Applied Ergonomics 85 (2020) 103077

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: http://www.elsevier.com/locate/apergo

It's time to bring human factors to primary care policy and practice

John W. Beasley[a,b,c,*], Richard J. Holden[a,e], Erkin Ötleş[a,f], Lee A. Green[a,d], Linsey M. Steege[a,g], Tosha B. Wetterneck[a,b,c]

[a] International Collaborative to Improve Primary Care Through Industrial and Systems Engineering (I-PrACTISE), USA
[b] University of Wisconsin School of Medicine and Public Health, USA
[c] University of Wisconsin Department of Industrial and Systems Engineering, USA
[d] University of Alberta Department of Family Medicine, USA
[e] Indiana University School of Medicine, USA
[f] University of Michigan Medical School and College of Engineering, USA
[g] University of Wisconsin School of Nursing, USA

ARTICLE INFO

Keywords:
Primary care
Human factors
Health information technology

ABSTRACT

Primary health care is a complex, highly personal, and non-linear process. Care is often sub-optimal and professional burnout is high. Interventions intended to improve the situation have largely failed. This is due to a lack of a deep understanding of primary health care. Human Factors approaches and methods will aid in understanding the cognitive, social and technical needs of these specialties, and in designing and testing proposed innovations. In 2012, Ben-Tzion Karsh, Ph.D., conceived a transdisciplinary conference to frame the opportunities for research human factors and industrial engineering in primary care. In 2013, this conference brought together experts in primary care and human factors to outline areas where human factors methods can be applied. The results of this expert consensus panel highlighted four major research areas: Cognitive and social needs, patient engagement, care of community, and integration of care. Work in these areas can inform the design, implementation, and evaluation of innovations in Primary Care. We provide descriptions of these research areas, highlight examples and give suggestions for future research.

1. It's time to bring human factors to primary care policy and practice

> Ms. A. comes in for a scheduled 15-min visit, accompanied by her husband. The nurse tells me that as Ms. A. was being prepared for the visit that she broke down in tears, fearful that she would have to leave her home due to health problems. She was recently discharged from the hospital, but a summary of the hospital stay is not available. She has kidney failure and is on dialysis. She also has diabetes, limited vision, coronary artery disease, osteoarthritis and depression. Today, she is concerned about her dizziness. She is on 8 different medications, and I'm searching the electronic health record to figure out when the medication doses were changed, which is not at all clear. Also, I am running 30 minutes behind schedule already as another patient of mine had to be sent to the hospital. As I re-order a medication for Ms. A., a medication alert fires informing me of a possible allergy – to a medication which she has already tolerated well! At the end of the visit, as I prepare to leave the room, she mentions that she is concerned that her husband has memory loss. He angrily denies this.

The above vignette, taken from actual Family Medicine clinic visits, is one of countless illustrations of the issues in primary care to which human factors (HF) and related disciplines can be applied. The example is replete with concepts amenable to HF study and intervention but overlooked by most primary care researchers, clinicians, and policy makers: mental workload, decision making under uncertainty and time pressure, team communication, usability, and human-technology interaction, to name a few. In this paper, we describe the challenges faced by primary care, argue for the value of applying HF to primary care, and highlight opportunities for HF researchers and practitioners.

* Corresponding author. University of Wisconsin School of Medicine and Public Health, Department of Family Medicine and Community Health, 1100 Delaplaine Court, Madison, WI, 53715, USA.
E-mail address: jbeasley@wisc.edu (J.W. Beasley).

https://doi.org/10.1016/j.apergo.2020.103077
Received 10 December 2018; Received in revised form 4 February 2020; Accepted 11 February 2020
Available online 19 February 2020

2. What makes primary care so challenging?

Primary care is essential for a healthy population (Starfield et al., 2005) and is the most utilized type of care(Green et al., 2001). However, there is general agreement that the primary care delivery system is in deep trouble, with suboptimal care, rising levels of burnout among clinicians, and no consensus on the remedy(Bodenheimer et al., 2009). The challenge for the primary care medical specialties (General Internal Medicine, Pediatrics and Family Medicine) is to provide "integrated, accessible health care by clinicians who are accountable for addressing a large majority of personal health care needs, who develop a sustained partnership with patients, and practice in the context of family and the community." (Donaldson et al., 1996) Primary care is both knowledge work and relational work and its delivery is complex. Patients present with multiple problems at each encounter, each requiring individual attention while considering the patient and their problems as a whole (Beasley et al., 2004a,b) (Wetterneck et al., 2011a,b) (Fortin et al., 2005) (Abbo et al., 2008). There is an enormous need for care coordination among members of the primary care team, i.e., physicians, nurses, medical assistants, clerks, etc., and with other sources and settings of care, for example, specialists and hospitals (Pham, O'Malley, Bach, Saiontz-Martinez and Schrag, 2009). Information chaos (Beasley et al., 2011a,b) increases the risk of errors, potentially leading to worse care (Singh et al., 2013). Primary care requires intensive cognitive resources to meet the demands of practice. Not supporting clinician cognitive work poses significant patient and workforce safety risks due to "information chaos". (Beasley et al., 2011a,b).

