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User Evaluation of an Innovative Digital Reading Room

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Abstract Reading room design can have a major impact on radiologists' health, productivity, and accuracy in reading. Several factors must be taken into account in order to optimize the work environment for radiologists. Further, with the advancement in imaging technology, clinicians now have the ability to view and see digital exams without having to interact with radiologists. However, it is important to design components that encourage and enhance interactions between clinicians and radiologists to increase patient safety, and to combine physician and radiologist expertise. The present study evaluates alternative workstations in a real-world testbed space, using qualitative data (users' perspectives) to measure satisfaction with the lighting, ergonomics, furniture, collaborative spaces, and radiologist workstations. In addition, we consider the impact of the added collaboration components of the future reading room design, by utilizing user evaluation surveys to devise baseline satisfaction data regarding the innovative reading room environment.

Keywords Radiology reading room · Ergonomics · User evaluation · Musculoskeletal

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Background

Reading room design can have a major impact on radiologist's health, productivity, and accuracy in a reading environment. Technological developments, such as improvements in network infrastructure, workstations with more reliable and brighter monitors, improved image presentation and navigation software, image enhancement, and integrated speech recognition, have improved radiology imaging tremendously. Researchers have focused on the potential for modifications in radiology reading room design to enhance radiologist performance [1]. A study of 12 radiologists at Tripler Army Medical Center, Honolulu found that 33% were clinically symptomatic with either carpal tunnel syndrome or cubital tunnel syndrome; the symptomatic radiologists spent more time on computers and mostly experienced their symptoms when using their digital workstations [2]. The impact of moving to filmless radiology was evaluated in a before and after survey of the reactions of 380 people (radiologists, nurses/technologists, secretarial, nurses' aides, and maintenance staff) to the introduction of new digital imaging and a picture archiving and communication systems (PACS) in the X-ray departments of two large hospitals in the County of Stockholm, Sweden. Results showed that while there were positive expectations for the benefits of the PACS implementation, use of the digital systems resulted in more sedentary work and a substantial increase in headaches and musculoskeletal symptoms [3].

To minimize such symptoms, digital reading room design must take into account several factors: architectural planning, room layout, workstation design, ergonomics, and optimal environmental elements [4–6]. This has been reiterated at a refresher course given at the Radiology Society of North America (RSNA) in 2006 by Dr. Siegel

regarding optimal reading room design and summarized in an RSNA news publication. In the course, a list of recommendations to consider when designing or redesigning a reading room was created:

(Re)Designing Your Department (Basic Imaging Informatics)

- Changes in the radiologist workstation and reading room for transition from film to filmless practice
- Optimizations for task-focused workstation design including ergonomic furniture, input devices, proper room and task lighting, noise abatement, ventilation, and temperature controls
- How workstation and environment affect efficiency, fatigue, and stress-related injuries
- How key drivers of architectural design and planning are changing in the digital department
- How to plan flexible imaging environments that can better accommodate the currently unknown medical technology that may be available in the future
- Design for multidisciplinary collaboration among various specialists [7]

The ergonomic requirements for a radiology reading room have been summarized in the Cornell Digital Reading Room Ergonomics Checklist [8]. This checklist was developed based on empirical studies of reading rooms in the USA and Iceland [9].

The majority of the literature on reading room environments only focuses on recommendations and best practices for future reading room design. The literature that does focus on the evaluation of reading room designs are minimal and are dated [8–10]. The focus of our study is to evaluate an innovative radiology reading room, concentrating on the perspective of radiologists, administrators, and coordinators satisfaction towards the environment. We focus not only on musculoskeletal health but also on radiologist satisfaction in terms of whether the new designs are well setup in terms of lighting, noise levels, and ease of communication with others.

Radiology Reading Room Testbed Features

The radiology department at University of Virginia has invested in creating a digital reading room testbed that takes into account the above identified considerations of designing a digital reading room. The testbed contains several alternative workstations, layouts, lighting, seating, etc. and includes ergonomic furniture, with some height-adjustable work surfaces fitted with downward tilting adjustable keyboard trays and an attached mousing platform, advanced computer controlled lighting, acoustic systems, and a consolidated workstation [11]. The ambient lighting was optimized using light-emitting diode lights of different colors for increased energy efficiency, reduced eye fatigue, and decreased lighting contrast. The testbed also features sound-proof walls and sound-absorbing clouds that are located above each radiologist workstation (Fig. 1).

The new reading room was designed to incorporate components to increase collaboration between radiologist and refereeing physicians. The reading room has an open floor design that includes an open reading room environment, sound proof walls, ambient lighting, and walls that can change color (Fig. 2).

Radiologists are only separated by a partition and not in separate or adjacent rooms. The new room allows radiologists to create custom spaces using partitions; it also incorporates open areas for collaboration and areas for privacy. There are other key aspects that help with allowing more collaborative effort. There is a radiology reading pod that allows up to three radiologists to be enclosed to discuss difficult patient cases without being disturbed by the external environment (Fig. 3).

