Comparative Review of Research on Health Information Technology in Biomedical Informatics and Human-Computer Interaction

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Abstract. This paper provides a comparative review of literature in Biomedical Informatics (BI) and Human-Computer Interaction (HCI) communities that conducted human-subject studies of health information technology (HIT) to understand the kinds of knowledge these two fields develop and disseminate. We systematically searched 8 databases to retrieve relevant articles published between 2007 and 2016. Articles involving human-subject studies of HIT were eligible for inclusion. Among 1,355 articles identified by the search strategy, 593 articles were selected for final analysis. Text mining techniques were used to cluster the selected articles into five themes, followed by a thematic analysis of randomly selected 3 articles per cluster through which a hierarchical taxonomy of research areas was created. The results illustrate that BI contributes mainly to generating knowledge associated with the use of HIT in clinical settings, while HCI focuses primarily on the design and evaluation of personal healthcare applications. We believe that better understanding and bringing together the strengths of each field's perspectives would yield results that are more generalizable and have greater potential impact in healthcare research.

Keywords: Health information technology · Human-computer interaction · Biomedical informatics

1 Introduction

Health information technology (HIT) has the enormous potential to transform healthcare practices by positively influencing quality, efficiency, and cost-effectiveness of healthcare [33]. However, these efforts have been made in several disjointed research communities, including but not limited to biomedical informatics (BI) and human-computer interaction (HCI). While these fields often pursue mutual goals of improving healthcare, they typically work in separation without established pathways for transfer of knowledge and expertise, as different fields have their own publication venues for disseminating research results that seldom overlap. Therefore, researchers and practitioners in different communities have suffered from lack of opportunities to interact with each other and develop a shared body of knowledge across communities [33].

Researchers in BI and HCI communities can greatly benefit from increased familiarity with the work of the other, as their strengths can complement each other. Furthermore, a shared understanding of the types of knowledge each community provides

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could serve as a basis for cross-disciplinary collaborations that would lead to improved clinical outcomes and to new conceptual, generalizable knowledge. A key issue in developing a shared body of knowledge across different communities is to establish a common ground to understand differing research design, development, and evaluation practices and the inherently contrasting priorities and values of the different fields.

Efforts have been made to increase the interaction among different communities. These efforts have been in the form of workshops, seminars, and social events where researchers and practitioners get together to share and discuss methods, study designs, and findings within communities. A key outcome of these interactions was agreement about the need for greater collaboration among different research communities interested in the design, implementation, and use of HIT to transcend the mutual respect of one another's work [33].

While such effort promotes better understanding of each other's work, it does not provide for a systematic understanding of the differences and commonalities across different research communities. Thus, this study aims to contribute to existing efforts to advance shared understanding through a comparative analysis of published HIT articles in the BI and HCI communities. This paper identifies the distinct characteristics and contributions of HIT research in the fields of BI and HCI to shed light on the opportunities for integrating their perspectives, leveraging their complementary strengths, and developing better research practices for healthcare technology.

We conducted a comparative review of 593 articles from 8 publication venues in BI and HCI. We clustered these articles into five themes using text-mining techniques. Then, 3 articles from each cluster were randomly selected to conduct a thematic analysis through which a hierarchical taxonomy of research topics and contributions was created. The results illustrate that the primary focus of BI is on the clinical contexts that contribute to generating knowledge associated with the use of health information in clinical settings, while HCI focuses primarily on the everyday contexts that contribute to the design and evaluation of personal healthcare applications.

The contribution of this paper is to identify the kinds of knowledge that BI and HCI communities develop and disseminate systematically and comparatively. For people who are already working in the intersection of BI and HCI, there might be nothing much surprising about the findings. However, we believe that it is nonetheless useful to have this analysis done systematically. Furthermore, a categorization of research themes and methods in different communities can help researchers who are unfamiliar with the other community to easily comprehend and acknowledge similarities and differences. We believe that better understanding and bringing together the strengths of each research field's perspectives would yield results that are more generalizable and have greater potential impact in healthcare research.

2 Background

2.1 HIT Research in the HCI Community

HCI is the study of how people interact with computers and to what extent computers are or are not developed for successful interaction with human beings, spanning a

number of disciplines, including computer science, design, psychology, ergonomics, etc. Among a wide range of application domains of HCI studies, healthcare has been one important area of inquiry. Thus, a large body of HCI research has been amassed to understand and enhance the relationships between humans and technology in the context of healthcare.

