions can provide the theoretical foundation for the cognitive taxonomy. In our opinion, the cognitive theory of human action most appropriate for medical errors is the seven-stage action theory developed by Norman (Norman, 1986, 1988) and refined by Zhang and colleagues (Zhang, 1987; Zhang, Patel, & Johnson, in press). The seven-stage action theory is shown in Figure 3, with a demonstration showing the action of deleting a file on a DOS system. According to this theory, any action has seven stages of activities: (1) establishing the goal (e.g., "delete file"); (2) forming the intention (e.g., "use remove command"); (3) specifying the action specification (e.g., "remove ../../home/paper/talk_old.ver1"); (4) executing the action (e.g., "typing command text, hit return"); (5) perceiving the system state (e.g., "prompt symbol :>, no feedback"); (6) interpreting the state (e.g., "nothing happened"); and (7) evaluating the system state with respect to the goals and intentions (e.g., "form sub-goal to find out current state of the system").

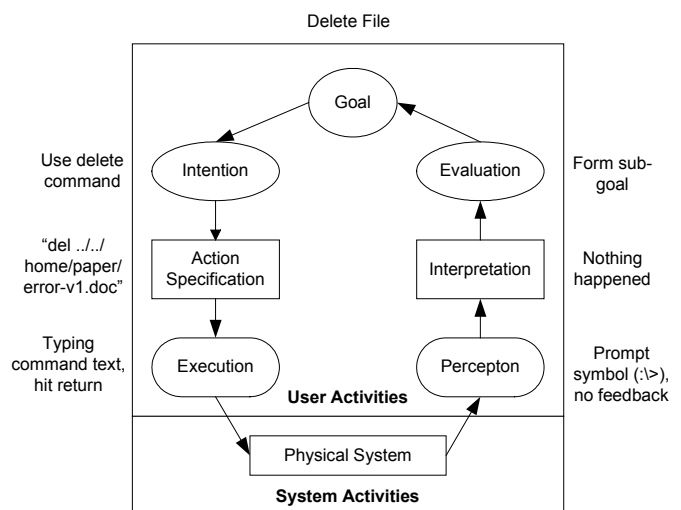


Figure 3. Norman's seven-stage theory of action.

3. The Cognitive Taxonomy

Reason developed one taxonomy of human errors (Reason, 1992); however, it was not based on a systematic theory of human action; it was primarily for slips, not for mistakes; and it has not been systematically applied to medical settings. Norman's (Norman, 1986) seven-stage action theory was developed for the study of human-computer interaction and the design of user interfaces--it has not been applied to the study of errors.

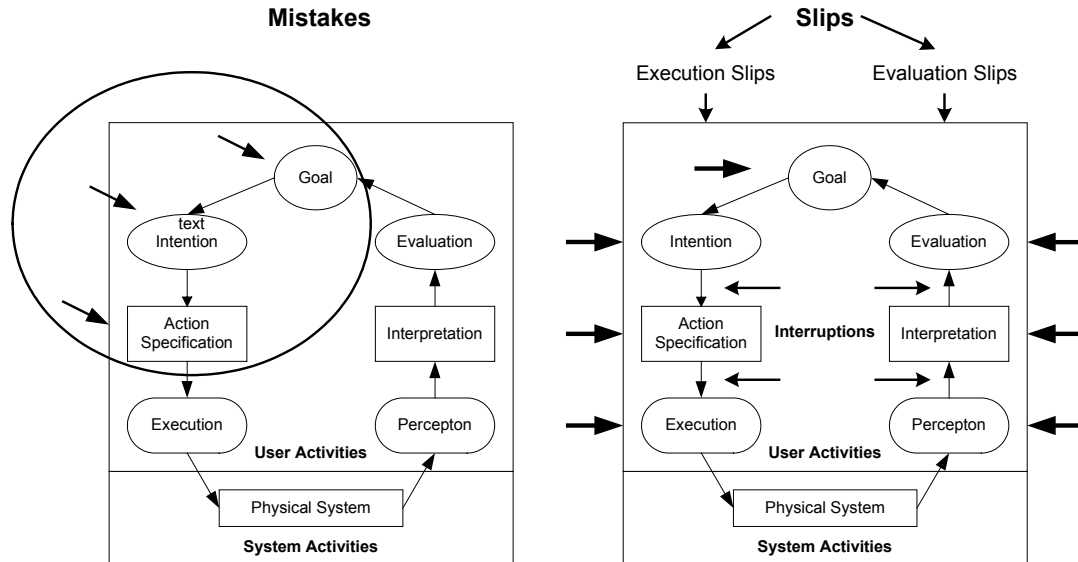


Figure 4. Slips can occur at all stages, whereas mistakes can only occur at the first three stages.