The testbed also has a concierge service, which enables scheduling consults or booking the image interpretation rounding room and provides a quiet space for clinician–radiologist consultations (Fig. 4). The rounding room, or image interpretation theater, features a touchscreen interface that allows interaction with the radiology information system and the PACS software (Fig. 5). It can accommodate up to 15 people and is furnished with swivel chairs, variable lighting, advanced audiovisual systems, and a touchscreen video wall interface.

Theater

This study was undertaken to evaluate the testbed components for a future reading room environment by eliciting users' perspectives. The aim was to assess components of

Fig. 1 Radiologist work stations

Fig. 2 Open floor reading room environment

the environment based on radiologists' satisfaction. The user evaluation survey and musculoskeletal survey establishes a baseline for satisfaction and key improvement opportunities toward the future reading room testbed.

When evaluating any type of design, it is imperative to gain knowledge from actual users of the system. Successful implementation of a design depends on the users' willingness to adopt the new system and their satisfaction. The added significance to our particular study is that we are evaluating a fully functional future reading room design after being used for 3 months to determine which components work well in a radiology reading room environment and which need improvement.

Materials and Methods

The testbed that was evaluated is located in the radiology department at the University of Virginia medical center in Charlottesville, Virginia. The radiology reading room consists of radiologist work stations, one reading room pod, one concierge service, one image interpretation theater, and coordinator workspaces. To date, only chest and neuroradiology radiologist have utilized the reading room testbed.

Fig. 3 Reading room pod

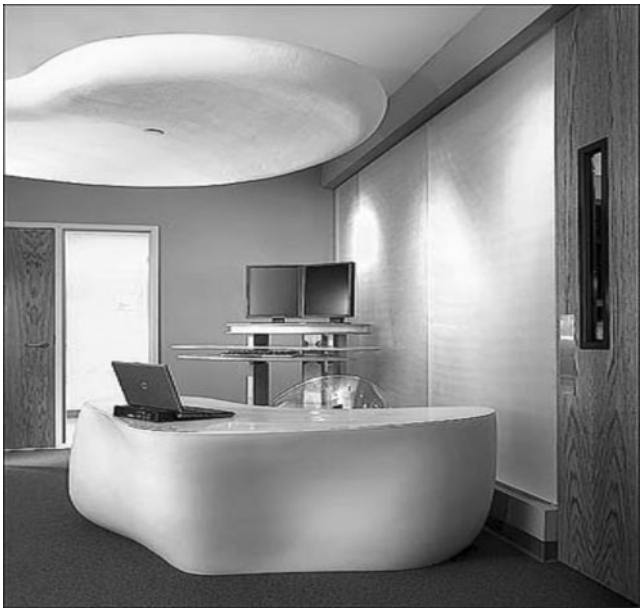


Fig. 4 Concierge service area

User Evaluation Survey

The first survey solicited feedback on the various testbed workspaces and features and was created and validated utilizing qualitative methodologies. Specifically, semistructured interviews were conducted with a neuroradiology attending, chest attending, and radiology administrator, followed by a focus group that was conducted with two chest residents, a neuroradiology resident, and a coordinator. Feedback from the interviews and focus groups helped to focus the questions and categories for

Fig. 5 Image interpretation theater

the survey which were then validated by a neuroradiology attending, chest attending, and administrator to ensure the survey contained pertinent questions that would aid in evaluating the reading room space.

The final survey contained 52 Likert-scale questions (rated on a five-point scale, where 1=very dissatisfied, 2=dissatisfied, 3=neutral, 4=satisfied, and 5=very satisfied), four multiple-choice questions, and five open-ended questions. These were grouped according to five categories (image interpretation theater, concierge service, reading room pod, furniture and workspace, and environmental elements; Fig. 6).

The survey was administered through a web-based software system (Survey Monkey) for a period of 3 weeks. Participants were informed that the survey would be sent via e-mail during a monthly quality assurance meeting that is sponsored by the radiology department. In the e-mail, participants were given a brief description of the purpose of the survey, the link to the survey, and requested to complete the survey by a certain time. The results were collected through the web software and evaluated using Microsoft Excel and SPSS. From the results, the mean and standard deviation were calculated. Although surveys could not be conducted before and after the new radiology reading room was completed, the radiologists were familiar with the previous design and with other comparable reading rooms in the facility.