HCI researchers, however, have put relatively less effort in a systematic review of literature in healthcare. One exception is a comprehensive review by Fitzpatrick and Ellingsen that gives an overview of health-related research through review of literature published in the Journal and related conferences of Computer Supported Cooperative Work in the past 25 years (from 1986 to 2011) [13]. Their analysis illustrated a range of topics and solutions that the HCI community studied in healthcare, suggesting three areas for improvement: broadening the scope of study settings and perspectives, having a greater impact on larger-scale HIT projects, and adopting and adapting to traditional methods in clinical settings. While this review provided helpful insights on enhancing the impact of HCI research on healthcare, it did not investigate healthcare studies conducted in other fields.

2.2 HIT Research in the BI Community

BI is the interdisciplinary field that studies and pursues the effective uses of biomedical data, information, and knowledge for scientific inquiry, problem solving and decision making to improve human health. Like HCI, the work of BI spans a number of disciplines, including computer science, human factors, and medicine. The American Medical Informatics Association sees the goal of BI as "transforming health care through trusted science, education, and the practice of informatics".

BI literature references HCI literature, particularly in the context of usability and cognitive science. For example, in a textbook on informatics, Biomedical Informatics [37], the authors of a chapter on cognitive science and biomedical informatics defined HCI as a "multifaceted discipline devoted to the study and practice of usability". Usability aspect has been addressed within the BI community particularly within the context of electronic health records (EHRs) and patient safety. As part of the Health Information Technology for Economic and Clinical Health (HITECH) Act, enacted as part of the American Recovery and Reinvestment Act of 2009, the Office of the National Coordinator for Health Information Technology (ONC) funded four Strategic Health IT Advanced Research Projects (SHARP). One of these, SHARPC was to study "usability, workflow, and cognitive support issues of EHRs" [46]. One major product of the project was developing a framework for usability for EHRs resulting in a number of books. The authors of the first book, "Better EHR", emphasized that usability issues have not received attention in the BI until recently [46], and a follow-up, entitled "Inspired EHRs", focuses on design principles and usability aspects of EHR [7].

2.3 Current Efforts to Connect BI and HCI Communities

For years, efforts have been made to bring together researchers and practitioners working on HIT to foster conversation and promote deeper understandings and more profound connections between a range of relevant communities, including BI and HCI.

An increasing number of HCI researchers have published in both BI and HCI publication venues, playing key peer roles in connecting these disjointed communities. Also, HCI researchers are increasingly working closely with clinicians to conduct HIT research that embraces both the HCI concern for understanding the nuances of experience and to develop new conceptual understandings and systems, as well as a BI concern for measurable clinical impact and making more applied contributions. [6] is an example article which authors are from different domains to study an HIT problem using a range of methods, including observation, participatory design, and a randomized controlled trial.

Another form of effort has been made through workshops, seminars, and social events where people from different research communities meet and get to know each other. For example, the Workshop on Interactive Systems in Healthcare was enacted in 2010 to bring together researchers and practitioners in different communities to work together to improve the design, adoption, and use of health information technology. Another example is a series of CHI workshops that focused on understanding how the design of medical technology impacts its use in clinical settings [36], which yielded guidebooks on HCI fieldwork in healthcare [16]. To our knowledge, however, there has not been much effort to establish a comprehensive understanding of research articles published in these disjointed communities through a systematic, comparative literature review.

Table 1. Search of electronic resources.

Database for BI articles
Journal of Medical Internet Research (JMIR)
Journal of the American Medical Informatics Association (JAMIA)
Journal of Biomedical Informatics (JBI)
International Journal of Medical Informatics (IJMI)
Database for HCI articles
ACM conference on Human Factors in Computing Systems (CHI)
ACM conference on Computer-Supported Cooperative Work and Social Computing (CSCW)
ACM Conference on Pervasive and Ubiquitous Computing (Ubicomp)
International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI)

3 Methods

This study was carried out with reference to the PRISMA statement to aid transparent and complete reporting of the study [28]. A study protocol documenting keywords and eligibility criteria was produced in advance.

3.1 Search Strategy

To retrieve BI articles, we selected four relevant publication venues with the highest h5-index from the Medical Informatics category of Google Scholar. To retrieve HCI articles, we selected four relevant publication venues with a high h5-index from Human-Computer Interaction category of Google Scholar (See Table 1). Journals were retrieved to search BI articles, and conferences were retrieved to search HCI articles. These choices reflect the different publication proclivities: journal publications are predominant in the BI community, whereas the HCI community publishes high-quality papers to conferences due to the fast-evolving nature of technology.

