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Collaborating with Mammographers to Address Their Work-Related Musculoskeletal Discomfort

Carolyn M. Sommerich[1,2,*], **Steven A. Lavender**[1,2], **Kevin D. Evans**[1], **Elizabeth Sanders**[3], **Sharon Joines**[4], **Sabrina Lamar**[5], **Radin Zaid Radin Umar**[2], **Wei-Ting Yen**[2], and **SangHyun Park**[2]

[1]The Ohio State University, College of Medicine

[2]The Ohio State University, College of Engineering

[3]The Ohio State University, Department of Design

[4]North Carolina State University, School of Design, Durham NC

[5]North Carolina State University, Independent Scholar, Durham NC

Abstract

Mammographers are an understudied group of healthcare workers, yet the prevalence of musculoskeletal (MSK) symptoms in mammographers appears to be elevated, similar to many occupations in healthcare. In this study, we used a participatory approach to identify needs and opportunities for developing interventions to reduce mammographers' exposures to risk factors that lead to development of MSK symptoms. In this paper, we present a number of those needs and several intervention concepts along with evaluations of those concepts from experienced mammographers. We include findings from a preliminary field test of a novel intervention concept to reduce the need to adopt awkward postures while positioning patients for a screening or diagnostic mammogram.

Keywords

mammographer; musculoskeletal discomfort; design; intervention; healthcare

1. Introduction

Many studies have documented an elevated prevalence of work-related musculoskeletal (MSK) symptoms and disorders in medical sonographers (Evans, Roll, & Baker, 2009; Friesen, Friesen, Quanbury, & Arpin, 2006; Muir, Hrynkow, Chase, Boyce, & Mclean, 2004; Ransom, 2002; Russo, Murphy, Lessoway, & Berkowitz, 2002; Schoenfeld, Goverman,

*corresponding author: Carolyn M. Sommerich, PhD, The Ohio State University, Department of Integrated Systems Engineering, 1971 Neil Ave., Columbus, OH 43210, USA, phone: 614.292.9965, sommerich.1@osu.edu.

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Weiss, & Meizner, 1999; Vanderpool, Friis, Smith, & Harms, 1993) and several studies have also reported on work-related MSK discomfort concerns for radiographers (x-ray technologists) (Kumar, Moro, & Narayan, 2003, 2004a, 2004b; Lorusso, Bruno, & L'Abbate, 2007; Wright & Witt, 1993). However, few reports appear in the literature on work-related MSK discomfort in mammographers, (Costa, Oliveira, Reis, Viegas, & Serranheira, 2014; Gale, Hunter, Lawton, & Purdy, 2007; Hearn & Reeves, 2003; Lavell & Burkitt, 2008), imaging technologists who perform mammograms (radiographic examinations of breast tissue). Yet MSK symptoms appear to be as prevalent in mammographers as in other types of imaging technologists (Figure 1).

Mammographers in the US engage in three types of imaging acquisition activities, in addition to performing exam documentation, patient education, and other non-image acquisition activities. Image acquisition activities include 1) screening mammograms, typically requiring two standard views of each breast, 2) diagnostic mammograms, wherein the images required depend on the anomalies identified on the screening images, and 3) image-guided biopsy. In screening and diagnostic mammography, the mammographer positions the mammography machine, patient, and patient's breast, and then steps away to a shielded console to make the x-ray exposure. All mammographers are federally mandated to provide screening and diagnostic views in accordance with the American College of Radiology standards (American College of Radiology, 2014). Figures 2a and b illustrate the two standard screening views. Figure 2a shows a mammographer using her right arm to position the patient's torso and head and her left hand to position the patient's breast for a craniocaudal (CC) view. Figures 2b and c are demonstrations of positioning a patient for a mediolateral oblique (MLO) view and a 90 deg. (lateral) view, respectively.

Mammographers often assume awkward work postures, such as illustrated in Figures 2b and c, in order to visually verify that all areas of the breast are correctly positioned before acquiring an image (Costa et al., 2014; Gale et al., 2007). This visual verification increases the likelihood that the image will contain all the tissue of interest to the radiologist and thus reduce the need to repeat an image, which would expose the patient to an additional radiation dose. The need to assume awkward postures is influenced by the view (MLO, etc.), height difference between mammographer and patient, accreditation requirements for image acquisition, layout and design of equipment and examination room, patient scheduling, and other factors. Mammographers can also experience MSK discomfort in their hands as a result of repeatedly getting caught when the paddle (indicated by a black arrow in Figure 2a) moves down to compress the patient's breast against the receptor plate (indicated by a white arrow in Figure 2a). The mammographer wants to ensure the breast tissue remains in place while the paddle lowers and compression on the breast is increasing, in order to ensure proper positioning. To do this, mammographers often wait to withdraw their hand until significant compressive pressure is being applied to the breast.