Musculoskeletal Discomfort Survey

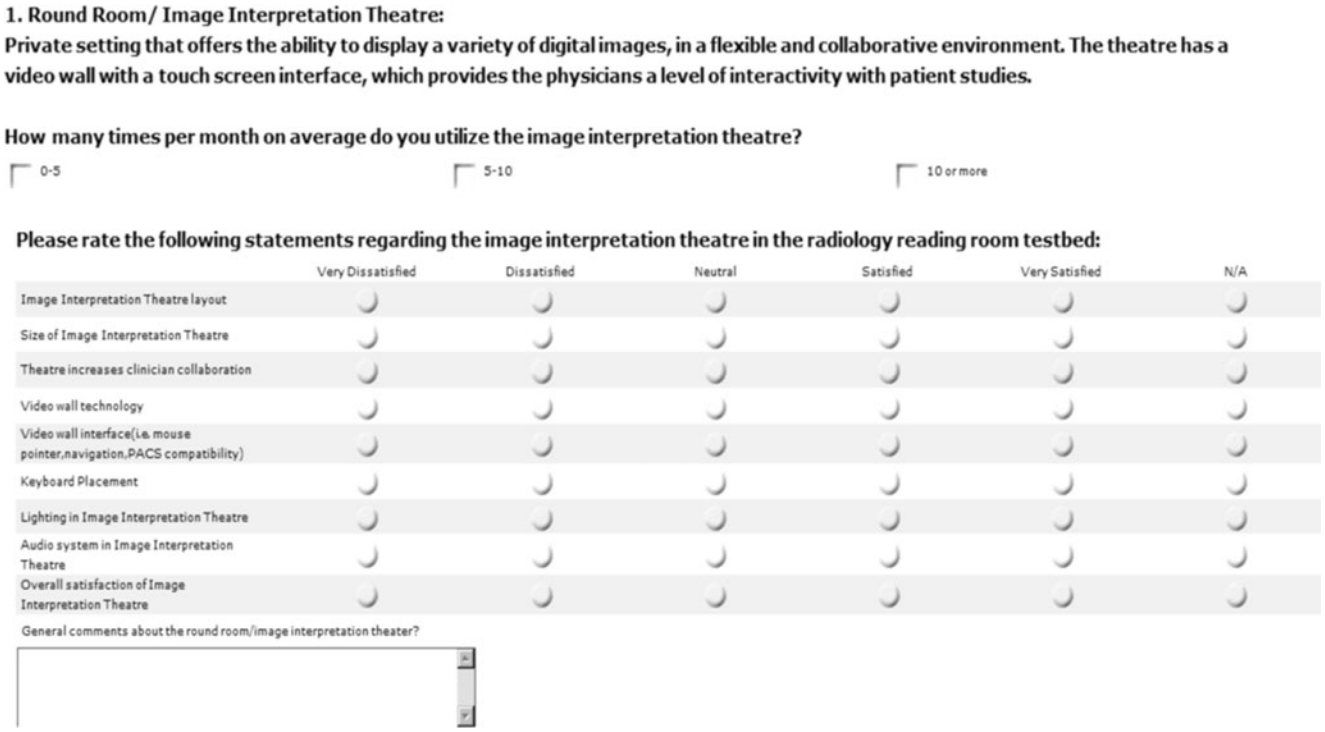
The second survey administered (Fig. 7) was a subset of the Cornell Musculoskeletal Discomfort Questionnaires (CMDQ) [11]. The questions are based on published research studies of musculoskeletal discomfort among workplace personnel [12].

The survey was distributed on paper during morning rounds. Residents in the room at the time were asked to fill out the survey and return it to their modality coordinator. The results of the questionnaires were evaluated using the CMDQ Scoring Guidelines [11]. Specifically, frequencies were scored as: never=0, one to two times per session=1.5, three to four times per session=3.5, everyday=5, and several times every day=10. The Discomfort score was scored as: slightly uncomfortable=1, moderately uncomfortable=2, and very uncomfortable=3. The Interference score was scored as: not at all=1, slightly interfered=2, and substantially interfered=3. The total score is the result of multiplying together the Frequency Score, the Discomfort Score, and the Interference score.

Results

Response Rates and Demographics

All 63 users of the reading room (attendings, fellows, residents, administrators, and coordinators) were recruited



1. Round Room/ Image Interpretation Theatre:
Private setting that offers the ability to display a variety of digital images, in a flexible and collaborative environment. The theatre has a video wall with a touch screen interface, which provides the physicians a level of interactivity with patient studies.

How many times per month on average do you utilize the image interpretation theatre?

0-5 5-10 10 or more

Please rate the following statements regarding the image interpretation theatre in the radiology reading room testbed:

	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	N/A
Image Interpretation Theatre layout						
Size of Image Interpretation Theatre						
Theatre increases clinician collaboration						
Video wall technology						
Video wall interface(i.e. mouse pointer,navigation,PACS compatibility)						
Keyboard Placement						
Lighting in Image Interpretation Theatre						
Audio system in Image Interpretation Theatre						
Overall satisfaction of Image Interpretation Theatre						

General comments about the round room/image interpretation theater?