The cognitive taxonomy we develop here is an application and extension of Norman’s action theory to the categorization of medical errors. It is an action-based cognitive taxonomy. This taxonomy covers all types of human errors, because a human error is an error in an action and any action has to go through the seven stages. According to our taxonomy, errors can occur at any of the seven stages of action and between any two adjacent stages: due to incorrect translation from goals to intentions, incorrect action specifications from intentions, incorrect execution of actions, misperception of system state, misinterpretation of data perceived, and misevaluation of interpreted information with regard to the goal of the task. Unlike other taxonomies, our taxonomy specifies the places where mistakes and slips may occur (Figure 4). A slip is the incorrect execution of a correct action sequence. Slips can occur at all seven stages of action and between stages. Mistakes, however, can only occur at the first three stages of action because a mistake is the correct execution of an incorrect action sequence and only the first three stages can contribute to the formation of an incorrect action sequence.

3.1. Slips

Under our cognitive taxonomy, slips can be divided into execution slips and evaluation slips (see Figure 4 and Table 1).

Execution slips are associated with the execution of an action. They occur at stages of Goal, Intention, Action Specification, and Execution. For the slips at each stage, there are corresponding cognitive mechanisms. A correct goal could be distorted due to its strongly shared schema with another irrelevant goal. A correct intention could be deactivated due to

memory decay or swapped by another irrelevant intention due to similarity of schemas. A correct action specification could be distorted due to many factors such as attention shift, situational stimulation, etc. The execution of an action sequence could misfire due to memory and attention problems or various environmental factors. Table 4 shows a list of possible cognitive mechanisms for slips at each of the stages.

Similarly, evaluation slips are associated with the evaluation of the outcomes of an action. They occur at the stages of Perception, Interpretation, and Evaluation. There are also corresponding cognitive mechanisms associated with the slips at each of these stages. The outcome of an action might be impossible to perceive, hard to perceive, or perceived in an incorrect way. The interpretation stage may also induce errors due to prior knowledge, lack of context, or as a direct result of misperception. The evaluation stage may fail due to insufficient feedback, delayed feedback, information overload, memory failure, and other factors.

Table 1 shows not just the types of slips under the cognitive taxonomy but also examples of slips in each category and potentials solutions that can prevent the slips from happening.

3.2. Mistakes

Under our cognitive taxonomy, mistakes are categorized into goal mistakes, intention mistakes, and action specification mistakes. These correspond to the first three stages in the action cycle where mistake can occur. Goal mistakes and intention mistakes are mostly knowledge-based mistakes, such as faulty conceptual knowledge, incomplete knowledge, biases and faulty heuristics, incorrect selection of knowledge, information overload, etc. Action specification mistakes are

mostly rule-based mistakes, such as misapplication of good rules, encoding deficiencies in rules, action defi-

ciencies in rules, dissociation between knowledge and rules, etc.