We searched articles from aforementioned 8 databases using specific queries. We tried several iterations of combinations of different keywords to retrieve the most relevant but still widely inclusive set of search results. In the end, we determined the final set of BI keywords as technology, participant, patient, and usability (or user study), and HCI keywords as health, patient, participant, and clinical (or medical). We then found out the retrieved HCI articles included studies about wellbeing and persuasive technology for behavior change that are beyond the scope of traditional HIT research. Thus, we included extra keywords to exclude such articles, including wellness (or well-being, wellbeing) and persuasive in HCI keywords. Last, we selected the articles published within the last 10 years (2007 to 2016) to reflect recent publication trends in the fields. Consequently, the final search queries for each database are as following:

BI search query: `((technology AND participant AND patient AND (usability OR user study))) AND ("2007"[Date-Publication]: "2016"[Date-Publication])`

HCI search query: `((health AND patient AND (clinical OR medical)) NOT ((wellness OR wellbeing OR well-being) AND persuasive)) AND("2007"[Date-Publication]:"2016"[Date-Publication])`

3.2 Eligibility Criteria

Any articles that reported human subject studies of HIT were eligible for inclusion. Human subject studies refer to systematic, scientific investigation that involves humans as research subjects, and HIT refers to information technology that captures, stores, manages or transmits information related to healthcare of individuals or the activities of organizations that work within the context of healthcare. The following criteria were used to exclude articles from consideration:

- An article that did not involve human subject studies
- An article with no section describing study methods
- Systematic review papers
- An article that is not a formal paper, such as workshop papers, extended abstracts, and letters

Table 2. Themes and randomly selected 3 sample publications for each theme.

Topic	Theme	Articles
BI	Technology and evaluation	Chan et al. [9]
		Goud et al. [18]
		Magrabi et al. [26]
	Web and usability	Atkinson et al. [4]
		Rabius et al. [32]
		Flynn et al. [14]
	Communication and management	Merrill et al. [27]
		Anderson et al. [3]
		Madathila et al. [25]
	Health information	Xue et al. [44]
		Jadhav et al. [21]
		Frost and Massagli [15]
	Behavior, activity and assessment	Chiu and Eysenbach [10]
		Veinot et al. [41]
		Cimperman et al. [11]
HCI	Device and application	Ananthanarayan et al. [2]
		Buttussi et al. [8]
		Larson et al. [24]
	Health document	Sarcevic [35]
		Park and Chen [29]
		Kientz et al. [22]
	App for disease and symptom	Rolland and Lee [34]
		Yun and Arriaga [45]
		Hailpern et al. [19]
	Sensor, game and exercise	Hernandez et al. [20]
		Alankus et al. [1]
		Balaam et al. [5]
	Display and screen	Piper and Hollan [31]
		Zadow et al. [42]
		Wilcox et al. [43]

3.3 Data Analysis

Text Mining for Document Clustering. The selected articles were clustered into themes using document-clustering techniques. Document clustering is to organize a large document collection into groups of related documents and to discern the most common general themes hidden within the corpus [23]. Using this method, we classified the selected articles into five themes that are not mutually exclusive.

More specifically, the latent structures within the identified articles were identified based on the similarity of article contents. First, a list of stop words was generated by NLTK to eliminate obvious non-technical words and was stemmed down into its root

using the Snowball Stemmer. We then analyzed each article for text similarities of meaningful, content-related words using tf-idf vectorizer parameters. Cosine similarity was measured against the tf-idf matrix and used to generate a measure of similarity between articles. As a result, the mining process yielded more accuracy and reduced-noise in clusters. Five clusters were generated for each set of articles to represent major themes. Each cluster was indexed and sorted to identify the top 10 words nearest to the cluster centroid. This gives a good sense of the main topic of the cluster.