Interventions to improve the situation are critically needed (Bodenheimer and Sinsky, 2014). Attempted interventions include the patient-centered medical home (PCMH), quality scorecards, and the implementation of health information technology (HIT), particularly Electronic Health Record (EHR) systems. The effectiveness of these interventions is questionable. EHRs in particular have not mitigated the problems (Friedberg et al., 2013). The complex demands of primary care delivery pose many hazards related to EHR use in particular, some of which may be subtle (Sinsky and Beasley, 2013) (Stead and Lin, 2009). Patient-centered workflows are non-linear and place special demands on information systems such as the EHR to support care (Holman et al., 2015). The current use of EHRs leads to disruption of "flow" and diminished patient engagement during the encounter (Csikszentmihalyi and LeFevre, 1989; Toll, 2012; Zheng, Haftel, Hirschl, O'Reilly and Hanauer, 2010) (Sinsky and Beasley, 2013). Clinical decision support functions in the EHR can produce distractions resulting in break-in-task effects, which not only increase the potential for error but may hinder communication and cause professional fatigue, all while failing to have positive impact on patient outcomes(Zheng et al., 2010) (Karsh, 2009) (Moja et al., 2014) (Chisholm et al., 2000). Moreover, the way the EHR is typically implemented, particularly the shunting of clerical tasks to clinicians, has increased physician work after typical work hours (Arndt et al., 2017) and led to burnout (Shanafelt et al., 2016).

In addition to the questionable impacts on patient outcomes of existing interventions, they have paradoxically increased the demand on physicians' time and attention, thus exacerbating the problems of professional dissatisfaction and burnout(Sinsky et al., 2016) (Shanafelt et al., 2016) (Arndt et al., 2017). We argue the main reason for these interventions' failure and adverse unintended consequences is they are not informed by an in-depth understanding of the fundamental realities of primary care(Sinsky et al., 2014). They are "solutions" that are not based on an understanding of the problems but rather are a form of technological determinism resulting in "technogoverance," not higher quality(May et al., 2006) (Rosenbaum, 2015). As we argue below, HF is uniquely able to rectify this situation by meeting the need for an in-depth understanding of primary care and designing solutions that are based on such an understanding.

3. Why does primary care delivery need human factors approaches and methods?

To have optimal systemic change in primary care, an in-depth understanding of primary care is needed. Healthcare professionals subscribe to "evidence-based medicine", the concept that interventions to improve patient health should be scientifically valid, rigorously designed and tested, and found to be safe and efficacious, before being implemented as the standard of care. The same should be demanded for the design of our healthcare systems. As former National Academy of Medicine Director Elias Zerhouni, MD, stated, "Without scientific knowledge, it is hard to have a public health policy that makes sense."" (Zerhouni, 2008) This comment also applies to primary care policy and practice. Our national policies and more local organizational policies require good science.

Furthermore, only recently have healthcare systems recognized the importance of quality of working life of its professionals and the link of system design to professional wellbeing and burnout. In contrast, worker wellbeing has long been a fundamental concern of HF(Dul et al., 2012). Simply put, as care delivery complexity has increased, technology developers, policy makers, and organizations have tried to redesign its systems and processes without HF input. Suboptimal patient, organizational, and professional outcomes have resulted, for nurses as well as physicians (Shanafelt et al., 2016; Wisner et al., 2019) (Tawfik et al., 2018) (Han et al., 2019). HF input can improve system design and improve outcomes. HF can help detect some subtle forms of system design flaws such as the under-use of paper for communication and the promotion of keyboarding for data entry by physicians (Jabr, 2013; Muller and Oppenheimer, 2014).

HF input *has* been incorporated in other areas of healthcare delivery, but to a large degree in acute care and procedure-based settings, e.g., hospitals, operating rooms, and anesthesia procedures. Primary care has had less attention from HF, despite a unique match between HF and the needs and complexity of primary care. HF offers the tools, methods, and theories to develop an in-depth understanding of primary care to characterize the cognitive and relational processes, the real problems, to shape appropriate solutions, and evaluate them for efficacy in the lab and for effectiveness and adverse effects in the real world of practice. A recent review summarizes the potential for HF in health care, albeit with a focus on patient safety (Carayon et al., 2018).

As an example of a potential HF approach to design for clinical decision making, we would highlight the need to understand the basic cognitive processes involved in patient care. Specifically, to provide good, efficient and safe care for patients requires the establishment of Situation Awareness (SA), which consists of understanding what is happening (e.g. data such as what the vital signs are), comprehending the meaning of the data (e.g. assessing if the data deviations are significant), and projecting the future status of the situation (e.g. "Is the heart failure getting worse?"") (Endsley and Jones, 2004). Using HF to analyze cognitive work will lead to strategies to aid in the establishment of effective situation awareness by designing interventions (technical or social) that are effective in reducing the information chaos, decreasing workload and improving safety (Beasley et al., 2011a,b).

Developing an in-depth understanding of primary care delivery requires a multifaceted skillset matching the complexity of primary care — capable of delineating its clinical and social demands (Wetterneck et al., 2011a,b) (Wetterneck et al., 2011a,b), the cognitive (knowledge) work (Drucker, 1959) and workflow (technical work) (Barley and Orr, 1997) of patient encounters(Wetterneck et al., 2011a,b). Primary care must partner with experts on systems in which people, technology, process, and organizations intersect(Beasley et al., 2011a,b) (Holman et al., 2015) (Scott et al., 2008). These experts are found in the field of HF.

4. Human factors, systems engineering and primary care

Industrial and Systems Engineering (ISyE) is a field "concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy". ISyE is divided into several areas, and here we emphasize HF, a sub-discipline of ISyE as well as psychology. HF is of particular relevance to improving primary care delivery because it is human-centered, systems-oriented, and encompasses three domains of system design: physical, cognitive, and organizational.