Fig. 6 Portion of user satisfaction survey

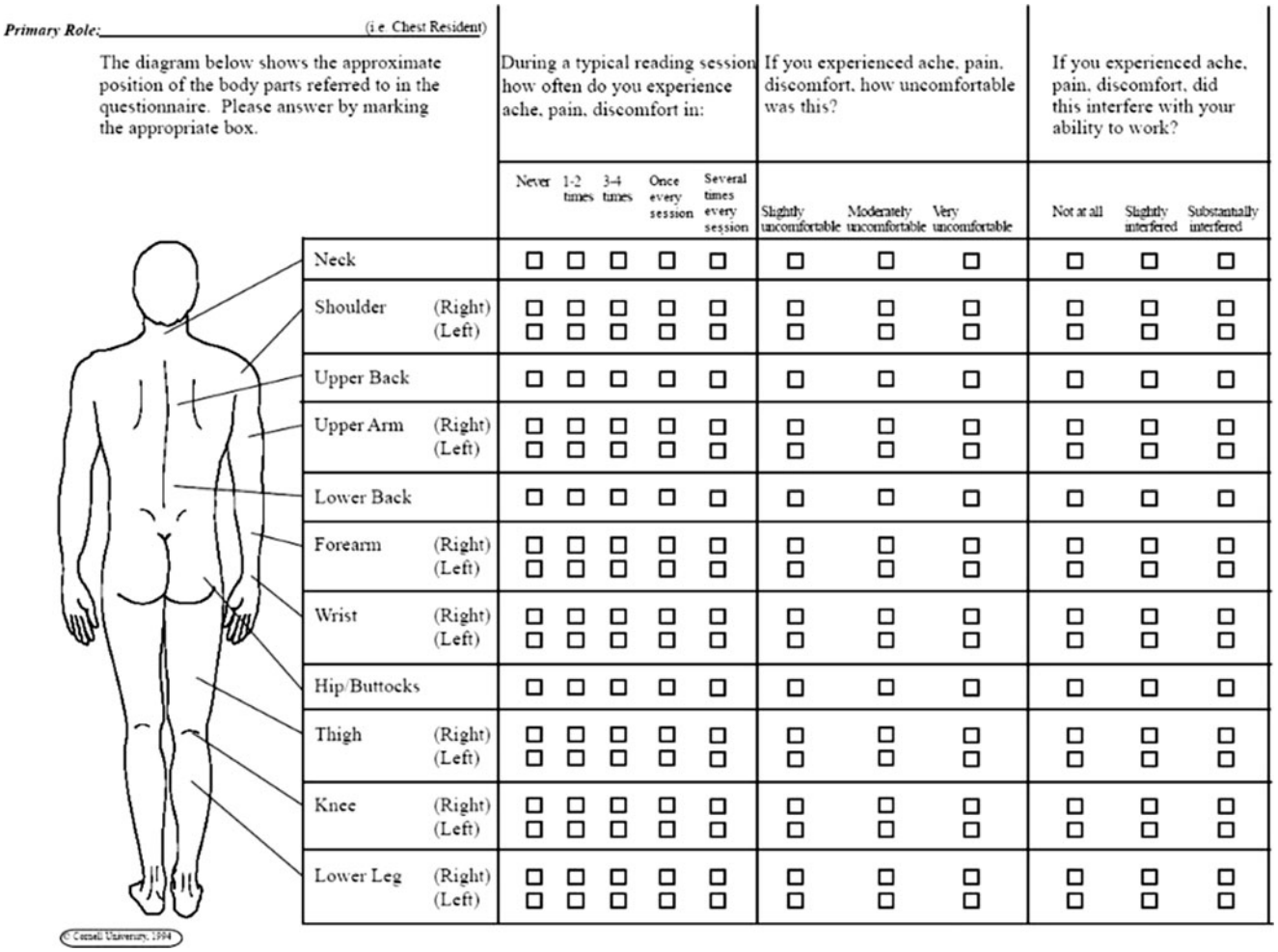


Fig. 7 Musculoskeletal discomfort surveys

to participate in the first survey and 30 responded (47.6% response rate) with the majority of the responses coming from residents and attendants (Table 1). Respondents were allowed to choose more than one primary role for demographic information, i.e., residents choose both chest and neuroradiology resident as primary role.

Table 1 User survey demographics

Category	Number	Percentage
Neuroradiology resident	11	36.7
Chest resident	6	20
Neuroradiology fellow	1	3.3
Chest attending	7	23.3
Nuero attending	5	16.7
Coordinator	6	20
Administrator	1	3.3

Participants were allowed to choose more than one category as their primary role. Six participants choose both chest and neuroradiology. One participant chose coordinator and administrator

The second survey was distributed to 20 neuroradiology and chest radiologsgy residents who currently use the reading room and seven responded (35% response rate). All respondents were male, five chest residents and two neuroradiology residents.