Reports of interventions to reduce MSK discomfort in mammographers are rare. The report by Gale et al. (2007) described a number of interface design improvements in mammography equipment, but in general these do not address the awkward postures and other factors that contribute to MSK discomfort in mammographers. Lavell and Burkitt (2008) presented the concept of the seated mammographer, specifically for reducing awkward postures when acquiring MLO views. It was mentioned by Gale et al. (2007), as worthy of consideration, but currently is rarely observed in practice. A Finnish company offers a mammography machine with a tube head that rotates up to 30 deg to facilitate positioning. Evans (2000) investigated the quality of exams of seated elderly patients, to determine if this posture would be a viable option for patients who have difficulty standing for the 10–20 minute duration of a typical screening exam. Though the study did not explicitly address benefits to mammograhers, the support provided to the patient by the seat back and seat pan, as well as the ease of positioning provided by the chair's casters, suggests that seating some patients could be considered an intervention that also addresses some amount of MSK disorder risk factor exposure in mammographers.

Given the paucity of intervention efforts directed at reducing work-related MSK symptoms in mammographers, a participatory ergonomics process was initiated in order to work with mammographers to attempt to develop interventions to improve their work conditions and thereby reduce their occupational exposure to risk factors for work-related MSK symptoms. This effort was part of a larger study, the goal of which was to develop interventions with and for five types of imaging technologists: mammographers, radiographers, cardiac sonographers, diagnostic medical sonographers, and vascular technologists. The focus of this paper is the participatory research with mammographers. Part 1 of this paper describes the needs assessment and concept development and review phases of the research. Part 2 describes a field trial of a novel intervention concept for reducing awkward work postures in mammographers. Both parts of the research were approved by the university's institutional review board for human subjects protection.

2. Part 1 – Needs Assessment and Concept Review

2.1 Methods

Data were collected from study participants in two sequential phases: needs assessment (Phase 1) and intervention concept development and review (Phase 2). Informational flyers, word of mouth, and visits to staff meetings were used to inform mammographers working for two large, local hospital systems about the opportunity to participate in the study. Both systems operate hospitals and several clinics where mammograms are performed. As reported by The American Registry of Radiology Technologists (2008), 75% of mammographers work in hospitals or free-standing/breast imaging centers. Mammographers who were interested in participating informed the researchers in person or contacted the research team later. However, not everyone who expressed interest was able to participate because sessions could not be scheduled to accommodate all schedules. With support and permission from clinic managers, both phases were conducted outside of normal work hours in fully functional mammography suites, which facilitated discussion and demonstrations of concerns and solution concepts.

2.1.1 Phase 1: Needs Assessment

2.1.1.1 Study participants: Nine female mammographers participated in needs assessment activities. Their years of experience in mammography ranged from 15 to 35, and totaled 212 years.

2.1.1.2 Procedures and data collection: Needs assessment data were provided through workbooks completed by the participants (n=9) and through discussion and creation of intervention artifacts during a focus group workshop (n=8 of 9). In advance of the 2 hr workshop, participants completed a workbook that included questions about physical aspects of their work, schedules, and characteristics that made patients more challenging to image. The workbook contained a two day diary in which to record exam details, including type, duration, anything that made the exam challenging, and any physical discomfort the mammographer experienced during the exam. The workbook also contained a photo album, that participants were asked to complete by adding photos taken by them of equipment they liked or disliked, exam rooms they liked or disliked, and anything else they wanted to show us about their workspace. Researchers provided cameras to the study participants who were cautioned against taking photos of patients. They were asked to annotate the photos with explanatory arrows and text. Preparing and submitting workbooks in advance of the focus group workshop provided participants the opportunity for reflection and priming, and reviewing workbooks in advance provided the researchers opportunities to fine tune the workshop.

Portions of the workshop included moderator-guided discussion about some of the photos provided by participants and responses to some select workbook questions. Notes were taken by two of the researchers during the discussions on large ‘issues notecards’ that the participants subsequently sorted into categories and labeled with themes. Participants then identified their most important challenges based on the issues they had just discussed, and determined which issues they wanted to address working in small groups during the latter portion of the workshop which was designed to aid the participants in generating intervention ideas to address the issues. The latter element was conducted from the viewpoint of design as co-creation between end users and designers, engineers, and ergonomists. Sanders (2002) described this participatory methodology as a manifestation of “a belief that all people have something to contribute to the design process and that they (non-designers) can be both articulate and creative when given appropriate tools with which to express themselves”. At the end of the intervention generation element of the workshop one mammographer from each group presented the group’s results, after which the other mammographers and the researchers asked questions and provided additional ideas and suggestions. The intervention generation element of the workshop, including presentation, was video-recorded.