Thematic Analysis. We randomly selected 3 articles per cluster from the identified articles (see Table 2) to conduct an in-depth thematic analysis [40]. Two investigators analyzed the randomly sampled articles. Each investigator independently analyzed the complete content of the selected articles to identify the theme of the study, its human-subject study methods, and the relation between themes and methods. The analyses were then compared across investigators to develop an exhaustive set of sematic fields. We combined the clusters that emerged from text mining and the semantic themes identified from thematic analysis of the sampled articles, and gave a theme name for each cluster. AQ1

4 Results

The initial search yielded 1,023 BI articles and 332 HCI articles. Through a review of titles and abstracts of these articles, 607 BI articles and 97 HCI articles were selected for full-text relevance screening. The articles were then selected on the basis of pre-determined inclusion/exclusion criteria, resulting in a selection of 533 BI articles and 60 HCI articles that met all eligibility criteria. The selected articles were deemed to be

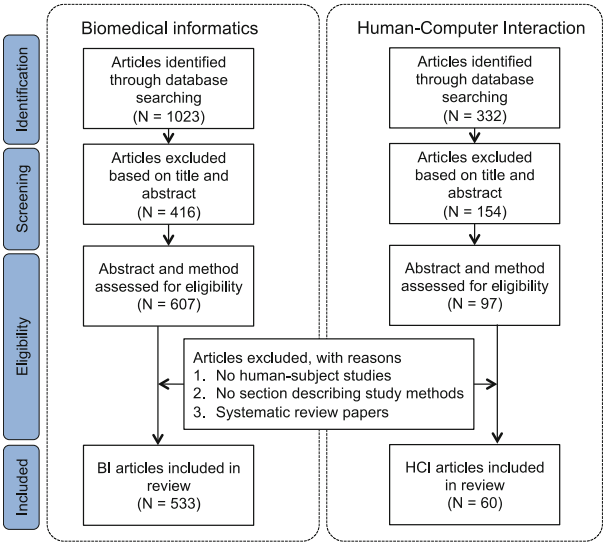

Fig. 1. PRISMA flowchart showing systematic search of review articles from BI and HCI.

of sufficient quality to contribute equally to the meta-analysis using text-mining and thematic analysis.

It was not surprising that over half of the initially identified BI articles met all eligibility criteria and only 20% of the initially identified HCI articles met all eligibility criteria, as the primary focus of BI encompasses healthcare, health information, and healthcare technology, while HCI articles study human factors and computing systems in a range of domains, one of which is healthcare. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is presented in Fig. 1. In what follows, we describe the findings of our comparative analysis with emerged research themes with keywords in each theme.

4.1 BI Themes and Methods

Technology and Evaluation has emerged from the largest BI cluster (189 articles, 35%). Articles in this cluster investigated the use of HIT with an aim to improve the quality of HIT or enhance clinical outcomes through its use. Example research topics include evaluating the effectiveness of an e-prescribing system [26] or studying the effects of HIT in teaching patients with care strategies [9]. The major theme words identified via text-mining include technology, develop, implementing, design, data, information, evaluation, process, technological, and model, and the method terms include interviews, observations, and modeling. Controlled laboratory experiments and semi-structured interviews were identified as common methods used in this cluster.

Web and Usability emerged as a theme of the second cluster (111 articles, 21%). This theme pertains to studies that explore the current or potential use of web-based systems for various healthcare purposes. Example research topics include designing health promotion websites [4] or assessing the usability of Internet-based smoking cessation services [32]. Various qualitative data collection methods were used in this cluster, such as interview, focus group, and case study. The identified major theme words include web, participants, test, online, usability, significant, surveys, rates, measurement, and effective, and primary method terms identified are surveys and questionnaire.

Communication and Management emerged as a theme of the third cluster (91 articles, 17%). This theme represents studies to support healthcare communication or to improve the management of healthcare information in clinical contexts, such as investigating the current state of data management needs of biomedical researchers [3] or exploring ways to provide systematic support for public health information management [27]. Various qualitative data collection methods were mentioned in this cluster as well, such as interview, survey, and case study. The identified major theme words include health, information, management, participants, design, communication, providers, patient, managers, and data, and method terms include interviews, surveys, and coding.

Health Information emerged as a theme of the fourth cluster (81 articles, 15%). This theme is rather vague, as it could cover a wide range of healthcare studies. Example research topics include exploring older women's acceptance of mobile-based health information [44] or investigating social uses of online community to support health information exchange between patients [15]. Content analysis, interview, and survey

were identified as primary methods of this cluster. The identified major theme words include patient, health, information, medical, clinical, record, electronic, participants, communication, and access, and method terms include interviews and coding.