HF's systems-oriented philosophy states that systems must be designed to support the work of people, rather than designing systems to which people must adapt. This philosophy, along with allied research in, e.g., macrocognition, decision making, and distributed cognition, has been useful in other complex systems such as aviation, nuclear power, and the military (Klein et al., 2001) (Norman, 1988) (Endsley and Jones, 2004). Applied with the input of clinicians, staff, patients, and other stakeholders, HF can guide research, policy, technology development, and system implementation to improve the safety and efficiency of primary care delivery for patients and their caregiver teams. The opportunities for improving primary care are immense – but if, and only if, the interventions are designed based on an in-depth understanding of primary care delivery and are tested for effectiveness and unintended consequences. We describe one transdisciplinary initiative to move in this direction.

5. The International Collaborative to improve primary care through Industrial and Systems Engineering (I-PrACTISE)

In 2000, ISyE experts started working with primary care clinicians as a transdisciplinary research team under the leadership of the late Ben-Tzion Karsh, PhD. At the outset of this transdisciplinary work using HF to understand primary care, initial studies focused on factors impacting workforce satisfaction and commitment to the organization (Beasley et al., 2005; Karsh et al., 2010a,b), medical error reporting (Beasley et al., 2004a,b; Karsh et al., 2006), and the impact of technology use (Karsh et al., 2004) (Karsh et al., 2010a,b). The focus then shifted to research intended to lead to a better understanding of the nature of the work of primary care (Beasley et al., 2011a,b; Holman et al., 2015; Wetterneck et al., 2011a,b). Two textbook chapters resulted (Beasley et al., 2006; Wetterneck et al., 2011a,b).

Dr. Karsh conceived the idea of a transdisciplinary conference bringing together primary care and HF experts but died in 2012 before the conference was held. Through support from the Agency for Healthcare Research and Quality (AHRQ) the International Collaborative to Improve Primary Care Through Industrial and Systems Engineering (I-PrACTISE), was formed to continue the work (I-PrACTISE, 2016).

The first I-PrACTISE conference in April 2013 focused on defining critical areas of investigation for ISyE and HF. Seven workgroups, forming expert consensus panels, were organized around the principles of the Patient Centered Medical Home: Team-Based Care, Coordination and Integration, Health Information Technology (HIT) (Registries and Exchanges), HIT (Clinical Decision Support and Electronic Health Records), Patient Engagement, Access and Scheduling, and Addressing All Health Needs. These groups: (A) Explored critical issues from a primary care perspective and ISyE and HF tools and methods that could address these issues; (B) Generated potential research questions; and (C) Described methods and resources, including other collaborations, needed to conduct this research. A qualitative summary of the group discussions resulted in 118 unique ideas and more than 60 research questions. Most ideas aligned along two dimensions - System Design Factors and Problems and Issues in Primary Care.

Problems and Issues in Primary Care for research:

Cognitive needs
Patient and family engagement
Care of community
Integration and transitions of care

System Design Issues –Three general categories were identified:

Teams and workload distribution
Technology
Policy (governmental and healthcare organizations)

Examples of these, generated by the workgroups, are provided in the text below. Details are available in the I-PrACTISE white paper (Beasley et al., 2013).

6. Opportunities for HF research and application in primary care

Below, we list specific examples, drawn from the expert consensus panels of the 2013 I-PrACTISE conference and resulting White Paper. We identified four Problems and Issues in Primary Care for research either have been or should be addressed across each level of system design (team, technology, policy). This is by no means an exhaustive list and the entries are not mutually exclusive; some overlap is to be expected.

7. Cognitive needs

7.1. Cognitive needs: teams

Team cognition and the resulting team situation awareness (SA) are critical for good, personalized care as well as workforce satisfaction. As teams get larger and communication is more electronic and less face-to-face, issues of the quality of care arise (Mundt et al., 2015, 2016). As one example, HF can help design systems around the need for team cognition using strategies such as Goal Directed Task Analysis (GDTA). GDTA is a technique for determining cognitive work requirements and is specifically designed to study complex cognitive work, including in aviation and the military (Endsley and Jones, 2004). Applied to primary care, GDTA can provide a map of the cognitive work requirements for individuals and teams in this setting to improve the design of the EHR. GDTA focuses on the goals of the care process rather than the specific tasks and is grounded to the cognition needed to establish situation awareness. Future work could address optimal means of communication for team members, and the best ways to support this. (e.g. What architectural changes can best support verbal communication' what is the appropriate use of both electronic and non-electronic communication?)

7.2. Cognitive needs: technology

Displays and screens of patient information need significant improvement. Some medication lists are shown in ways that make assessment of when or why a medication was changed very difficult. There are far better ways to present data to assist in the cognition that supports the development of SA and clinical performance (Belden et al., 2014). One aspect of technology use includes when to <u>not</u> use it. For example, there is evidence that using a keyboard to record information leads to less effective understanding than hand-writing notes and information is sometimes better transmitted using paper rather than screens (Muller and Oppenheimer, 2014) (Jabr, 2013). As noted above, the HF technique of GDTA can inform technology design and use. In the vignette above, the poor display of the medication list caused increased mental workload and increased the chance of error, and the clinical decision support (the allergy alert) was not helpful and added distraction. Future work could involve more laboratory and real-word testing of display modalities to better support the development of team SA and communication.

7.3. Cognitive needs: policy

Current governmental and institutional policies may require input that is of little use but of significant burden to clinicians in the practice setting. These rules may require extensive, but cognitively useless, procedures and documentation (Holman et al., 2018) (Downing et al., 2018). HF can provide guidance about which information is actually needed to support SA and promote efficiency. Future work with HF can help policy makers and organizational leaders to prioritize system design and implementation so that care is improved without being a burden on clinicians and other team members (Cook, 2005).