2.1.1.3 Data analysis: Workbook entries were entered into spreadsheets to facilitate review, researchers made notes from audio recordings of the discussions and generative element presentations, and photos and video were triangulated for thematic and specific content. Through detailed review of these materials (grounded theory analysis), a document was created that was organized by a number of major categories (such as Patient-comfort, Patient-positioning, Workload-schedule, Workstation-design, Equipment-paddle, etc.), that emerged from the data. Within each category, every expressed need was listed, along with its source (audio recording, workbook entry, etc.), the interpretation of that expressed need, initial intervention ideas to address the need, an initial rating of the feasibility of prototyping and/or testing the intervention idea, and the researcher’s comments. Two researchers performed the initial assessment of the data. Each independently completed an analysis and then they worked together to develop the analysis, based on consensus, that they presented to the research team for further analysis and discussion.

2.1.1.4 Intervention concept generation: The next step was to develop intervention categories (for example, Patient Scheduling - incorporate exam characteristics; Provide visual aids in strategic locations; Improve location of paddle storage; etc.) along with a list of intervention concepts for each category. Various types of brainstorming techniques, internet searches, and literature searches were employed to generate intervention concepts. The next step was to refine and reduce the number of concepts to those that were most promising, potentially viable, and within the scope of the study; within scope meant that the concepts addressed issues that have a direct effect on the musculoskeletal health of mammographers. These concepts were then discussed with the mammographers in a concept review session (Phase 2).

2.1.2 Phase 2: Concept Review

2.1.2.1 Study participants: Eight female mammographers participated in this phase of the study (2 to 35 years of experience; 121 years in total), including three who participated in Phase 1.

2.1.2.2 Procedures and data collection: Illustrated posters and some physical prototypes were presented to the participants, who provided their opinions of the usability, usefulness, and desirability of each concept, potential barriers they anticipated in use or implementation, and improvement suggestions, via evaluation forms and discussion. An example of one of the posters is presented in the Appendix to this paper. Time was allocated for each concept, including presentation of the concept, discussion, and time for completing the evaluation form. Hands-on interaction and role-playing were encouraged where prototypes were present. Once participants completed their evaluation form, the next concept was presented; the duration of the session was 3 hr.

Usability items on the evaluation form addressed ease of use and ease of learning to use; usefulness items addressed predicted effects on the mammographer's physical effort, fatigue, and efficiency, and patient comfort; desirability items addressed level of interest in using the intervention by the participant and co-workers. Participants used a 5 point response scale ranging from Strongly Agree to Strongly Disagree to respond to each item. Participants also provided an overall rating of each category (Usability, etc.), using a 1 (very poor) to 7 (very good) range. Finally, participants were asked to indicate which concepts should be made a priority. They were each given 6 green voting dots to distribute among the concept(s).

2.1.2.3 Data analysis: Evaluation form responses were entered into a spreadsheet to facilitate analysis. Medians scores were calculated for each statement. For each concept, the number of green dots (priority votes) were counted and the number of barriers were counted and normalized to provide counts per participant.

2.2 Results

2.2.1 Phase 1: Needs assessment—Eight of the nine mammographers reported experiencing work-related musculoskeletal discomfort (in response to the question ‘Have you experienced musculoskeletal discomfort that you specifically associate with your work as an imaging technologist?’). The average number of exams they reported performing per day ranged from 12–18 for those with no administrative responsibilities (6 of the 9 participants). When asked to describe the most physically demanding exam or procedure they perform on a regular basis, seven responses involved specific patient attributes, alone or in the context of a specific type of exam. The attributes include tenseness, mobility limitations (including wheelchair use), obesity, certain breast attributes, height difference from mammographer, and sensory or cognitive limitations. Regarding working with challenging patients, the average percentages of patients categorized as elderly, ‘heavy’, having a physical impairment, or as different in stature from the mammographer were 30%, 40%, 10%, and 25%, respectively (note that some patients have more than one of these characteristics). The main themes that emerged from the workshop discussions in the current study concerned problems with equipment (machine design, paddles, foot pedals), patient characteristics, room layout (image acquisition room and computer workstation room), and mammographers’ work postures. The needs assessment analysis for the mammographers is summarized in Table 1.

2.2.2 Phase 2: Concept review—The research team’s idea-generating activities yielded a total of 22 intervention concepts to address the interpreted needs of the mammographers. Fourteen were determined to be within the scope of the study and were presented to the mammographers in the concept review session (see Table 2).

Results from the concept review evaluation forms are summarized in Figure 3. For each concept, results include overall scores of potential usefulness, usability, and desirability, the number of priority (“pursue this”) green voting dots received, and the number of barriers normalized to the number of participants.

While many concepts were evaluated as having potential by the concept review participants, after analyzing the results from the concept review sessions for each group of imaging technologists for the study as a whole, an ‘A’ list of ten most promising concepts were identified and pursued for the remainder of the study. In Part 2 of this paper, further work is described concerning one of the ‘A’ list items that addressed the fundamental need to reduce the repetitive awkward work postures of the mammographers.

3. Part 2 – Prototype Development and Pilot Testing

‘Mirrors on the mammography machine’ received fairly high scores from the mammographers, was determined to be a highly novel concept with great impact potential, was thought to be readily implementable by the researchers, and therefore was chosen as one of the ‘A’ list items.