Behavior, Activity and Assessment emerged as a theme of the last cluster (61 articles, 11%). The articles in this cluster focused on assessing human behaviors and activities relating to the use of HIT, such as studying family caregivers' use of electronic health services [10] or analyzing older adults' acceptance of telehealth services [11]. Various qualitative data collection methods, again, were identified as primary methods used in this cluster, such as interview, survey, and focus group. The identified major theme words include intervention, control, activity, effective, behavioral, significant, health, compared, assessing, and measurement, and method terms include controlled study and questionnaire.

4.2 HCI Themes and Methods

Device and Application emerged as a theme of the largest HCI cluster (21 articles, 35%). This theme covers a wide range of articles that study, implement, and deploy consumer health technologies, such as smartphone applications to support deaf people's communication in medical emergency situations [8] or to measure lung function [24]. Controlled laboratory experiments and semi-structured interviews were identified as primary methods used in this cluster. The identified major theme words include subjects, mobility, devices, sensors, clinicians, interfaces, treatment, application, scores, and families, and method terms include participants, subjects, information, data, and times.

Health Document emerged as a theme of the second cluster (19 articles, 32%). Articles in this cluster investigated ways to effectively adopt and adapt to electronic healthcare documents. Example research topics include examining the adaptation process of an EMR system in ED [29] or developing a new HIT system to improve the record-keeping process of children's early years for pediatricians and parents [22]. Observation and interview were identified as primary methods used in this cluster. The identified major theme words include nursing, team, ED, EMR, documented, clinicians, coordinates, doctors, hospital, and communications, and method terms include interviews, cases, and communication.

Application for Disease and Symptom emerged as a theme of the third cluster (7 articles, 11%). Specific diseases or health symptoms were prominent in this theme, such as aphasia [19] or pediatric asthma [45]. Controlled laboratory experiments and semi-structured interviews were identified as primary methods used in the sampled articles. The identified major theme words include chronic, pain, symptoms, health, variables, diseases, sharing, ill, searches, and diabetes, and method terms include interview and observations.

Sensor, Game, and Exercise emerged as a theme of the fourth cluster (7 articles, 11%). Articles that studied developing games or applications to promote relevant exercises for various health conditions, such as stroke rehabilitation [1] or cerebral palsy [20], were clustered in this theme. Participatory design and interview were identified as primary methods used in this cluster. The identified major theme words

include games, exercise, home, session, controlled, motivation, motion, sensors, play, and movements, and method terms include data and logged.

Display and Screen emerged as a theme of the last cluster (6 articles, 10%). Articles in this theme described display-based systems to facilitate communication in various clinical contexts. Example research topics include an interactive display to support conversations between a deaf patient and a physician [31] or a patient-centric information display for inpatients [43]. Participatory design, wizard-of-OZ, observation, and interviews were identified as primary methods used in this cluster. The identified major theme words include images, simulates, interpreter, screen, safety, context, communications, table, and surfaces, and method terms include subjects, data, and times.

5 Results

Based on the analysis of the emergent themes and keywords, we propose taxonomy of two dimensional HIT research themes that categorize prevalent research topics and approaches to solving HIT-related problems in the BI and HCI communities (See Fig. 2). In what follows, we explain how we came up with this taxonomy, highlighting key differences in the communities.

5.1 Taxonomy of BI Themes

As mentioned before, we found that some themes encompass other themes (e.g., BI > health information), and other themes address particular aspects of healthcare and HIT (e.g., BI > Communication and Management). We also found that there is overlap between the themes in BI, which makes it hard to distinguish among different themes (e.g., BI > Technology and Evaluation vs., BI > Web and Usability), compared to HCI themes.

Health information is representative of other BI themes to encompass a wide range of research topics in healthcare and HIT. In fact, this theme is rather vague or too obvious, and thus could be applicable to any articles that studied HIT. However, this theme did not emerge in the HCI articles, which highlights one key difference in a focal point of research in BI and HCI communities. It means that health information is a basic or fundamental component of research in BI but not necessarily in HCI.

From the rest of the four BI themes, two perspectives have emerged. The first is a systems perspective that is to determine how HIT should function. Technology and Evaluation and Web and Usability are the themes focusing on the enhancement of experiences with health information from a systems perspectives, seeking ways to ensure or improve usability, effectiveness, and efficiency of HIT. These two themes are similar, as the term “technology” and “web” can be used interchangeably, as well as the term “evaluation” and “usability”. The difference is that the articles in the Technology and Evaluation cluster investigated various forms of technical instruments (i.e., a tablet-based system, mobile apps) and evaluated them through diverse measures, while the articles in the Web and Usability cluster focus primarily on the usability aspect of online HIT systems (i.e., an e-prescription website).

