Using Cognitive Ergonomics and Metacognition Processes for Understanding and Improving Medication Safety Systems

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Abstract Cognitive ergonomics implies understanding how people make decisions, and how to design safer systems for the people involved. Understanding how experts in medication safety management think and make decisions, give a new vision of how to design safer systems. A study was achieved for characterizing ergonomic cognitive and metacognitive processes developed by some experts in medication safety (pharmacists, doctors, nurses) solving problems related to unsafe medication (prescription, preparation, dispensing, and administration). Using a "think aloud" methodology was possible to identify how the experts think and which are the principles to have in mind for designing safer medication management processes. We found that the experts think about the goal in a task, balancing how to keep a Patient out of risk against it, this requires planning and developing task-oriented thinking in mitigating every risk rather than just performing the task. While monitoring the task, experts reflect on whether the patient is responding in the same way as would be expected. Any alteration of the medication's therapeutic effect may be the result of a possible mistake. They find a better way of controlling the task by taking alternative decisions using their knowledge and previous experiences for developing their task. Using a critical mindset, they modify their actions dynamically in the process. Finally, evaluation includes a metacognition process to identify improvement opportunities, which could be used in situations they might face later. Using cognitive and metacognitive process descriptions is possible to design a safer medication system.

Keywords Cognitive ergonomics · Metacognition · Medication safety · Pharmacovigilance

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M. Melles et al. (eds.), *Convergence: Breaking Down Barriers Between Disciplines*, Springer Series in Design and Innovation 30,
https://doi.org/10.1007/978-3-031-32198-6_4

1 Background

Medication errors (ME) are one of the most important problems in patient safety and have a big impact on public health, recognized as such by the World Health Organization (WHO) in the challenge "Medication without harm" (WHO 2004; Donaldson et al. 2017). Multiple strategies have been tried to minimize its incidence and impact, however, apparently, no improvement has been obtained in this indicator (Kohn et al. 2000; Bates and Singh 2018). On the other hand, cognitive and metacognitive processes have been studied for some health careers and it is considered feasible for professionals to reflect on their practice (Andersson 2012; Banning 2008; Crosckerry 2003; Cutrer et al. 2013; Nielsen et al. 2007). Cognitive Ergonomics and cognitive biases could be useful to better define tasks to use medications safely and design safer processes in complex systems (Zhang et al. 2002).

This article characterizes the metacognitive strategies of planning, monitoring, control and evaluation used by 8 experts in safe medication (pharmacists, doctors, nurses, ergonomists) when solving, through role plays, problems related to unsafe situations for patients when using medications.

Knowing the cognitive and metacognitive processes that the experts develop when solving problems of prescription, preparation, dispensing and administration of medications, allows to establishing educational implications that could be developed to encourage students and professionals in the health areas to understand the risky situations in the use of medications, and the mechanisms to mitigate them through a better system design.

The goal of this article is to understand how cognitive ergonomics and metacognitive processes help to establish safer systems in Medication management.

2 Methodology

Within the framework of a Master's thesis in Education, an investigation was carried out based on a qualitative, interpretive paradigm, using a case study method. It implies asking each participant that she/he must consider that they have a specific role and they needed to solve the case from that role, acting as if they have all the tools for resolution. Previously some authors used simulated cases for analyzing metacognitive processes (Burke and Mancuso 2012; Figueroa et al. 2016; Jimenez 2016).

The first step was the design of the cases. It was designed considering real cases of medication errors reported in the news or in the literature. Of these cases, important common elements were characterized to be considered, such as, if that had happened in vulnerable patients (pediatric or neonatal), including high-risk medications ad problems related to "human factors" such as deficiency of leadership, effective communication, and teamwork, additionally considering the cases happened

within complex systems with the interaction of multiple stakeholders such as doctors, pharmacists, nurses, patients, and family members.

For each element of the real cases, the author defines which metacognitive strategy could be characterized, for example, if the cases include taking a bad decision, it was considered part of the "planning" strategy, or if the element was a decrease in the security of the patient during the treatment it was inside the strategy of "monitoring", etc. The most important elements were chosen to elaborate the cases for the experts.