3.1 Prototype Development

The idea of mounting mirrors on the mammography machine arose from the needs analysis from the first set of focus group sessions. Specific design features, such as mirror shape and mounting them on flexible stalks came from feedback and suggestions provided during the concept review sessions, and individual feedback during prototype development. Through an iterative process, functional prototypes were developed that could be mounted to one type of mammography machine in order to be able to perform proof-of-concept testing.

3.2 Prototype Evaluation Methods

A field study was conducted at two breast imaging facilities. Informed consent was provided by seven experienced mammographers who volunteered to participate in the field study (9 to 35 years of experience in mammography; total of 162 years); five had not participated in a previous phase of the study. A pair of mirror prototypes was mounted on one of the mammography machines at each of the two facilities (Figure 4). An instructional brochure was created that contained photographs and explanations of how to use the mirrors for each view, with patients who were taller and shorter relative to the mammographer. Figure 5 shows the use of the mirrors for each view. Prior to commencement of data collection, participating mammographers were shown the photographs in the brochure, given a demonstration, and practiced using the mirrors while positioning members of the research team. They were also shown how to complete the mirror use data form, that, via check boxes, requested information on the patient’s height relative to the mammographer, views acquired with or without use of the mirrors, if the mirrors were useful if used, and barriers to mirror use. Blank forms were kept in the exam room along with a locked drop box for completed forms.

Participating mammographers were asked to use the mirrors in their regular mammography examinations whenever the opportunity arose and they were comfortable using them. The data collection period varied for each participant, ranging from 1 to 4 weeks; from one week to the next, a participating mammographer could be scheduled at a facility other than one with a machine with the mirrors. After the data collection period ended, four of the seven mammographers participated in a moderator-guided, in-depth, group discussion about their experiences using the mirrors and their suggestions for moving forward.

3.3 Prototype Evaluation Results

All in all, at the conclusion of the field test the mammographers gave a favorable assessment to the ‘mirrors on the machine’ concept, providing average usefulness, usability, and desirability ratings of 6.3 out of 7 for each. Based on information provided on the field test mirror use data forms, participants found the mirrors were helpful for 44% of the CC views on which they reported and 22% of the MLO views on which they reported. There were no patterns in these data with respect to patient height relative to mammographer height. In general, the mammographers thought that the mirrors were large enough, though they were interested to try some other sizes before recommending a final size. They thought the oblong rectangular shape was useful, allowing them to view the entire breast, including key areas such as the inframammary fold and axilla. The flexible stalk allowed the mirror to be pushed out of the way when not in use, but was a bit too stiff to enable positioning the mirrors as easily as they would have liked. They also wanted more adjustability where the mirror was attached to the stalk. They did not consider the mirrors to be too complex or cumbersome, and thought that mammographers could easily learn to use them given sufficient instruction and practice opportunity. The mammographers were able to obtain high quality images with the mirrors and did not think using the mirrors adversely affected exam time. They thought that use of the mirrors would make exams physically easier on mammographers, and that they would likely feel less fatigued at the end of a work day when using the mirrors. They reported that the mirrors were particularly useful for patients who used a wheelchair and for the CC view with taller patients. They also reported that the MLO view required more practice and, in general, they all would like more time to learn to become adept at using the mirrors.

When the mammographers were asked if the mirror concept should be pursued, they all agreed that it should. They also agreed that they did not want to wait for the mirrors to be integrated into the next generation of mammography machines, but wanted an after-market design to be pursued that would allow existing machines to be retrofitted with mirrors. The latter poses a non-trivial challenge to designers to develop a means of attaching the mirrors to a given machine. The targeted machine in the field study had a long handle on both sides that facilitated the attachment, whereas some newer machines have indentations instead, which pose a greater design challenge.

The mirrors present a completely new way for mammographers to perform their exams, and as such, discovering how to use the mirrors with patients who are diverse in height, circumference, breast condition, degree of comfort with having a mammogram, etc. will require time. Mammographers normally learn by doing, with experienced mammographers sharing their expertise with students and with newer mammographers. From the adoption literature, an influential onsite mirror ‘champion’ would likely be an essential process element when the mirrors are introduced to an imaging facility, in order for the adoption process to be successful. Typically as upgrades or new features are provided by equipment manufacturers, an application specialist assists staff with mastering these changes. This model of utilizing an equipment application specialist to provide a focused in-service on the use of the mirrors would be a preferred method for implementation.