User Evaluation Survey

Results were analyzed using various methods. For each attribute, the mean, response count, frequencies, and percentages were calculated. Inferential statistics were performed on particular questions post hoc to gauge the difference on relationships between attributes. Scores of "1" and "2" were combined and represented as "Dissatisfied". Scores of "4" and "5" were combined and are represented as "Satisfied".

The mean response for satisfaction regarding the furniture and workspace was 3.68 (between neutral and satisfied). Respondents scored many of the categories for the furniture and workspace questions favorably with chair comfort and ease of access to reading room coordinators spaces having a mean average rating of 4.0 or higher (Table 2).

Table 2 Results from furniture and workspace layout questions

Questions	Dissatisfied *n* (%)	Neutral *n* (%)	Satisfied *n* (%)	N/A *n* (%)	Rating average *u* (SD)	Response count *N*
Adequacy of desk space	5 (16.7)	6 (20)	19 (63.4)	0 (0)	3.73 (1.05)	30
LCD monitor placement	2 (7.2)	5 (17.9)	21 (75)	0 (0)	3.89 (0.95)	28
Keyboard & mouse placement	6 (20.7)	4 (13.8)	(19) 65.5	0 (0)	3.45 (1.26)	29
Dictation microphone placement	6 (20.7)	5 (17.2)	18 (62)	0 (0)	3.55 (1.10)	29
Adjustability of desk	7 (23.3)	3 (10)	20 (66.7)	0 (0)	3.7 (1.22)	30
Chair comfort	1 (3.4)	5 (17.2)	23 (79.3)	0 (0)	4.1 (.93)	29
Sufficient space for personal belongings	13 (43.3)	6 (20)	11 (36.7)	0 (0)	2.93 (1.45)	30
Fabric portable dividers between workstations	4 (13.4)	7 (23.3)	19 (63.4)	0 (0)	3.6 (1.11)	30
Open floor layout of reading room	5 (17.2)	6 (20.7)	18 (62)	0 (0)	3.66 (1.30)	29
Layout encourages collaboration between radiologist	4 (14.3)	9 (32.1)	15 (53.5)	0 (0)	3.57 (1.36)	28
Amount of space in reading room	3 (10)	5 (16.7)	22 (73.3)	0 (0)	3.93 (0.94)	30
Ease of access to reading room coordinators spaces	2 (6.7)	5 (16.7)	23 (76.7)	0 (0)	4 (0.86)	30
Reading room testbed enhances radiology workflow	1 (3.4)	14 (48.3)	13 (44.8)	1 (3.4)	3.64 (1.10)	29
Overall comfort of workspace	4 (13.3)	5 (16.7)	21 (70)	0 (0)	3.8 (1.04)	30

Of the respondents, 44.8% scored neutral (rating=3) for the question stating that the reading room testbed enhance radiology workflow. Of the subjects, 43.3% were dissatisfied with the adequacy of space for personal belongings.

The mean average rating for environmental elements was 3.78. The environmental elements questions (Table 3) were rated as satisfied or very satisfied by over 50% of respondents. The only component that had a relatively high level of dissatisfaction (23.3%) was for the translucent wall panel that periodically changes colors. There was also a small subset of users who expressed some dissatisfaction with the other features. The most successful feature seems to be the independently controlled lighting at workstations. For the open-ended questions, 12 respondents made positive comments pertaining to the overall comfort of the environment. In addition, the commentary also included comments about the sound-masking features.

The Reading Room Pod questions (Table 4) had the most variability for respondents in terms of dissatisfaction. The best performing parameters, with a median score of 3 or 4, included LCD monitor placement, keyboard and mouse placement, adjustability of desk, air flow, and temperature, lighting, and noise level.

Features rated low (median value 1 or 2) were layout, desk/workspace, chair comfort, increased clinical collaboration, and overall satisfaction. These results indicate that improvements are definitely required in the reading room pod area, particularly in overall layout, chair comfort and desk/workspace, where the percentage of dissatisfaction was 46.5%, 50%, 59.2%, and 50%, respectively. This is also consistent with comments from open-ended questions, “the monitor layout was very inconvenient, as was the bench seating”; “Workstation is not ergonomic or user friendly, especially mouse and keyboard arrangements”.