8. Patient and family engagement

8.1. Patient and family engagement: team

Appropriate HF guided applications of Health Information Technology (HIT) can make it easier for all team members, including those off-site, to have available the basic knowledge that is necessary for relating to the patient – age, family members, medical history. HF can help to balance the need for specific data (e.g. the blood pressure) and the opportunities for autonomy in their interaction with the patient. If policy makers (above) require team members to complete low-value data entry (e.g., "the patient's pain score") open-ended dialogue may suffer. In the vignette above, the ability of the nurse to engage in open-ended dialogue is critical for the clinician to be able to address the patient's most pressing issue. However, the lack of adequate pre-visit planning resulted in the issue of the husband's memory loss coming up at the last moment, making it much more difficult to address. Future work can highlight the best ways for primary care systems to use (or not use) technology to support team and family engagement.

8.2. Patient and family engagement: technology

The appropriate use of HIT in the patient interaction can be improved through good HF research. Evidence shows that when the screen is shared the EHR can become a bridge rather than a barricade (Sinsky and Beasley, 2013) (Patel et al., 2017) (Weiler et al., 2018). Patient portals provide easier access for some patients, but paradoxically may increase the in-clinic workload (Bavafa et al., 2017). Future HF work can help design, study and monitor technological interventions for unintended side effects and mitigate them.

8.3. Patient and family engagement: policy

It is clear that institutional policies can impact patient engagement if, for example, they require excessive attention to the EHR or demand rote protocols to be executed by support staff. HF can help inform Institutional policies that help the clinician dis-engage from the screen (e.g., less ordering and clerical tasks) including scribes and clinical coaches and/or dictation in the presence of the patient. This can help the clinician engage more fully with the patient(Sinsky and Beasley, 2013) (Asan et al., 2014) (Montague and Asan, 2012) (Beasley and Danford, 2015). Future work can provide a HF informed understanding of the impact of policies on patient and family engagement will help design appropriate solutions.

9. Care of community

9.1. Care of community: team

HF can define the requirements for information about the needs of the population served, and the community resources available to a clinic to help the team provide better care. In the vignette above, the availability of home health resources could help the patient meet her goal of staying at home. Additionally, the clinical team itself can be considered as a community, and effective communication based on HF principles will facilitate care (Mundt et al., 2015) (Mundt and Zakletskaia, 2016). (See also below.) Future HF work will help design systems to foster team cohesiveness and promote both better outcomes and work force satisfaction.

9.2. Care of community: technology

The use of population-based medicine can be facilitated by well-designed HIT systems. A notable example of this is the use of EHR databases by a pediatrician in Flint, Michigan who noticed an increasing incidence in lead exposure among her patients (Gomez et al., 2018). Future work with experts in data analysis can help identify "hot spots" in patient care and give direction as to ways to address these.

9.3. Care of community: policy

The PCMH was proposed to be a way to improve the quality of care for individuals and communities.(Agency for Healthcare Research & Quality) Unfortunately, the evidence that PCMH implementation really improves outcomes is not entirely clear(Shi et al., 2015). While the PCMH model provides a list of system elements needed for optimal care, organizations that simply show evidence of these system elements without integrating them together into care processes have not realized true care transformation and improvement in patient outcomes. Integration and change are not easy. Future HF work will help to inform policy makers as to the opportunities and roadblocks to community care – and help to avoid pitfalls associated with poorly designed and evaluated policies.

10. Integration and transitions of care

10.1. Integration and transitions of care: team

Team work is complex and the need for communication is paramount. Appropriate use of technology may help with this. (Coleman et al., 2003; Hesselink et al., 2012) However, there can be adverse consequences if electronic communication pushes out verbal, face-to face communication including time consuming asynchronous electronic communication. In many situations "synchronous analogue communication" – to wit, talking together – may improve outcomes (Hess et al., 2010) (Mundt et al., 2016) (Mundt and Swedlund, 2016). Attention to designing clinics to facilitate team dialogue (co-location) will help (Sinsky et al., 2013). Future HF work can better inform the design of systems to integrate care.

10.2. Integration and transitions of care: technology

The change in care patterns from the days when one physician cared for his/her patients in all settings (office, hospital, nursing home) to the evolving model of physicians working in just one care setting (e.g., the office or hospital) has increased the need for effective communication across these transitions of care. Information chaos reigns supreme in transitions. Information is missing due to the lack of interoperability between different EHRs. Inadequate summarization of key issues and handoffs of this information to the correct people is a recurrent theme among frustrated clinicians. Designing EHR systems to assure effective interoperability is a critical need. (Lane et al., 2018). Future work using HF methods lead to better design (and use) of technology to decrease the risks associated with transitions while improving the quality of care.

10.3. Integration and transitions of care: policy

Transitions of care can be hazardous as not only is factual information lost but nuances valuable to establishing the primary care clinician's SA may be missing. HF can help to define what the clinicians' cognitive needs are and the best ways to communicate when transitions of care occur. The communications can be electronic, on paper or verbal, but they must occur and be appropriate to the situation. As noted above, verbal dyadic communication should be facilitated. Policies that lead to the collection of low-value data can make integration of data and accessing data more difficult (Holman et al., 2018). Future HF research can help policy makers balance the need for quantitative information with more nuanced qualitative and relational information.

11. Discussion and conclusions

We have highlighted the need to have an in-depth understanding, informed by HF, of the organizational, social, cognitive, and physical elements of primary care systems. In addition to the opportunities identified during the 2013 expert consensus conference, HF has the opportunity to guide the applications of newer technologies within primary care. For example, there has been increasing interest in applying machine learning and augmented intelligence to primary care. There is a pressing need for HF researchers joined with primary care experts to guide these efforts. Issues of model explanation and interpretability are perhaps the most pressing, as they impact physician trust and acceptance of these tools (Miotto et al., 2018). Additionally, there is the classic issue of automation: If decision making is passed to automated systems how do we design systems that facilitate higher-level thought and management of patients in primary care? Moreover, additional sources of important clinical data include systems for remote sensing and transmission of patient data (Cornet and Holden, 2018). These data can be acted on either directly or with the help of augmented intelligence.

