International Journal of Industrial Ergonomics 49 (2015) 131–143

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Micro- and macroergonomic changes in mental workload and medication safety following the implementation of new health IT

Richard J. Holden [a,*], Roger L. Brown [b], Matthew C. Scanlon [c], A. Joy Rivera [d], Ben-Tzion Karsh [e,†]

[a] Departments of Medicine and Biomedical Informatics, Vanderbilt University, Nashville, TN, United States
[b] Clinical Health Science, School of Nursing, University of Wisconsin-Madison, Madison, WI, United States
[c] Department of Pediatrics, Division of Critical Care, Medical College of Wisconsin, Wauwatosa, WI, United States
[d] Department of Industrial Engineering, Clemson University, Clemson, SC, United States
[e] Department of Industrial & Systems Engineering, University of Wisconsin-Madison, Madison, WI, United States

ARTICLE INFO

Article history:
Received 28 April 2012
Received in revised form
9 April 2013
Accepted 8 April 2014
Available online 15 August 2014

Keywords:
Health information technology
Bar coded medication administration
Macroergonomics
Mental workload
Medication safety
Nursing

ABSTRACT

Health information technology (IT) is a promising way to achieve safer medication management in the delivery of healthcare. However, human factors/ergonomics dictates that in order to make the complex, cognitive work of healthcare delivery safer, health IT must properly support human cognition. This means, for example, that new health IT must reduce, not increase, workload during safety-critical tasks. The present study was the first to quantitatively assess the short- and long-term impact of bar coded medication administration (BCMA) IT on nurses' mental workload as well as on perceived medication safety. One-hundred seventy registered nurses across 3 dissimilar clinical units at an academic, freestanding pediatric hospital in the Midwest US participated in surveys administered before, 3 months after, and 12 months after the hospital implemented BCMA. Nurses rated their external mental workload (interruptions, divided attention, being rushed) and internal mental workload (concentration, mental effort) during medication administration tasks as well as the likelihood of each of three medication safety events: medication administration errors, medication errors on the clinical unit, and clinical unit-level adverse drug events. Clinical unit differences were assessed. Findings generally confirmed the hypothesis that external but not internal mental workload was associated with the perceived likelihood of a medication safety event. Comparisons of mental workload from pre- to post-BCMA revealed statistically significant changes in the critical care unit only. Medication safety appeared to improve over the long term in the hematology/oncology unit only. In the critical care and medical/surgical units, medication safety exhibited short-term improvements that were eliminated over time. Changes in mental workload and medication safety, two classically microergonomic constructs, were deeply embedded in macroergonomic phenomena. These included the fit between the BCMA system and the nature of nursing work, the process of BCMA implementation, and BCMA interactions with concurrent changes occurring in the hospital. Findings raise questions about achieving sustainable performance improvement with health IT as well as the balance between micro- and macroergonomic approaches to studying technology change.

Relevance to industry: Designers must consider how technology changes cognitive work, including mental workload. Hospitals and other implementers of technology must ensure that new technology fits its users, their tasks, and the context of use, which may entail tailoring implementation, for example, to specific clinical units. Evaluators must look over time to assess both changes in cognitive work and implementation issues. Healthcare practitioners must also recognize that new technology means a complex transformation to an already complex sociotechnical system, which calls for a macroergonomic approach to design and analysis.

* Corresponding author. Center for Research and Innovation in Systems Safety, Vanderbilt University Medical Center, 733 Medical Arts Building, 1211 21st Avenue S, Nashville, TN 37212, United States. Tel.: +1 615 936 4343; fax: +1 615 936 7373.
E-mail address: richard.holden@vanderbilt.edu (R.J. Holden).
† Deceased.

http://dx.doi.org/10.1016/j.ergon.2014.04.003
0169-8141/

"The effects of automation on … workload can vary, and will depend greatly on the extent to which key human factors issues are considered during the design of the automated system."

Kantowitz and Campbell, 1996.

1. Introduction

Health information technology (IT) is a promising way to achieve safer medication management in the delivery of healthcare (Bates, 2000; Bates et al., 2001; Bates and Gawande, 2003). In particular, bar coded medication administration (BCMA) systems can potentially reduce errors during the medication administration process and related adverse drug events (ADEs) (Poon et al., 2010). However, human factors/ergonomics dictates that in order to make the complex, cognitive work of healthcare delivery safer, technology such as BCMA must properly support human cognition (Holden, 2011; Karsh, 2009; Karsh et al., 2006; Lawler et al., 2011; Stead and Lin, 2009). A common human factors consideration for cognitive support is mental workload, or the balance between the cognitive demands of a particular task and the cognitive capacity of workers performing the task (Tsang and Vidulich, 2006).