The second perspective that emerged from BI themes is a users perspective that is to understand how users would operate HIT. Behavior, Activity and Assessment and Communication and Management are the themes to focus on enhancing experiences with health information from a user's perspective, seeking to understand human behaviors that might influence or be influenced by the use of HIT. The articles in Behavior, Activity and Assessment assessed human behaviors and activities to influence or to be influenced by the use of HIT in general, while the articles in Communication and Management explored how communication among multiple stakeholders in clinical contexts or health data management can be facilitated through the use of HIT.

Consequently, we developed a hierarchical taxonomy of the BI themes to account for different approaches to investigating various health information aspects of HIT. Health information is at the first level to encompass two approaches: a systems perspective and a users perspective. Technology and Evaluation and Web and Usability are categorized as the themes to study HIT from a system's perspective, and Behavior, Activity and Assessment and Communication and Management are categorized as the themes to study HIT from a user's perspective (See Fig. 2 top).

5.2 Taxonomy of HCI Themes

Compared to the BI themes, it was relatively easier to categorize HCI themes. We found it especially interesting that all the emerged HCI themes refer to different types of consumer health technologies used on an everyday bases by patients or in inpatient wards. That being said, Device and Application is representative of the rest of the HCI themes, investigating various types of consumer health technologies, including patients' access to health documents (Health Document), exergames (Sensor, Game, and Exercise), and displays for health communication and information (Display and Screen).

One reason HCI articles primarily focus on studying consumer health technology might be because it is not easy for researchers in the HCI community to access the clinical context without collaboration with clinicians. Another possible explanation might be because the proliferation of personal and mobile computing technologies has opened up opportunities for HCI researchers to explore novel ways to empower patients to manage their health concerns. The third possible explanation might be the different traditions of what is acceptable to be published in different venues. For example, it would be harder to get qualitative work published in a medical venue, and thus it is not surprising to see the pattern that many qualitative HIT studies are published in non-BI venues. Thus, there has been an argument among researchers in a medical community of accepting ethnographic work within BI [17]. Lastly, different research incentives and expectations from the different disciplines might have driven this pattern. For example, different funding resources have different expectations in terms of contribution types, study structure, and research methods (e.g., NIH vs. NSF), although this is only a US-centric perspective. Regardless of the reason, the trend was conspicuous that HCI articles primarily focused on the study and design of consumer health technologies.

There is one theme that does not refer to any specific type of consumer health technology: Application for Disease and Symptom. In fact, most HITs studied in HCI articles are deemed to be for diseases or symptoms. Thus, this theme is considered rather vague or too obvious, as Health Information in the BI themes. However, we found that the majority of HCI articles focused on the standpoint of patients to investigate casual healthcare practices, such as care plans, patient-provider communication, and patient access to health information. Meanwhile, articles in this cluster focused on managing specific symptoms or diseases, such as cancer, aphasia, or asthma. Thus, we took Application for Disease and Symptom into account as a subtheme of Device and Application.

There was one exception in the type of HIT that is not consumer health technology: EMR (Electronic Medical Record). EMR is a digital version of the traditional paper-based medical record for an individual patient and is not consumer health technology. Interestingly, the term EMR emerged as one of the keywords in the Health Document cluster of the HCI articles, but nowhere in BI, even though EMR has been an important topic of research and widely studied in the BI community. This might be because of the way the themes are structured: BI themes are to explain different approaches to studying health information in relation to HIT so that a specific type of HIT did not emerge, whereas HCI themes are classified into different types of HITs, one of which is EMR.

Consequently, we came up with a hierarchical taxonomy of HCI themes to classify different types of HIT. Device and Application is at the first level and four subsequent types of HIT include: Health Document; Sensor, Game ad Exercise; Display and Screen; and Application for Disease and Symptom (See Fig. 2 bottom).

Fig. 2. Hierarchical taxonomy of themes and keywords in BI and HCI articles

5.3 Methodologies Used in BI and HCI

Overall, methods used in the studies were similar across BI and HCI communities. Various qualitative methods were used in both communities, such as interview, observation, focus group, and case study, among which semi-structured interview was identified as the most popular method. Most sample articles in both communities conducted semi-structured interviews as a primarily data collection method, and data were analyzed employing a thematic analysis based on a grounded theory approach or other relevant qualitative analysis frameworks. This indicates a clear similarity between the BI and HCI communities in conducting HIT studies: researchers understand and solve problems through hearing directly from the current or potential users of HIT. The fact that the semi-structured interview is one popular method for data collection can be used as a starting point of mutual interest where researchers share practices and experiences, establish mutual understanding and appreciation, and engage in collective efforts to achieve a shared goal.