Attention to the above system design issues as applied to the problems in primary care will be a useful approach to improving care outcomes for patients and healthcare teams alike. We propose that ISyE and, in particular HF, are essential disciplines to help to accomplish this. This is transdisciplinary work, utilizing expertise from the primary care specialties as well as ISyE and HF. Other disciplines can, and should, be involved (e.g. nursing, pharmacy, anthropology, communications, and more). We recommend that institutions expand upon the work of I-PrACTISE colleagues and develop formal collaborations both at local institutions and nationally. These collaborations should develop formal educational contacts with legislators, healthcare organizations (policies and the implementation of technology), schools (education of HF researchers), and clinicians (appropriate use of technology). The application of HF to primary care will improve patient outcomes while reducing the problems that clinicians and their teams face.

11.1. The vignette revisited after HF-designed system improvement

MS A. comes in for a scheduled 30-min visit, accompanied by her husband. She was recently hospitalized, and I had the chance to communicate with the physicians caring for her multiple times during her stay and at discharge. I gave input on needed medication changes to address her problems based on knowledge of her past treatment plans and medication use over the past 30 years. The brief hospital discharge summary was viewable on the day of discharge and my nurse called the patient at home to check in and set the agenda for today's visit. After the call we huddled and, knowing that she was fearful about leaving her home, we extended her appointment time with me and arranged to have our nurse case manager in clinic see her as well, who has seen her in the past. In addition, the nurse scheduled an appointment for her husband for the following week because of concerns of mild memory loss, noting that he was due for his 6 month check anyway. Because I had another patient emergency to take care of, I saw Ms. A briefly and gave a warm handoff to my nurse case manager while I finished up with the patient emergency. Afterwards when I saw Ms. A, my Medical Assistant accompanied me during the visit. She was also involved with nurse case manager visit and shared information about what was shared during that time. I had all the information I needed about her hospitalization and it was clear which medications were changed, added and stopped. When Ms. A mentioned mild dizziness I was able to attribute this to a new medication trial and we stopped this medication and started an alternative that the cardiologist in the hospital had recommended in the event that she needed to change medications.

Declaration of competing interest

None Declared.

Acknowledgements

"This research was supported by grant number 1R13HS023028, 1R13HS022170 and 1R01HS022505 from the Agency for Healthcare Research and Quality. The contents of this product are solely the responsibility of Drs. Beasley and Wetterneck, and the Board of Regents of the University of Wisconsin and do not necessarily represent the official views of or imply endorsement by AHRQ or the U.S. Department of Health and Human Services."

The authors acknowledge the help of Christine A. Sinsky, MD, in reviewing and commenting on drafts of this publication. We thank Laura Cruz for her editorial assistance. Finally, we give heartfelt recognition to the late Professor Ben-Tzion Karsh, PhD, for his critically important leadership in creating the collaboration between Industrial and Systems Engineering, Human Factors and the Primary Care specialties.

References

Agency for Healthcare Research & Quality. Defining the PCMH. Retrieved from. https://pcmh.ahrq.gov/page/defining-pcmh.

Abbo, E.D., Zhang, Q., Zelder, M., Huang, E.S., 2008. The increasing number of clinical items addressed during the time of adult primary care visits. J. Gen. Intern. Med. 23 (12), 2058–2065. https://doi.org/10.1007/s11606-008-0805-8.

Arndt, B.G., Beasley, J.W., Watkinson, M.D., Temte, J.L., Tuan, W.J., Sinsky, C.A., Gilchrist, V.J., 2017. Tethered to the EHR: primary care physician workload assessment using EHR event log data and time-motion observations. Ann. Fam. Med. 15 (5), 419–426. https://doi.org/10.1370/afm.2121.

Asan, O., Smith, P.D., Montague, E., 2014. More screen time, less face time - implications for EHR design. J. Eval. Clin. Pract. https://doi.org/10.1111/jep.12182.

Barley, S.R., Orr, J.E., 1997. Between Craft and Science: Technical Work in U.S. Settings. Cornell University Press, Ithaca, N.Y.

Bavafa, H., Hitt, L.M., Terwiesch, C., 2017. The impact of E-visits on visit frequencies and patient health: evidence from primary care. Manag. Sci. https://doi.org/10.1287/mnsc.2017.2900, 0(0), null.

Beasley, J.W., Danford, C., 2015. Dictating your notes during the patient visit. Retrieved from. http://www.fammed.wisc.edu/our-department/media/795/dictating.

Beasley, J.W., Escoto, K.H., Karsh, B.T., 2004a. Design elements for a primary care medical error reporting system. Wmj 103 (1), 56–59.

Beasley, J.W., Hankey, T.H., Erickson, R., Stange, K.C., Mundt, M., Elliott, M., et al., 2004b. How many problems do family physicians manage at each encounter? A WReN study. Ann. Fam. Med. 2 (5), 405–410.

Beasley, J.W., Karsh, B.T., Hagenauer, M.E., Marchand, L., Sainfort, F., 2005. Quality of work life of independent vs employed family physicians in Wisconsin: a WReN study. Ann. Fam. Med. 3 (6), 500–506. https://doi.org/10.1370/afm.369.

Beasley, J.W., Hamilton-Escoto, K., Karsh, B., 2006. Human factors in primary care. In: Carayon, P. (Ed.), Handbook of Human Factors and Ergonomics in Patient Safety. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 921–936.