Table 3 Results from environmental elements questions

Questions	Dissatisfied *n* (%)	Neutral *n* (%)	Satisfied *n* (%)	N/A *n* (%)	Rating average *u* (SD)	Response count *N*
Air flow in the reading room	3 (10.3)	6 (20.7)	19 (65.5)	1 (3.4)	3.75 (1.21)	29
Temperature in the reading room	3 (10)	5 (16.7)	21 (70)	1 (3.3)	3.79 (1.04)	30
Sound masking features (i.e., sound absorbing ceiling panels and wall panels)	5 (16.7)	7 (23.3)	10 (56.6)	1 (3.3)	3.59 (1.28)	30
Music and white noise systems	3 (10.3)	8 (27.6)	14 (48.2)	4 (13.8)	3.6 (1.57)	29
Translucent wall panel	7 (23.3)	5 (16.7)	16 (53.4)	2 (6.7)	3.57 (1.44)	30
Independently controlled lighting at private workstations	1 (3.3)	6 (20)	22 (73.3)	1 (3.3)	4.03 (1.04)	30
Overall lighting in reading room	3 (10)	2 (6.7)	24 (80)	1 (3.3)	4.07 (1.03)	30
Overall noise level in reading room	4 (13.3)	4 (13.3)	21 (70)	1 (3.3)	3.76 (1.10)	30
Overall comfort of reading room environment	3 (10.3)	6 (20.7)	19 (65.5)	1 (3.40)	3.86 (1.29)	29

Table 4 Results from reading room pod questions

Questions	Dissatisfied *n* (%)	Neutral *n* (%)	Satisfied *n* (%)	N/A *n* (%)	Rating average *u* (SD)	Response count *N*
Reading room pod layout	13 (46.5)	6 (21.4)	7 (25)	2 (7.1)	2.58 (2.10)	28
Desk/workspace in reading room pod	14 (50)	5 (17.9)	7 (25)	2 (7.1)	2.62 (1.94)	28
LCD monitor placement in reading room pod	7 (25.9)	6 (22.2)	12 (44.4)	2 (7.4)	3.16 (1.31)	27
Keyboard & mouse placement	9 (33.3)	7 (25.9)	9 (33.3)	2 (7.4)	2.88 (1.40)	27
Adjustability of desk	8 (29.6)	5 (18.5)	12 (44.4)	2 (7.4)	3.08 (1.30)	27
Chair comfort	16 (59.2)	3 (11.1)	6 (22.2)	2 (7.4)	2.08 (1.34)	27
Air flow in reading room pod	6 (23)	9 (34.6)	9 (34.6)	2 (7.7)	3.08 (1.17)	26
Temperature in the reading room pod	4 (14.8)	9 (33.3)	12 (44.4)	2 (7.4)	3.32 (1.01)	27
Lighting in reading room pod	1 (3.7)	9 (33.3)	15 (55.5)	2 (7.4)	3.64 (1.19)	27
Noise level in reading room pod	2 (7.4)	5 (18.5)	18 (66.6)	2 (7.4)	3.88 (1.40)	27
Reading room pod increases clinician collaboration	10 (37)	8 (29.6)	5 (18.5)	4 (14.8)	2.57 (1.68)	27
Overall satisfaction of reading room pod	12 (42.9)	7 (25)	7 (25)	2 (7.1)	2.65 (1.30)	28

There are a number of N/A responses and the response rate is variable due to lack of use of the reading room pod. Two respondents did not answer the questions and two marked N/A across the board. The respondents in the categories consisted of coordinators, $n=4$ commented that they "don't use" the reading room pod.

There were a number of similarly asked questions that enable us to compare respondents' ratings of the reading room pod environment vs. the radiologist workstations. A correlation analysis was done to see if there is a difference in satisfaction based on the environment (Table 5). The analysis focuses on the satisfaction of residents, fellows, and attendants since they utilize both environments. Utilizing a *t* test to compare means, we find that there is a significant difference in means with *P* value <0.05 for all elements listed in Table 5.

The next set of questions focused on the Concierge Service (Table 6). For questions concerning availability of concierge, process of arranging consults, and process of reserving interpretation theater through the concierge, it is worth noting that respondents marked "Not Applicable" 31%, 42.9%, and 39.30%, respectively. There is a large percentage of N/A due to that lack of knowledge about the concierge service. In this case, five respondents marked 0 across the board and 12 respondents wrote in the open-ended question "I have no idea what the concierge is supposed to do." To further understand the differences between coordinators/administrators and radiologist and their knowledge of the overall understanding of what the concierge does, an analysis of variance using the nonparametric Kruskal–Wallis statistic was utilized to see if there are any difference among classification categories. The difference in response was significant $p=0.036$, with the highest mean ranks belonging to the administrator and coordinators at 34.5 and 27.3, respectively.