Two cases were finally written for the author and each participant was located in 3 different roles for 3 different moments during the case (for case 1: pharmacist, nurse, Medication Safety Officer/Ergonomist; for case 2: doctor, nurse, Medication Safety Officer/Ergonomist). The cases included the information that the medicines were administrated to pediatric patients (one of them to a newborn).

2.1 Case 1

Moment 1: A pharmacist attends to a vulnerable patient (newborn) and is faced with a prescription that is not clear in terms of dosage, sense of urgency (asks to administer "now"), date of issue, legality (not has a medical sign), the doctor's specialization (medication for a newborn and it is not clear if it was issued by a neonatologist or pediatrician).
Moment 2: A nurse who must administer the medication with the same unclear prescription.
Moment 3: A Medication Safety Officer/ Ergonomist needs to analyze a case of the death of a neonatal patient due to the dispensing and administration of a high-risk medication (adrenaline) that has been dispensed erroneously, he must base his analysis on the same prescription of the previous moments and additional information provided.

2.2 Case 2

Moment 1: A nurse is confronted with a confusing prescription issued by a doctor from the previous shift, in which he prescribes dextrose and which has inconsistencies such as the use of non-standard interpretation acronyms, a request to prepare a mixture without indicating the dosage exact, without administration speed, with the contradiction of initially ordering low-concentration dextrose and then high-concentration dextrose.
Moment 2: A doctor must answer the doubts that arise to the nurse of Moment 1, make the decisions and assume the responsibilities of the patient.

Moment 3: A Medication Safety Officer/ Ergonomist must analyze a case of death of a pediatric patient due to dextrose overdose, she/he must analyze the case with confusing prescription information and other elements.

After designing the cases, they were validated by healthcare professionals considering the information clarity and sufficiency in both cases. Any information that might not be clear to the reader was adjusted. Likewise, a "Self-observation questionnaire of metacognitive strategies" was developed, It considers each type of strategy (Planning, monitoring, control, and evaluation). Each participant was invited to explore the metacognitive strategies that they used during the resolution of the problems and to be aware of the learning achieved by developing the case. The self-observation questionnaire was also validated. Eight healthcare professionals (pharmacists, doctors, nurses, and ergonomists) were invited to solve the cases.

The participants were selected considering the following criteria:

- Healthcare Professionals with big experience in medication errors analysis.
- With extensive knowledge of safe drug use, patient safety, human factors, or cognitive ergonomics (at least 10 years of experience).
- Recognized in their countries as referents of the topics previously exposed for their intellectual production in this regard. (Lecturers, consultants, researchers)
- Willing to participate in research and develop the analysis of problem scenarios by solving them with the Thinking Out Loud technique.

The only exclusion criterion was rejecting the invitation. All the guests signed the informed consent in which the objective and methodology of the research were explained.

The process of capturing the information was developed through problem-solving sessions. Each session consisted of the following moments:

1. Verification of the understanding and signing of the informed consent, as well as the resolution of doubts, if any.
2. A Think Out Loud method training.
3. The resolution of cases.
4. The development of the self-observation questionnaire of the metacognitive strategies used.

The cases were resolved by 2 Physicians, 2 Pharmacists, 2 Nurses, and 2 experts in Ergonomics and Human Factors. Each one analyzed the cases assuming the defining roles. For the self-observation questionnaire, the experts answered it by remembering their performance and analysis processes from their own role in their profession and, in a second moment, as Medication safety officers.

The analysis of the information was carried out through the analysis of categories and subcategories by metacognitive strategy as shown below.

3 Results

The metacognitive strategies characterization was carried out considering the profession of the participants and reviewing the strategies used for Planning, Monitoring, Control, and Evaluation (Flavel 1979; Allueva 2002; Efklides 2008; Robson 2015). This article just described the ergonomist's answers, and how they consider the medication management systems must be improved.

3.1 Planning Strategy

Regarding the organization of the tasks and the steps to follow for achieving them, the experts talked about the present risks and the mitigation activities in preparation and administration processes, they said some sentences as follows:

> I ask her to give me the prescription and the medication that she picked up at the pharmacy, I review and verbally reiterate the instructions: "Ma'am, the doctor tells me to apply a vial"", "I would tell the lady that it is a venous injection, she may have minimal problems, that it is a bit painful, but with my experience she may not have pain.
>
> Well, I greet her, I ask her what she needs, the lady gives me the medicine prescription, and well I check the prescription, I check that it matches the medicine that the lady has in her hand, if everything matches then I proceed to the administration, in this exercise generates distrust in me but from the exercise I must assume…

The interest of the experts in human factors was the interaction with the family member (user of the system) and the interest in maintaining effective communication by engaging them in the process.