4. Discussion

Few published studies have examined mammographer’s work with regards to exposure to risk factors for MSK symptoms or interventions to reduce risk factor exposure. However, amongst these few studies and the current study, there are a number of consistencies, in addition to the unique contributions of each study. Prevalence of MSK symptoms in Hearn and Reeves (2003) and the current study were similar, at 83% and 89%, respectively. At 12–18, the number of exams performed in typical a day was somewhat less for the participants in the current study than the 20 reported by (Gale et al., 2007), but the numbers are not uncommon for mammographers in the US. In a practice analysis survey by The American Registry of Radiology Technologists (2008), 54% of respondents performed 6–15 exams per day and another 26% performed 16–25 exams per day. Similarly awkward postures adopted by mammographers during patient positioning were depicted in Gale et al. (2007), Costa et al. (2014), and the current study (Figures 2b and c). Height differential between patient and mammographer was reported by mammographers in the current study and in other studies (Costa et al., 2014; Hearn & Reeves, 2003) to be an important factor contributing to the adoption of these awkward postures. These postures can be exacerbated by view, particularly MLO, and machine design (rigid tube head location) (Costa et al., 2014; Gale et al., 2007; Hearn & Reeves, 2003), as well as repetition. Per Hearn and Reeves (2003), the awkward postures with the MLO view are particularly problematic because they occur "twice for every woman screened" and are held for several seconds. As noted in our study and by Gale et al. (2007), glare on paddles remains a problem for mammographers, as does the breast positioning task. Based on these and other consistencies, we believe that the participants in the current study and their working conditions and experiences are similar to those reported in other studies of mammographers and work-related MSK concerns. As such, the needs identified in the current study and the intervention concepts should be relevant to practicing mammographers outside of this study.

5. Conclusion

One of the primary goals of this study was to identify areas of need and opportunity for intervention to reduce the exposure to work-related risk factors that contribute to the high prevalence of musculoskeletal discomfort and disorders in mammographers. This paper presents several areas of intervention need and opportunity. The other primary goal of the study was to develop intervention concepts and testable physical prototypes. This paper presents several intervention concepts and the description of a field test of a novel intervention for reducing mammographers' exposure to a primary risk factor for MSK symptoms, awkward work postures. A key component of this research has been the continued engagement of end users, which has ensured that the interventions address users' needs and requirements. This study demonstrates a model of collaboration between engineers, ergonomists, and mammographer-subject matter experts, that yielded a number of promising engineering and administrative control concepts to reduce the mammographers' exposures to MSK symptom risk factors. We hope this model will be emulated by others for the benefit of this understudied group of health care professionals.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Practitioner Summary

This paper discusses needs, opportunities, and methods for working with mammographers in order to develop interventions to reduce their exposure to risk factors for work-related musculoskeletal discomfort. Results from a field test of a novel intervention to reduce mammographers' awkward work postures while positioning patients are presented.

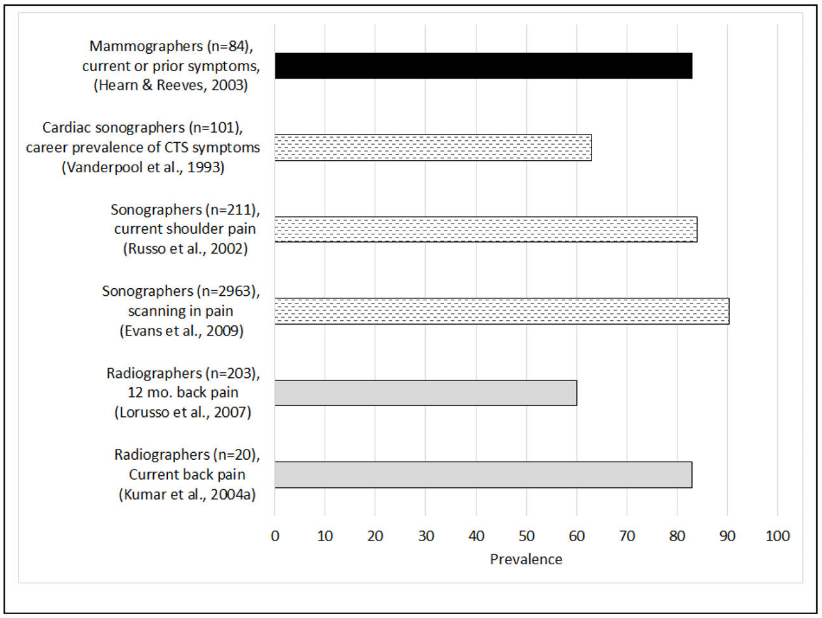

Figure 1.

Prevalence of musculoskeletal discomfort that exceeds 50% is consistently found in studies of various types of imaging technologists.

Figure 2.
Mammographer positioning patient to acquire a CC view (a); black arrow points to paddle that compresses the breast after it is positioned on the receptor plate (white arrow). Image source: http://www.cdc.gov/cancer/breast/basic_info/mammograms.htm Simulation of mammographer positioning patient to acquire an MLO view (b); black arrow points to tube head at 45 deg angle for this view, white arrows point to foot controls. Simulation of mammographer positioning patient to acquire a 90 deg. (lateral) view (c).