For quantitative methods, survey and controlled lab study were common across communities, but ways in which these methods were applied were quite different. First, we found a clear difference in conducting a survey: in the HCI articles a survey was commonly used as a supplement to qualitative methods to collect background or demographic information and answers to short-answer questions from a relatively small number of participants. For example, pre- or post-interview surveys were a common form, with an interview being a primary method for data collection. On the other hand, we identified several BI articles that used a survey as a primary method to collect a vast amount of quantitative data from a few hundred to thousands of subjects. Several BI articles conducted large-scale surveys and turned the results into quantitative analysis reports, which we did not find in the HCI articles. Second, a controlled lab study was also commonly used across communities, but we identified that the purposes were different: BI articles that reported on controlled lab studies were to investigate ways in which people interact with existing HIT or to measure an existing system's usability in a clinical context, whereas HCI articles reported on studies that ran experimental tasks in a lab setting to determine the effectiveness, efficiency and/or satisfaction of new HIT. Different approaches to the same method can be an interesting topic of discussion among researchers to help better understand and learn from each other.

We identified one method often reported in the HCI articles but rarely in the BI articles: participatory design. Participatory design is a method where the potential users of a system actively engage in the design process to ensure that the system meets their needs [29]. It makes sense that participatory design is used primarily in the HCI studies but not much in the BI studies due to different research goals and publication trends of these communities. One research goal of HCI is to create novel, interactive systems reflecting user needs. Participatory design can help better understand users, their needs, and challenges in the design of new technology. On the other hand, the BI community might be using participatory design relatively less, as technology design itself is seldom the focal point of the BI literature. (Apparently, participatory design has been used in the BI community – e.g., [38, 39], but none among the selected BI articles reported studies involving participatory design). This is a good example to demonstrate a significant difference between BI and HCI in the human-subject study of HIT. It can be a

topic of interest for BI researchers to broaden their methodological approaches to studying HIT, since there is sheer volume of HCI studies that used participatory design to effectively identify and solve critical problems in HIT design and use. Furthermore, it can be an opportunity for HCI researchers to contribute to HIT research with their specialty and expertise when collaborating with BI researchers.

6 Limitations

We acknowledge that this study has limitations. First, this research included papers published only in the selected databases related to healthcare between 2007 and 2016. Therefore, there may be other relevant studies published in other publication venues that were not included in the systematic review in this paper. Also, the findings from our analysis may not capture a publication trend before 2007. Second, the number of articles selected in BI and HCI differs greatly due to their different primary foci of study, which may have influenced how the documents were clustered. However, such difference stems from the natural publication culture and circumstance, and thus the potential skewing in clustering may need to be considered as part of the trend. Last, we did not employ any theory or guidelines to evaluate the quality of each study we reviewed. Thus, all reviewed studies are assumed to be of the same quality.

7 Conclusion

This paper presents a comparative review of 593 articles in the BI and HCI publication venues that reported on human-subject studies of HIT. The primary goal of this paper is to advance shared understandings of the literature in the disjointed BI and HCI communities through a comparative analysis of published articles. Using text mining techniques, five themes emerged from each set of articles, and from these we created a hierarchical taxonomy of BI and HCI articles. The results illustrate that the BI community contributes mainly to generating knowledge associated with the use of health information in clinical settings, whereas the HCI community focuses primarily on the design and evaluation of personal healthcare applications. For people who are already working in the intersection of BI and HCI, there might be nothing surprising about the findings. However, we believe it is nonetheless useful to have this analysis done systematically. Furthermore, a categorization of research themes and methods in different communities can help researchers who are unfamiliar with the other community to easily comprehend and acknowledge similarities and differences.

This study contributes to existing efforts to increase familiarity across BI and HCI communities and promote collaboration more effectively and productively to achieve shared goals of enhancing healthcare. We believe that researchers would benefit from increased familiarity with the work done by the other. Bringing together the strengths of different communities, we will be able to yield results that are more generalizable and have greater potential impact in healthcare research.

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