Beasley, J.W., Holden, R.J., Sullivan, F., 2011a. Electronic health records: research into design and implementation. Br. J. Gen. Pract. 61 (591), 604–605. https://doi.org/10.3399/bjgp11X601244.

Beasley, J.W., Wetterneck, T.B., Temte, J., Lapin, J.A., Smith, P., Rivera-Rodriguez, A.J., Karsh, B.T., 2011b. Information chaos in primary care: implications for physician performance and patient safety. J. Am. Board Fam. Med. 24 (6), 745–751. https://doi.org/10.3122/jabfm.2011.06.100255.

Beasley, J.W., Carayon, P., Smith, M.A., 2013. Improving the quality and efficiency of primary care through industrial and systems engineering – a white paper. Retrieved from. http://www.fammed.wisc.edu/sites/default/files//webfm-uploads/documents/research/i-practise/i-practise-white-paper.pdf.

Belden, J., Patel, J., Lowrance, N., Plaisant, C., Koopman, R., Moore, J., 2014. Inspired EHRs: designing for clinicians. Retrieved from. http://inspiredehrs.org/.

Bodenheimer, T., Sinsky, C., 2014. From triple to quadruple aim: care of the patient requires care of the provider. Ann. Fam. Med. 12 (6), 573–576. https://doi.org/10.1370/afm.1713.

Bodenheimer, T., Chen, E., Bennett, H.D., 2009. Confronting the growing burden of chronic disease: can the U.S. health care workforce do the job? Health Aff. 28 (1), 64–74. https://doi.org/10.1377/hlthaff.28.1.64.

Carayon, P., Wooldridge, A., Hose, B.Z., Salwei, M., Benneyan, J., 2018. Challenges and opportunities for improving patient safety through human factors and systems engineering. Health Aff. 37 (11), 1862–1869. https://doi.org/10.1377/hlthaff.2018.0723.

Chisholm, C.D., Collison, E.K., Nelson, D.R., Cordell, W.H., 2000. Emergency department workplace interruptions: are emergency physicians 'interrupt-driven' and 'multitasking'? Acad. Emerg. Med. 7 (11), 1239–1243.

Coleman, E.A., Boult, C., American Geriatrics Society Health Care Systems, C., 2003. Improving the quality of transitional care for persons with complex care needs. J. Am. Geriatr. Soc. 51 (4), 556–557.

Cook, R.I., 2005. Lessons from the war on cancer: the need for basic research on safety. J. Patient Saf. 1 (1), 7–8.

Cornet, V.P., Holden, R.J., 2018. Systematic review of smartphone-based passive sensing for health and wellbeing. J. Biomed. Inf. 77, 120–132. https://doi.org/10.1016/j.jbi.2017.12.008.

Csikszentmihalyi, M., LeFevre, J., 1989. Optimal experience in work and leisure. J. Pers. Soc. Psychol. 56 (5), 815–822.

Donaldson, M., Yordy, K., Lohr, K., 1996. Primary Care America's Health in a New Era. National Academy Press, Washington, D.C.

Downing, N.L., Bates, D.W., Longhurst, C.A., 2018. Physician burnout in the electronic health record era: are we ignoring the real cause? Ann. Intern. Med. 169 (1), 50–51. https://doi.org/10.7326/M18-0139.

Drucker, P.F., 1959. The Landmarks of Tomorrow. Harper and Row, New York.

Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W.S., et al., 2012. A strategy for human factors/ergonomics: developing the discipline and profession. Ergonomics 55 (4), 377–395. https://doi.org/10.1080/00140139.2012.661087.

Endsley, M.R., Jones, D.G., 2004. Designing for Situation Awareness: an Approach to User-Centered Design, second ed. ed. CRC Press - Taylor and Francis Group, Boca Raton, FL.

Fortin, M., Bravo, G., Hudon, C., Vanasse, A., Lapointe, L., 2005. Prevalence of multimorbidity among adults seen in family practice. Ann. Fam. Med. 3 (3), 223–228.

Friedberg, M.W., Chen, P.G., Van Busum, K.R., Aunon, F.M., Caloyeras, J.P.S.M., et al., 2013. Factors Affecting Physician Professional Satisfaction and Their Implications for Patient Care, Health Systems and Health Policy. Retrieved from. http://www.rand.org/pubs/research_reports/RR439.html.

Gomez, H.F., Borgialli, D.A., Sharman, M., Shah, K.K., Scolpino, A.J., Oleske, J.M., Bogden, J.D., 2018. Blood lead levels of children in Flint, Michigan: 2006-2016. J. Pediatr. 197, 158–164. https://doi.org/10.1016/j.jpeds.2017.12.063.

Green, L.A., Fryer Jr., G.E., Yawn, B.P., Lanier, D., Dovey, S.M., 2001. The ecology of medical care revisited. N. Engl. J. Med. 344 (26), 2021–2025. https://doi.org/10.1056/NEJM200106283442611.

Han, S., Shanafelt, T.D., Sinsky, C.A., Awad, K.M., Dyrbye, L.N., Fiscus, L.C., et al., 2019. Estimating the attributable cost of physician burnout in the United States. Ann. Intern. Med. https://doi.org/10.7326/M18-1422.

Hess, D.R., Tokarczyk, A., O'Malley, M., Gavaghan, S., Sullivan, J., Schmidt, U., 2010. The value of adding a verbal report to written handoffs on early readmission following prolonged respiratory failure. Chest 138 (6), 1475–1479. https://doi.org/10.1378/chest.09-2140.

Hesselink, G., Schoonhoven, L., Barach, P., Spijker, A., Gademan, P., Kalkman, C., et al., 2012. Improving patient handovers from hospital to primary care: a systematic review. Ann. Intern. Med. 157 (6), 417–428. https://doi.org/10.7326/0003-4819-157-6-201209180-00006.