Table 1. An Action Based Cognitive Taxonomy: Slips

	Stage in Action Cycle	Examples	Cognitive mechanisms	Potential solutions
Execution Slips	Goal slips	<i>A doctor was called out of the room to answer an urgent call and afterwards he went to the room of a different patient who was next in the queue. (Loss of activation)</i>	<ul style="list-style-type: none"> •Loss of activation •Cross talk (concurrent) •Cross talk (sequential) •Altered goal •Delayed activation •Overflow of goal stacks 	<ul style="list-style-type: none"> •Provide memory aids •Reduce multitasking •Reduce interruptions •Reduce goal stacks •Train users
	Intention Slips	<i>"I went into my bedroom intending to fetch a book. I took off my rings, looked in the mirror and came out again—without the book." (Loss of activation)</i>	<ul style="list-style-type: none"> •Loss of activation •Cross talk (concurrent) •Cross talk (sequential) •Reversal of schema •Activation of incorrect schema 	<ul style="list-style-type: none"> •Provide memory aids •Reduce multitasking •Situating actions •Reduce interruptions
	Action Specification Slips	<i>IL-11 (Oprelvekin , or Interleukin-eleven) was misinterpreted as IL-2 (Aldesleukin, or Interleukin-two). 11 was read as the Roman numeral two. (Associative activation)</i>	<ul style="list-style-type: none"> •Associative activation •Failure of retrieval •Sequence mutation •Situating activation •Description •Cross talks 	<ul style="list-style-type: none"> •Automation •Decision support •Situating actions •Train users •Direct action
	Execution slips	<i>"I meant to turn off the antibiotics IV only, but turned off the infusion pump completely." (Double capture)</i>	<ul style="list-style-type: none"> •Capture •Double capture •Perceptual confusion •Deviation of motor skills •Misfiring •Omission 	<ul style="list-style-type: none"> •Automation •Visualization •Display design •Reduce interruption •Memory aids
Evaluation Slips	Perception slips	<i>A patient died of liquid aspiration Because the water trap connected with a tube had no mechanism to protect against reflux to patient's trachea, and there was no feedback in the system. (Lack of perception)</i>	<ul style="list-style-type: none"> •Lack of perception •Misperception •Mis-anticipation 	<ul style="list-style-type: none"> •Direct perception •Immediate feedback
	Interpretation slips	<i>A yellow flashing light on a medical device was interpreted as non-critical when it really meant critical. (Misinterpretation)</i>	<ul style="list-style-type: none"> •Misinterpretation •Default schema •Confirmation bias •Information overload •Loss of memory 	<ul style="list-style-type: none"> •Display design •Decision support •User training •Memory aids •Situation awareness
	Evaluation slips	<i>A nurse repeated radiation therapy to a patient three times in a row, due to poor feedback. The patient died three months later. (Lack of feedback)</i>	<ul style="list-style-type: none"> •Lost goal •Insufficient information •Evaluating different goal •Information overload •Lack of feedback 	<ul style="list-style-type: none"> •Memory aids •Display design •Action tracking •Information reduction

Table 2. An Action Based Cognitive Taxonomy: Mistakes

	Stage in Action Cycle	Examples	Cognitive Mechanisms	Potential solutions
Knowledge-based Mistakes	Goal mistakes	<i>Stick with a diagnosis that was generated through a large investment of time and effort even if there was evidence indicating other possibilities. (Biases)</i>	<ul style="list-style-type: none"> •Misdiagnosis •Faulty conceptual knowledge •Incomplete knowledge •Biases •Faulty heuristics 	<ul style="list-style-type: none"> •Training •Education •Representational Aid •Decision support
	Intention mistakes	<i>A physician treating a patient with oxygen set the flow control knob between 1 and 2 liters per minute, not realizing that the scale numbers represented discrete, rather than continuous, settings. (Incorrect knowledge)</i>	<ul style="list-style-type: none"> •Incorrect selection of knowledge •Misapplication of knowledge •Information overload •Incorrect knowledge 	<ul style="list-style-type: none"> •Training •Education •Decision support •Information reduction •Display design •Representational Aid
Rule-based Mistakes	Action Specification mistakes	<i>Strange burn scars appeared in post-operative patients in a hospital. The problem was caused by electric discharge of the device that was not grounded. The device has a blinking red to signal for the problem, but the device operators did not know the meaning of the signal. (Incomplete knowledge)</i>	<ul style="list-style-type: none"> •Misapplication of good rules •Encoding deficiencies in rules •Dissociation between knowledge and rules •Action deficiencies in rules •Incomplete knowledge 	<ul style="list-style-type: none"> •Decision support •Automation •User training •Representational Aid

Table 2 shows not only the types of mistakes under the cognitive taxonomy but also examples of mistakes in each category and potentials solutions that can prevent the mistakes from happening. In comparison with slips, mistakes are more complex and less understood.

Most studies about mistakes in the past were byproducts of studies of reasoning biases and heuristics in decision-making tasks (Hogarth & Einhorn, 1992; Tversky & Kahneman, 1974). Recently there have been a growing number of studies that explicitly examine various types of mistakes in medicine (Patel & Kaufman, 2000; Patel, Lloyd, & Melanson, 2000; Patel & Ramoni, 1997). We expect to see more studies of this kind and we will expand our taxonomy to accommodate new data and theories.