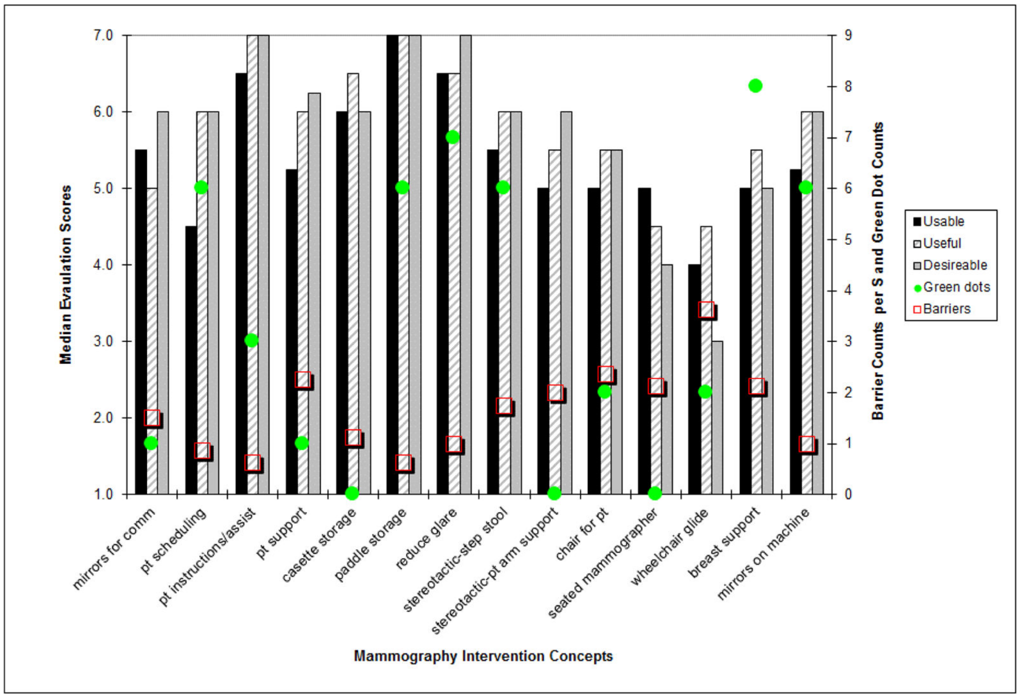

Figure 3.

Mammographers' evaluations of the intervention concepts. Evaluation score scale for overall usability, usefulness, and desirability: 1=very poor, 7=very good. Green dots refer to the number of priority votes each concept received from participants; contrast these with the barriers to use/implementation projected by participants.

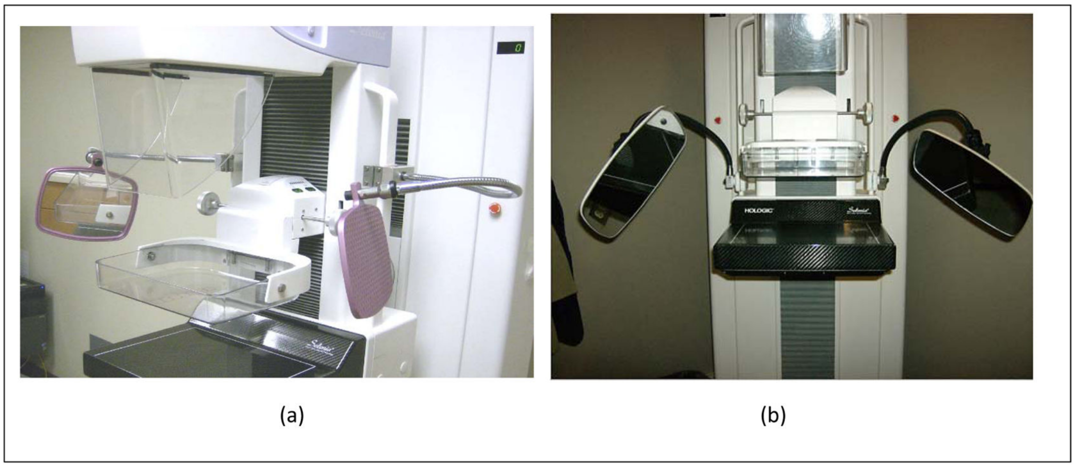

Figure 4.

Prototype pair of mirrors used in the field study (a); design refinements seen in the system that is currently in use were based on field study experience (b).