Holman, G.T., Beasley, J.W., Karsh, B.T., Stone, J.A., Smith, P.D., Wetterneck, T.B., 2015. The myth of standardized workflow in primary care. J. Am. Med. Inf. Assoc. https://doi.org/10.1093/jamia/ocv107.

Holman, G.T., Waldren, S.E., Beasley, J.W., Cohen, D.J., Dardick, L.D., Fox, C.H., et al., 2018. Meaningful use's benefits and burdens for US family physicians. J. Am. Med. Inf. Assoc. 25 (6), 694–701. https://doi.org/10.1093/jamia/ocx158.

I-PrACTISE, 2016. Improving Primary Care through Industrial and Systems Engineering. Retrieved from. http://www.fammed.wisc.edu/i-practise/.

Jabr, F., 2013. Why the brain prefers paper. Sci. Am. 309 (5), 48–53.

Karsh, B.-T., 2009. Clinical Practice Improvement and Redesign: How Change in Workflow Can Be Suipported by Clinical Decision Support. Agency for Healthcare Research and Quality, Rockville, MD. Retrieved from. https://healthit.ahrq.gov/sites/default/files/docs/page/09-0054-EF-Updated_0.pdf.

Karsh, B.T., Beasley, J.W., Hagenauer, M.E., 2004. Are electronic medical records associated with improved perceptions of the quality of medical records, working conditions, or quality of working life? Behav. Inf. Technol. 23 (5), 327–335. https://doi.org/10.1080/01449290410001693845.

Karsh, B.T., Escoto, K.H., Beasley, J.W., Holden, R.J., 2006. Toward a theoretical approach to medical error reporting system research and design. Appl. Ergon. 37 (3), 283–295. https://doi.org/10.1016/j.apergo.2005.07.003.

Karsh, B.T., Beasley, J.W., Brown, R.L., 2010a. Employed family physician satisfaction and commitment to their practice, work group, and health care organization. Health Serv. Res. 45 (2), 457–475. https://doi.org/10.1111/j.1475-6773.2009.01077.x.

Karsh, B.T., Weinger, M.B., Abbott, P.A., Wears, R.L., 2010b. Health information technology: fallacies and sober realities. J. Am. Med. Inf. Assoc. 17 (6), 617–623. https://doi.org/10.1136/jamia.2010.005637.

Klein, K.J., Conn, A.B., Sorra, J.S., 2001. Implementing computerized technology: an organizational analysis. J. Appl. Psychol. 86 (5), 811–824.

Lane, S.R., Miller, H., Ames, E., Garber, L., Kibbe, D.C., Schneider, J.H., et al., 2018. Consensus statement: feature and function recommendations to optimize clinician usability of direct interoperability to enhance patient care. Appl. Clin. Inf. 9 (1), 205–220. https://doi.org/10.1055/s-0038-1637007.

May, C., Rapley, T., Moreira, T., Finch, T., Heaven, B., 2006. Technogovernance: evidence, subjectivity, and the clinical encounter in primary care medicine. Soc. Sci. Med. 62 (4), 1022–1030. https://doi.org/10.1016/j.socscimed.2005.07.003.

Miotto, R., Wang, F., Wang, S., Jiang, X., Dudley, J.T., 2018. Deep learning for healthcare: review, opportunities and challenges. Briefings Bioinf. 19 (6), 1236–1246. https://doi.org/10.1093/bib/bbx044.

Moja, L., Kwag, K.H., Lytras, T., Bertizzolo, L., Brandt, L., Pecoraro, V., et al., 2014. Effectiveness of computerized decision support systems linked to electronic health records: a systematic review and meta-analysis. Am. J. Publ. Health 104 (12), e12–22. https://doi.org/10.2105/AJPH.2014.302164.

Montague, E., Asan, O., 2012. Trust in technology-mediated collaborative health encounters: constructing trust in passive user interactions with technologies. Ergonomics 55 (7), 752–761. https://doi.org/10.1080/00140139.2012.663002.

Muller, P.A., Oppenheimer, D.M., 2014. The pen is MIghtier than the keyboard: advantages of longhand over laptop note taking. Psychol. Sci. 25, 1159–1168.

Mundt, M.P., Swedlund, M.P., 2016. A human factors systems approach to understanding team-based primary care: a qualitative analysis. Fam. Pract. 33 (6), 721–726. https://doi.org/10.1093/fampra/cmw093.

Mundt, M.P., Zakletskaia, L.I., 2016. Electronic health record messaging and quality of care for type 2 diabetes patients in primary care. Stud. Health Technol. Inf. 225, 815–816.

Mundt, M.P., Gilchrist, V.J., Fleming, M.F., Zakletskaia, L.I., Tuan, W.J., Beasley, J.W., 2015. Effects of primary care team social networks on quality of care and costs for patients with cardiovascular disease. Ann. Fam. Med. 13 (2), 139–148. https://doi.org/10.1370/afm.1754.

Mundt, M.P., Agneessens, F., Tuan, W.J., Zakletskaia, L.I., Kamnetz, S.A., Gilchrist, V.J., 2016. Primary care team communication networks, team climate, quality of care, and medical costs for patients with diabetes: a cross-sectional study. Int. J. Nurs. Stud. 58, 1–11. https://doi.org/10.1016/j.ijnurstu.2016.01.013.

Norman, D.A., 1988. The Design of Everyday Things. Doubleday, New York.