As implied in the opening quote, human factors research in aviation, transportation, nuclear power, and other industries shows that technology, when properly designed and implemented, supports cognition by reducing unnecessary mental workload and distractions and allowing its users to concentrate on performance- and safety-critical tasks (Cuevas et al., 2007; Harris et al., 1995). "Clumsy" technology, on the other hand, hampers cognitive work by increasing workload during critical periods and reducing workload during less critical, already low-workload periods (Bainbridge, 1983; Sarter et al., 1997; Wiener, 1989). These unwanted mental workload consequences of technology, along with other problems such as overreliance on technology (Sheridan and Parasuraman, 2006) and workers being left "out of the loop" during automated periods of work (Endsley and Kiris, 1995) can jeopardize safety (Kantowitz and Campbell, 1996; Sheridan, 2002).

It remains to be seen what impact BCMA systems have on the mental workload of their primary users, i.e., nurses, during medication administration. In their qualitative study, Patterson et al. (2002) showed that new BCMA technology can indeed have unwanted side effects on mental workload, particularly by introducing additional demands during already high workload periods. At the same time, nurses in that study over time developed adaptive, though sometimes risky, strategies to cope with workload changes. This and other findings that healthcare professionals adapt when faced with safety-threatening changes, such as suboptimal mental workload (Patterson et al., 2006) highlight the need to study BCMA-related changes not only immediately after system implementation but also after workers have had an opportunity to adjust.

Accordingly, this study's central objective was to quantitatively assess the impact of a BCMA system on perceived mental workload during medication administration both in the short and long term. To our knowledge, this is the first study to quantitatively assess changes in mental workload over time following the implementation of any health IT—changes that could have major implications for medication safety. A secondary objective was to examine changes in perceived medication safety following BCMA implementation. Several existing studies report the medication safety benefits of BCMA (Poon et al., 2006, 2010; Sakowski et al., 2008) though some show that these benefits are not universal (Helmons et al., 2009; Paoletti et al., 2007). It is possible that safety benefits depend partially on whether BCMA decreases or increases nurses' mental workload during medication administration.

1.1. Mental workload and medication safety

Mental workload is a well-studied human factors phenomenon that has been shown to influence performance and safety outcomes outside of healthcare (Hancock et al., 1995; Tsang and Vidulich, 2006) and in healthcare settings such as anesthesiology (Gaba and Lee, 1990; Weinger et al., 2004), pediatric nursing (Holden et al., 2011b), pharmacy (Flynn et al., 1999; Grasha, 2002; Holden et al., 2010), emergency medicine (France et al., 2005), and telemedicine (Boultinghouse et al., 2007).

Findings from two recent studies (Holden et al., 2010; Holden et al., 2011b) lead us to propose two types of mental workload related to medication management:

- *External mental workload*: interruptions, divided attention, and being rushed during medication management tasks.
- *Internal mental workload*: requirements for concentration and mental effort during medication management tasks.

We recently reported that external mental workload was strongly and positively associated with the perceived likelihood of medication administration errors in six pediatric hospital nursing units (Holden et al., 2011b) and with the perceived likelihood of medication dispensing errors and ADEs in two pediatric hospital pharmacies (Holden et al., 2010). In contrast, internal mental workload (i.e., concentration and effort) was not associated with perceived medication safety event likelihood and perhaps was even beneficial for medication safety and employee well-being. With respect to health IT for medication management, those findings suggest that (a) systems that decrease rather than increase *external* mental workload would be desirable and (b) systems that decrease *internal* mental workload should be approached with caution.

1.2. Study objectives and specific research questions

The central objective of this study was to investigate the short- and long-term impact of point-of-care BCMA technology on nurses' mental workload during medication administration. We pursued this objective by answering three research questions (RQs). A fourth RQ was concerned with the secondary objective of assessing the impact of BCMA on medication safety. Below, each research question is presented and discussed in detail.

RQ1: How are nurses' external and internal mental workload related to the perceived likelihood of medication safety events (errors, adverse events)?

Addressing this question helps to establish the importance of mental workload with respect to medication safety and justifies measuring BCMA-related changes in mental workload. To answer this question, we looked at associations between nurses' self-reported mental workload and the perceived likelihood of three types of medication safety events: medication administration errors, unit-level medication errors, and unit-level ADEs. We modeled these associations over three time periods. Based on findings in our two previous studies, we hypothesized that external mental workload, but not internal mental workload, would be positively associated with perceived medication safety event likelihood.

RQ2: How does nurses' mental workload change following BCMA implementation in the short and long term?