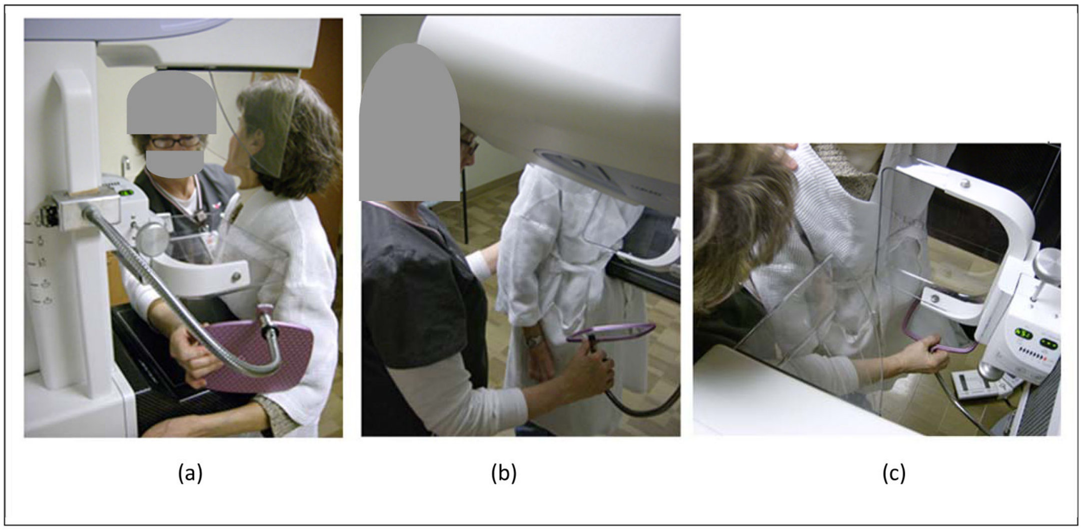

Figure 5.
Simulation of the mirrors being used for CC view (a), MLO view (b), and 90 deg. (lateral) view (c).

Table 1

Results of needs assessment analysis of focus group (Phase 1) data from mammographers.

Issue Category	Issues and needs
Office work environment	
Computer workroom	• Poorly designed computer workstations do not fit mammographers • Area is noisy and busy; not conducive for calling patients to speak with them about scheduling follow-up diagnostic exams
Stereotactic equipment (for biopsy procedures)	
Equipment design	• Requires mammographer to bend forward while seated or to kneel to operate controls that are located about knee level and retrieve specimens located about waist level.
Screening and diagnostic mammography equipment	
Interface design – controls (foot pedals, controls on machine, and keyboard console)**	• Poor layout and location of control buttons, including power, exposure, and emergency deactivation. Some control buttons must be activated together and this can be awkward to perform. Other important controls are too easily inadvertently activated (including by patient). • Foot control pedals can be difficult to reach and activate accurately; voice activation could be desirable • Mammographers would like to control essential functions of the machine without bending, reaching, twisting or kneeling
Tube head	• Location, size, and shape interfere with patient positioning. Mammographers adopt awkward postures in order to position patient and breast for quality image. Mammographers can hit their head on the tube head when attempting to view the breast; some must kneel on floor or adopt marked trunk flexion to see breast while positioning patient. • Face plate requires patients to adopt awkward posture, which makes positioning patient more difficult for mammographer. Turning head can be difficult for kyphotic patients and patients with neck pain.
Compression paddles	• Responsiveness of paddle movement can make compression a more difficult experience for patients, thereby making exam more difficult for mammographer to conduct with patients who are fearful, in pain, etc. • Lighting glare on paddles makes it difficult to see breast tissue. • Paddles are often stored in a low location (think bottom two rows of a bookcase), requiring mammographer to bend to knee height or lower to replace or retrieve paddles. • Paddles are heavy, must be treated carefully, and must be handled repeatedly (placed in and removed from the mammography machine) when performing diagnostic exams. • Paddles do not always positively lock into the machine
Relationship with equipment manufacturer	• In the past, manufacturer's representative would visit clinics and speak with mammographers; equipment features, issues, needs were discussed. Now, mammographers and reps no longer have this opportunity for interaction to discuss problems and solution ideas.
Patients	Needs summary: equipment modifications, schedules to provide more time for challenging patients, communication aids
Stiff	• Two parts to this are positioning the patient for the view and then the patient remaining in that position while mammographer steps away to take the image • Patients who are stiff and tense (elderly &/or anxious) are difficult to position for any views; they may also move out of position before the image is taken • Kyphotic patients are difficult to position (elderly)

Issue Category	Issues and needs
Patient and mammographer differ in stature	• Taller patient: Difficult to check breast position from above for CC view • Shorter patient (including pt using wheelchair): Difficult to check breast position for MLO view due to tube head interference; difficult to position and see breast for 90 deg view due to tube head interference; risk of injury to mammographer when getting up from kneeling on the floor because there is nothing she can use to support/steady herself
Large breast	• Large, heavy breasts require a lot of physical effort to position. *(Note: Breast weight can be approximated at 0.75 to 1% of body weight, though correlation with bra cup size is much stronger* (Brown et al., 2012; Katch et al., 1980).) • Additional images can be necessary if all the breast tissue cannot be included in a single image.
Obesity	• Receptor plate may contact abdominal adipose tissue, which keeps patient from leaning forward, thereby making positioning patient more difficult; axillary adipose tissue can make positioning more difficult. • Difficult to reach around large patient to guide her into correct position
Communication challenges	• Patient cooperation is necessary to obtain good images, making communication between mammographer and patient essential. It is important to be able to explain the exam procedures, what the patient needs to do, and what the mammographer is doing. Communicating this can be difficult when mammographer and patient do not speak the same language, or when the patient is cognitively impaired or has a hearing impairment. Poor communication quality makes positioning the patient more physically challenging for the mammographer.
Unsteady patient	• Due to anxiety or physical condition, a patient may have difficulty standing or may lean back when compression is released – mammographer may have to 'catch' an unsteady patient. Machine provides no support for patients, other than handle that they may be instructed not to hold because grasping it induces stiffness in the whole arm and beyond; patient's body must be relaxed in order to obtain high quality images.
Positioning patients	• Patients cannot position themselves; positioning patients is a 'whole body' exertion (Figures 2a and b) • "Positioning patients is the most physically demanding part of my job."
Scheduling patients	• Time allotted for an exam should include consideration of patient characteristics that increase exam time; insufficient allotment of time adds to the stress of this job • Informing mammographer in advance of patients' characteristics gives her the opportunity to make preparations that will make the exam procedure go more smoothly; affords mammographer more control over her work
Exam room	
Patient comfort	• No one should be able to unexpectedly enter the room during an exam • From the mammographer's position at the console, ability to make eye contact with patient is helpful for communication with anxious and hearing impaired patients.
Size and layout	• Small rooms and rooms that are poorly laid out further constrain and induce awkward working postures in mammographers • From her position at the console, mammographer should be able to see if patient has shifted before taking image