The most important considerations in the planning process were: The interest of the active participation of the patient, for which effective communication processes are generated, they are educated and included as a security barrier; the standardization of processes, considering the model "work as it is done" and the tool of analysis of cases by tasks; the use of technologies embedded in the process as security barriers; other elements of the medicine such as the packaging and the utensils included for the medicine administration.

In the "Self-observation questionnaire of metacognitive strategies" for the Planning strategy it was evidenced:

- A metacognitive knowledge on issues of knowing how to plan, recognize a problem and the objectives to be achieved.
- A metacognitive knowledge compared to the option of being able to use knowledge and resources to solve them, which were focused on technical knowledge in healthcare areas (pathology, pharmacology, physical chemistry, pharmacotechnics, etc.), knowledge about patient safety (medication errors, usual risks in medication management and how to mitigate them) and knowledge from human factors (effective communication, teamwork, process standardization, and leadership)

- The option of making use of their previous experiences to solve problems, turning them into metacognitive experiences that promote awareness and internalization of problem-solving mechanisms, to be used in planning new solutions when facing similar problems.

3.2 Monitoring and Control Strategy

In accordance with the case solution and the questionnaire solved by the ergonomists, was evidenced:

- A metacognitive knowledge to identify the need to monitor the tasks verifying that these was carried out properly and understanding if the task development deviates from the stated objective (the safe use of the medication). In this sense, experts contemplated at least two conditions to be monitored:
  1. The tasks are executed as it was designed, in the closest way that it should be, considering particular patient conditions, and
  2. The evolution of the patient shows that the process is developed properly.
- A metacognitive knowledge of the strategies that exist to successfully accomplish the task, contemplating not only the basic elements, such as the execution and control of the "correct" ones in medication management but also the alternative strategies based on the analysis of complex systems and human factors, empathy, critical thinking, the possibility of refusing the development of the task and the analysis of tasks from real conditions.

3.3 Evaluation Strategy

A final task developed by the participants was the analysis of the medication error from the role of Medication Safety Officer/Ergonomist. A question based on the study of complex systems and human factors was included in this analysis.

- The participants agreed that within the complex system, the relationship among the different stakeholders (pharmacists, physicians, nurses, managers, and other leaders) as well as their communication processes, was key. They showed that a large part of the inconveniences generated could have been solved with adequate communication processes, such as, for example, a direct number to communicate with the prescriber physician in both cases.
- Regarding communication, the experts expressed the importance of teamwork to provide mutual support and filter medication errors that could occur, so that it doesn´t reach the patient. Within the framework of the leadership factor, was considered the importance of managers for generating environments with a Culture of Safety and promoted it to each HCP involved.

- A commonly mentioned topic was the standardization of processes, as well as the existence of protocols, guidelines for handling procedures, and other information that would allow them to recognize which was the correct path to carry out the task. It was also mentioned having monitoring and evaluation procedures such as checklists, and controls by peers, other professionals, or supervisors to ensure that the performance of the task was adequate.
- Since the requested task was to analyze the error, they all considered that an in-depth evaluation should be carried out to determine the interactions that could have generated the event and take the corresponding measures, such as, for example, training in patient safety culture, minimizing the possibility of distractions or risk situations derived from the work environment like overload, stress and physical and mental exhaustion.
- The importance of recognizing the frequent existence of human error and, therefore, the need to implement constant adjustment measures, through supervision, participation of the work team and continuous improvement, is also highlighted.
- Patient Safety Expert 2 makes an interesting reflection on the difference between how tasks are executed, and how they are described as having to be executed. From this, it promotes the development of procedures linked to the real and operational performance of the people involved in the tasks. He suggests doing an analysis from ergonomics to establish the minimum requirements that each of the tasks must have to be safe and protocolize them from that point of view.
- Finally, as previously mentioned on several occasions, the participants consider the conditions in which the interactions between the officials of the healthcare area and the administrative staff to be very relevant. The hierarchical relationship that may exist between them is considered, where the interest in minimizing economic losses may prevail over the interest in guaranteeing conditions that favor patient safety. In this sense, it is key to understand the codependency of the actors, the interests of each one and how to achieve a win–win relationship, without the superiority of administrative aspects, mainly financial, arising over health actions that, as in the case described, involve invaluable loss of human life, but also a very strong economic risk in case of lawsuits against the hospital, or loss of the reputation of the institution.