4. Discussion and Conclusion

One critical step towards reducing medical errors in particular and human errors in general is a cognitive

taxonomy of errors that can (1) categorize all types of medical errors along cognitive dimensions, (2) associate each type of medical errors to a specific underlying cognitive mechanism, (3) explain why and even predict when and where a specific error will occur, and (4) generate intervention strategies for each type of error. Based on Reason's (Reason, 1992) definition of human errors and Norman's (Norman, 1986) cognitive theory of human action, we developed a preliminary action-based cognitive taxonomy of medical errors that to some extent satisfy these four criteria. Our taxonomy can categorize all types of errors (slips and mistakes) according the stages of the action cycle. We have identified a set of cognitive mechanisms (though not exhaustive) that underlie each type of slip or mistake. Our taxonomy can also explain why a specific error occurs, although we have not developed the taxonomy in enough detail to make predications on when and where an error will occur. Finally, at a high and conceptual

level, we have generated a set of possible solutions addressing each type of errors.

One important practical implication of the cognitive taxonomy of medical errors is that it can provide systematic, principled methods for the design of medical error reporting systems. Current medical error reporting systems are mostly based on free text in an unstructured format. Medical error data collected in this way are rarely useful for the detection of patterns, discovery of underlying factors, and generation of solutions, because user entered free text do not contain the right types of information needed for interventions and is difficult to analyze in a systematic way. Medical error reporting systems should not be merely record keeping systems. They should be systems for the identification of problems and generation of solutions. We are currently developing an online medical error reporting system that is based on the cognitive taxonomy we have been developing. In this system, questions and inquiries are generated to encode cognitively relevant information; the categorization of errors is along relevant cognitive dimensions; and it is designed to generate immediate recommendations on possible intervention strategies.

5. References

- Baecker, R. M. (Ed.). (1993). *Readings in groupware and computer-supported cooperative work: Assisting human-human collaboration*. San Francisco: Morgan Kaufmann.
- Bogner, M. S. (Ed.). (1994). *Human error in medicine*. Hillsdale, NJ: Erlbaum.
- Helander, M. G., Landauer, T. K., & Prabhu, P. V. (Eds.). (1997). *Handbook of human-computer interaction* (2nd ed.). New York: North-Holland.
- Hogarth, R. M., & Einhorn, H. J. (1992). Order effects in belief updating: The belief-adjustment model. *Cognitive Psychology*, 24, 1-55.
- Hutchins, E. (1995a). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Hutchins, E. (1995b). How a cockpit remembers its speed. *Cognitive Science*, 19, 265-288.
- Kohn, L. T., Corrigan, J. M., & Donaldson, M. S. (1999). *To err is human*. Washington, DC: National Academy Press.
- Norman, D. A. (1981). Categorization of Action Slips. *Psychological Review*, 88, 1-15.
- Norman, D. A. (1986). Cognitive engineering. In S. W. Draper (Ed.), *User centered system design*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.
- Patel, V. L., & Kaufman, D. R. (2000). *Conceptual and procedural errors in medical decision-making*. Proceedings of the Cognitive Society Conference.
- Patel, V. L., Lloyd, S. J., & Melanson, P. (2000). *Decision making in emergency care: The use of data and heuristics*: Centre for Medical Education, McGill University.
- Patel, V. L., & Ramoni, M. (1997). Cognitive models of directional inference in expert medical reasoning. In R. Hoffman (Ed.), *Expertise in context*. Menlo Park, CA: AAAI Press.
- Reason, J. (1992). *Human error*. Cambridge, UK: Cambridge University Press.
- Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185, 1124-1131.
- Woods, D. D., Johannesen, L., Cook, R. I., & Sarter, N. (1994). *Behind human error: Cognitive systems, computers and hindsight*. Dayton, OH: Crew Systems Ergonomic Information and Analysis Center, WPAFB.
- Zhang, J. (1987). *The effect of the timing of interruption on human action* (Unpublished Report). San Diego: University of California, Department of Psychology.
- Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science*, 21(2), 179-217.
- Zhang, J., & Norman, D. A. (1994). Representations in distributed cognitive tasks. *Cognitive Science*, 18(1), 87-122.
- Zhang, J., Patel, V. L., & Johnson, T. R. (in press). Medical error: Is the solution medical or cognitive? *Journal of American Medical Informatics Association*.