** Images of various control buttons and keyboards for a variety of mammography machines can be seen in the report by Gale et al. (2007); awkward postures assumed when reaching for foot controls can be seen in Costa et al. (2014).

Table 2

Concepts presented to the mammographers in the concept review sessions.

Concepts	Approaches	Interpreted need
Mirrors for communication	• Convex or flat mirror, mounted on wall or on a mobile stand	Maintain eye contact/ communication between patient and mammographer during scan; Improve patient position compliance during scan
Patient scheduling options	• Customized patient scheduling based on the unique needs of patients and the workload of mammographers; standard time is added by type of patient; mammographer can also customize time for specific patients	Patient scheduling should take exam characteristics and mammographer workload into consideration
Assistance with/for patient instructions	• Patient care assistant to work with patients who need assistance with dressing, instructions, emotional support, etc. • Instructional cards with images to help patients better understand positions required to obtain quality examination; ease anxiety of first time patients; aids communication with patients with hearing impairment or who do not speak the same language as the mammographer	Provide specific care and concern for mammography patients who need extra assistance
Patient posture support	• Provide seat for patient that has adjustable backrest pad that can provide support to help pt. remain in correct position during scan and not fall Push back from behind while seated • Pull patient towards machine using a cushioned support strap	Improve position maintenance for patients who have difficulty remaining in the correct position when mammographer steps to console or pt who need stability support when the paddle releases
Cassette storage in mobile mammography unit (bus)	• Cassette storage mounted to the wall: recessed, right-height wall unit; magazine rack style unit) • Mobile unit for cassette storage at waist height	Reduce bending and twisting to access film screen mammography (FSM) cassettes
Paddle storage options – right-height	• Elevate existing shelves: wall-mount or place on stand and brace to wall • Create shelves behind C-arm • Pull-down shelves for small exam rooms	Reduce bending and twisting to access compression paddles & Bucky trays
Reduce glare – Improved exam room lighting to enhance visibility for breast positioning	• Supplemental Upward-Directed Lighting (retrofit): fixed location lighting (sconces; rope lighting with crown molding); free-standing lighting (torchiere-style floor lamp) • Alternative Overhead Lighting (new/remodel): Indirect overhead fixtures and “cove” lighting	Reduce glare on mammography paddles
Step stool for stereotactic exam table access	• Alternative step stools (assistive device) that provide extra support for patients as they access or get off of exam table	Need ways to assist pts when interacting with stereotactic exam table, that also reduce strain on mammographer
Stereotactic exam – positioning aid	• Arm supports/rails, mobility aids (assistive device) for patients to use to position themselves on the exam table	Need ways to assist pts when interacting with stereotactic exam table, that also reduce strain on mammographer
Chair for patient	• Height-adjustable chair specifically designed for mammography exam (does not interfere with positioning patient); for patients who are not capable	Reduced effort and time needed to position challenging patients for their exams

Concepts	Approaches	Interpreted need
	of standing correctly during image acquisition, or to height-match patient and mammographer	
Seated mammographer	• Mammographer sits on wheeled stool with back support for MLO and/or 90 deg (Lateral) views	Reduce awkward postures while positioning patients
Wheelchair glide	• Concepts for flooring aids to assist with moving and guiding non-powered wheelchair into position	Reduce manual force required to position patient's wheelchair
Breast support - Provide positioning support for weight of heavy breasts	• Various concepts, for sling or holder to support weight of breast by the breast support/receptor of the mammography machine while positioning for MLO and 90 deg. images; possibly designed to remain in place during image acquisition	Reduce mammographer's hand support of breast while beginning compression
Mirrors on machine	• Pair of adjustable mirrors are attached to the mammography machine in viewing breasts during positioning	Reduce the need for mammographers to assume awkward postures to view breast while positioning patient