4 Discussion

Patient safety issues and particularly medication errors could be intervened and prevented considering Human Factors and ergonomics, (WHO 2009) including Cognitive Ergonomics, it means understanding how the complex system of medication use could be modified or designed considering the interests of people who are involved in that system (Patients and healthcare workers) and analyzing the cognitive factors of each person. With the methodology of metacognition strategies characterization is possible to define how experts in medication safety think, understand the

processes, and make decisions for having safer systems for all the stakeholders. These strategies include planning monitoring, control, and evaluation (Efklides 2008).

When ergonomists are solving problematic cases about medication errors, they could use their knowledge for considering different ways of analyzing and deciding how to change the systems. These experts think about the goal in a task, balancing how to keep a patient out of risk. This requires planning and developing task-oriented thinking in mitigating every risk rather than just performing the task (Sibbald 2011).

While monitoring the task, experts reflect on whether the patient is responding in the same way as would be expected. Any alteration of the medication's therapeutic effect may be the result of a possible mistake. They find a better way of controlling the task by taking alternative decisions using their knowledge and previous experiences for developing their task. Using a critical mindset, they modify their actions dynamically in the process.

The evaluation includes a metacognition process to identify improvement opportunities, which could be used in situations they might face later. The process of analyzing their performance helps to create new knowledge so it can be used for learning about mistakes before it happens in real life. Some researchers have found similar results in other healthcare topics (Hong et al. 2015; Cho et al. 2017; McFarlane et al. 2018; Medina et al. 2017; Wuryanto et al. 2017).

The option of being involved in hypothetical situations related to possible adverse events, allows HCP to "live" and experience uncomfortable situations which offers the experience of learning and understanding how they think and realize how they make decisions, and define how to act in a safer way. This knowledge could be shared with other HCP and students for giving information such as the best way for planning, monitoring or evaluating an action related with patient safety.

Ergonomists consider not just the necessity of developing the task but the way that this task is done inside complex systems, then they referred other important visions like, promoting a culture of safety, teamwork, leadership, and minimizing stress and unclear or undefined processes.

Other considerations informed in the processes designed include: To understand the cognitive biases that humans could have when using medications, minimizing the risk of mistakes limiting the choices of medication, and including the metacognitive process in regular training of healthcare students and professionals.

They list activities to be carried out, like checking that the risks are being controlled, which could be interpreted as an internalization of the presence of risks at each moment of medicines use, it should be achieved that the students in the approach of test environments detect, analyze and mitigate the present risk situations. This coincides with the research by Andersson (2012), Cutrer et al. (2013) and Lee (2016), on the frequent analysis of risky situations in health care and the clinical reasoning to be used.

It is suggested to use the cases built for this article, or develop other cases, with different situations and stages of medication use, from complex systems and human factors perspective for HCP training, it allows to consider how to act in a problematic situation related to medicines use. It helps the HCP to understand how they act compared with how an expert in medication safety act.

The use of these test environments is based, among other considerations, on what was stated by Hardin and Richardson (2012) in "Teaching the Concept Curricula: Theory and Method", as opposed to the student being able to transfer the knowledge generated in one environment to the others, in a continuous learning process.

One of the limitations of this study is that is not possible to consider every ergonomist thinks and makes decisions in the same way, but this study allows to analyze from a metacognitive experience how to modify systems.

5 Conclusion

Using cognitive and metacognitive processes is possible to identify strategies for minimizing the risk of patients building safer medication management systems.

Acknowledgements My acknowledgments to Dr. Lilian Parada, my master's in education thesis Director at Pontificia Universidad Javeriana, for giving me all the input about metacognition and her empathy about medication safety issues.

To Dr. Brian Edwards, for showing me the Human Factors and Ergonomics science, and give a new way to see the world of medication safety.

To Dr. Carlos Aceves for his support in this process.

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