Patel, M.R., Vichich, J., Lang, I., Lin, J., Zheng, K., 2017. Developing an evidence base of best practices for integrating computerized systems into the exam room: a systematic review. J. Am. Med. Inf. Assoc. 24 (e1), e207–e215. https://doi.org/10.1093/jamia/ocw121.

Pham, H.H., O'Malley, A.S., Bach, P.B., Saiontz-Martinez, C., Schrag, D., 2009. Primary care physicians' links to other physicians through Medicare patients: the scope of care coordination. Ann. Intern. Med. 150 (4), 236–242 doi:150/4/236 [pii].

Rosenbaum, L., 2015. Transitional chaos or enduring harm? The EHR and the disruption of medicine. N. Engl. J. Med. 373 (17), 1585–1588. https://doi.org/10.1056/NEJMp1509961.

Scott, J.G., Cohen, D., Dicicco-Bloom, B., Miller, W.L., Stange, K.C., Crabtree, B.F., 2008. Understanding healing relationships in primary care. Ann. Fam. Med. 6 (4), 315–322. https://doi.org/10.1370/afm.860.

Shanafelt, T.D., Dyrbye, L.N., Sinsky, C., Hasan, O., Satele, D., Sloan, J., West, C.P., 2016. Relationship between clerical burden and characteristics of the electronic environment WIth physician burnout and professional satisfaction. Mayo Clin. Proc. 1–13 (in press).

Shi, L., Lock, D.C., Lee, D.C., Lebrun-Harris, L.A., Chin, M.H., Chidambaran, P., et al., 2015. Patient-centered Medical Home capability and clinical performance in HRSA-supported health centers. Med. Care 53 (5), 389–395. https://doi.org/10.1097/MLR.0000000000000331.

Singh, H., Giardina, T.D., Meyer, A.N., Forjuoh, S.N., Reis, M.D., Thomas, E.J., 2013. Types and origins of diagnostic errors in primary care settings. JAMA Intern. Med. 173 (6), 418–425. https://doi.org/10.1001/jamainternmed.2013.2777.

Sinsky, C.A., Beasley, J.W., 2013. Texting while doctoring: a patient safety hazard. Ann. Intern. Med. 159 (11), 782–783. https://doi.org/10.7326/0003-4819-159-11-201312030-00012.

Sinsky, C.A., Willard-Grace, R., Schutzbank, A.M., Sinsky, T.A., Margolius, D., Bodenheimer, T., 2013. In search of joy in practice: a report of 23 high-functioning primary care practices. Ann. Fam. Med. 11 (3), 272–278. https://doi.org/10.1370/afm.1531.

Sinsky, C.A., Beasley, J.W., Simmons, G.E., Baron, R.J., 2014. Electronic health records: design, implementation, and policy for higher-value primary care. Ann. Intern. Med. 160 (10), 727–728. https://doi.org/10.7326/M13-2589.

Sinsky, C.A., Colligan, L., Li, L., Prgomet, M., Reynolds, S., Goeders, L., et al., 2016. Allocation of physician time in ambulatory practice: a time-motion study in four specialties. Ann. Intern. Med. (in press).

Starfield, B., Shi, L., Macinko, J., 2005. Contribution of primary care to health systems and health. Milbank Q. 83 (3), 457–502. https://doi.org/10.1111/j.1468-0009.2005.00409.x.

Stead, W.W., Lin, H.S., 2009. Computational Technology for Effective Health Care: Immediate Steps and Strategic Directions. National Academies Press, Washington, DC.

Tawfik, D.S., Profit, J., Morgenthaler, T.I., Satele, D.V., Sinsky, C.A., Dyrbye, L.N., et al., 2018. Physician burnout, well-being, and work unit safety grades in relationship to reported medical errors. Mayo Clin. Proc. https://doi.org/10.1016/j.mayocp.2018.05.014.

Toll, E., 2012. A piece of my mind. The cost of technology. Jama 307 (23), 2497–2498. https://doi.org/10.1001/jama.2012.4946.

Weiler, D.T., Slatterly, T., Rehman, S.U., Nussbaum, M.A., Chumbler, N.R., Fischer, G.M., Saleeem, J.J., 2018. Ambulatory clinic exam room design with respect to computing devices: a laboratory simulation study. IISE Trans. Occup. Ergon. Hum. Factors 1–30. Press.

Wetterneck, T.B., Lapin, J.A., Karsh, B., Beasley, J.W., 2011a. Human factors and ergonomics in primary care. In: Carayon, P. (Ed.), Handbook of Human Factors and Ergonomics in Patient Safety, second ed. Taylor and Francis, Boca Raton, FL, pp. 763–775. second ed. ed.

Wetterneck, T.B., Lapin, J.A., Krueger, D.J., Holman, G.T., Beasley, J.W., Karsh, B.T., 2011b. Development of a primary care physician task list to evaluate clinic visit workflow. BMJ Qual. Saf. 21 (1), 47–53. https://doi.org/10.1136/bmjqs-2011-000067.

Wisner, K., Lyndon, A., Chesla, C.A., 2019. The electronic health record's impact on nurses' cognitive work: an integrative review. Int. J. Nurs. Stud. 94, 74–84. https://doi.org/10.1016/j.ijnurstu.2019.03.003.

Zerhouni, E., 2008. The value of medical research. NIH MedlinePlus. Retrieved from. http://www.nlm.nih.gov/medlineplus/magazine/issues/summer08/articles/summer08pg2-3.html.

Zheng, K., Haftel, H.M., Hirschl, R.B., O'Reilly, M., Hanauer, D.A., 2010. Quantifying the impact of health IT implementations on clinical workflow: a new methodological perspective. J. Am. Med. Inf. Assoc. 17 (4), 454–461. https://doi.org/10.1136/jamia.2010.004440.