Table 7 shows the results from the Image Interpretation Theater section. Over 50% of respondents scored the questions 4 (satisfied) or 5 (very satisfied), except in three categories: video wall interface, keyboard placement, and audio system in theater. This corresponds with feedback from the open-ended questions that indicated problems with a lag in the keyboard and video wall interface. For the audio system, 42% of subjects marked N/A. The open-ended comments validate the high percentage of N/A for

Table 5 Reading room pod vs. radiologist workstations

Questions	Reading room pod mean (SD)	Radiologist workstations mean (SD)	*P* values
Keyboard and mouse placement	2.5 (1.35)	3.4 (1.26)	0.002
Adjustability of desk	2.9 (1.38)	3.7 (1.22)	0.006
Chair comfort	1.8 (1.31)	4.1 (.93)	0.001
Air flow	3 (1.21)	3.8 (1.12)	0.006
Temperature	3.1 (1.26)	3.7 (1.10)	0.026
Lighting	3.5 (1.29)	4 (1.16)	0.073
Noise level	3.7 (1.44)	3.6 (1.39)	0.82
Increases clinician collaboration	2.1 (1.46)	3.5 (1.10)	0.001
Overall satisfaction	2.4 (1.21)	3.75 (1.04)	0.001

Table 6 Results from concierge service questions

Questions	Dissatisfied *n* (%)	Neutral *n* (%)	Satisfied *n* (%)	N/A *n* (%)	Rating average *u* (SD)	Response count *N*
Availability of concierge	3 (10.3)	2 (6.9)	15 (51.7)	9 (31)	3.9 (1.22)	29
Process of arranging consults	3 (10.7)	3 (10.7)	10 (35.7)	12 (42.9)	3.63 (1.42)	28
Process of reserving Interpretation theater	1 (3.6)	4 (14.3)	12 (42.9)	11 (39.3)	3.88 (1.44)	28
Desk space in concierge area	2 (7.1)	3 (10.7)	16 (57.2)	7 (25)	3.76 (1.52)	28
Layout in concierge area	3 (11.1)	2 (7.4)	16 (55.5)	7 (25.9)	3.7 (1.13)	27
Sound and lighting level in concierge area	4 (14.8)	1 (3.7)	15 (55.5)	7 (25.9)	3.5 (1.60)	27
Overall understanding of what the concierge does/can do	6 (21.4)	5 (17.9)	12 (42.8)	5 (17.9)	3.39 (1.06)	28
Overall satisfaction of concierge service	2 (14.2)	1 (3.6)	15 (53.6)	8 (28.6)	3.7 (1.52)	28

the audio system in that respondents stated "not aware of the audio system capabilities".

Musculoskeletal Discomfort Survey

Table 8 shows total discomfort scores for each respondent of the musculoskeletal discomfort survey. The total score gives an assessment of the severity of discomfort during a typical reading session. The results showed that respondents only felt discomfort in the neck, shoulder, lower back, and forearm areas while reading at the radiologist workstation. All of the other areas received a score of 0. The highest score (20) found in the survey was for respondent 6 in the lower back area, which is only approximately 22% of the maximum possible score of 90, and this indicates very little discomfort in the new ergonomic design.

Discussion

Focusing on the importance of radiologist's satisfaction, our survey establishes a baseline for satisfaction and key improvement opportunities on the innovative radiology reading room design. The goal of this study was to assess the different features of a new radiology reading room testbed by obtaining the opinion from direct users of the system after 3 months of use. Overall, the satisfaction rating for components of the future reading room design was satisfied. However, there were some components where key improvements and recommendations can be made. The concierge service had a high number of "N/A" responses marked by respondents. For instance, the process of arranging consults and reserving the interpretation theater through the concierge service was marked as N/A for many respondents: 42% and 39%, respectively. To investigate the high number of "N/A" responses, we looked on a respondent by respondent basis and found that all participants marking N/A were radiologists. We can conclude that they have a lack of knowledge about the services the concierge provides, which corresponded to their responses to the open-ended questions, "It is not clear to me how, if at all, the concierge affects the process of discussing cases with clinicians. The clinicians still seem to just walk into the reading room to find someone"; "No idea what the concierge does, I have never used it." The concierge service has the potential to serve as a mediator to help foster more

Table 7 Results from image interpretation questions

Questions	Dissatisfied *n* (%)	Neutral *n* (%)	Satisfied *n* (%)	N/A *n* (%)	Rating average *u* (SD)	Response count *N*
Image interpretation theater layout	2 (7.2)	4 (14.3)	19 (67.8)	3 (10.7)	3.88 (1.60)	28
Size of image interpretation theater	2 (7.1)	4 (14.3)	19 (67.8)	3 (10.7)	3.92 (1.62)	28
Theater increases clinician collaboration	3 (10.7)	5 (17.9)	16 (57.1)	4 (14.3)	3.67 (1.50)	28
Video wall technology	4 (14.3)	4 (14.3)	17 (60.8)	3 (10.7)	3.72 (1.42)	28
Video wall interface(i.e. mouse pointer, navigation, PACS compatibility)	9 (31)	5 (17.2)	10 (34.4)	5 (17.2)	3.08 (1.07)	29
Keyboard placement	4 (14.3)	8 (28.6)	11 (39.2)	5 (17.9)	3.35 (1.16)	28
Lighting in image interpretation theater	0 (0)	2 (7.1)	22 (78.6)	4 (14.3)	4.21 (.90)	28
Audio system in image interpretation theater	5 (17.9)	3 (10.7)	8 (28.6)	12 (42.9)	3.25 (1.05)	28
Overall satisfaction of image interpretation theater	4 (14.3)	4 (14.3)	16 (57.1)	4 (14.3)	3.63 (1.55)	28

Table 8 Results from muscoskletal discomfort survey for each of the 7 respondents

	Respondents						
Body parts	1	2	3	4	5	6	7
Neck	0	14	0	3.5	0	14	5
Shoulder							
Right	0	10	0	1.5	0	5	0
Left	0	0	0	0	0	0	0
Upper back	0	0	0	0	0	0	0
Upper arm							
Right	0	0	0	0	0	0	0
Left	0	0	0	0	0	0	0
Lower back	1.5	10	3.5	0	1.5	20	3.5
Forearm							
Right	0	10	0	7	3.5	5	3.5
Left	0	0	0	0	0	0	0
Wrist							
Right	0	0	0	0	0	0	0
Left	0	0	0	0	0	0	0
Hip/buttocks	0	0	0	0	0	0	0
Thigh							
Right	0	0	0	0	0	0	0
Left	0	0	0	0	0	0	0
Knee							
Right	0	0	0	0	0	0	0
Left	0	0	0	0	0	0	0
Lower leg							
Right	0	0	0	0	0	0	0
Left	0	0	0	0	0	0	0

radiologist to ordering clinician collaboration if utilized properly. This issue can be improved upon by training the radiologists on the fundamental purpose of what the concierge does.

The reading room pod had a low satisfaction rating, with 42.9% of respondents dissatisfied with it overall. The factors that attributed to this included chair discomfort, keyboard and mouse placement, and inadequate space. There is sufficient room for one radiologist to dictate but not for consultations. The purpose of the reading room pod was to serve as a way for radiologists to discuss difficult cases in a group setting of two to five people. However, the overall affect of the environment was viewed negatively by radiologists and does not serve its sole purpose. Compared to the regular radiologist workstations, the reading room pod environment was significantly lower in terms of satisfaction. The cost-to-benefit ratio of the reading room pod is low and should be excluded from future reading room designs if not enhanced. The image interpretation theater, on the other hand, was seen as an added benefit for radiologists since it provides a space for rounds using an interactive touchscreen but a current issue with its design is that there is a lag between the mouse and keyboard with the interface and radiologists are unaware of the audio system capabilities.

There were several limitations to this study. One is that N/A was added as a scoring choice in the survey due to the fact that some of the questions only pertained to radiologists but coordinators also participated in the survey and vice versa. The coordinators which were included in the survey do not utilize the reading room pod and image interpretation spaces and therefore a high percentage of respondents marked N/A for this category. Most radiologists had not used the concierge service and thus a high percentage marked "N/A" for questions related to this service. Compared to questions regarding the furniture and environmental elements, there is a lower percentage of "N/A" respondents since everyone surveyed are exposed to these elements.

The musculoskeletal discomfort survey assessed whether the furniture incorporated in the reading room design concept was in fact ergonomically friendly and would aid in the comfort of the radiologist. In order to be productive, radiologists must be comfortable and not feel pain or discomfort while reading images for long periods of time. Researchers [2, 12–14] have investigated the severity of how poor ergonomics of workspace furniture in the reading room can hinder radiologist productivity. In most reading rooms, carpal tunnel syndrome is found to be the most prevalent discomfort among radiologists. None of the survey respondents indicated discomfort in the wrist area. The only discomfort was found in the lower back area but the level of discomfort was low. The results indicated that the radiologists found the ergonomically designed furniture in the new reading room to be comfortable overall. There is no baseline data (pretest) of discomfort in the older radiologist reading design, but low ergonomics problems found from the survey suggest that the furniture is not causing any problems or bothering radiologists. We can conclude that the furniture is relatively safe since there is no indication of severe or increased pain from respondents.

Many of the components in the testbed design were implemented to help enhance collaboration among fellow radiologists and between radiologists and referring clinicians. The image interpretation theater and radiologist workstation environment had a mean rating of 3.67 for the question regarding "enhances clinician collaboration" (commentary: "Love the room. It's the only room in the department that's comfortable to work in and encourages collaboration. It's great."). The reading room pod had a mean rating of 2.57 for the aforementioned question (commentary: "The pod is almost never used for consultation with clinicians. It is very uncomfortable to work in, and the space it takes up would be better used for extra workstations")

The feedback from these surveys is being taken into account to further improve and expand on the radiology reading room testbed. In the open-ended questions, many users complained about the mouse and keyboard interface utilized in Image Interpretation Theater. This has been improved by decreasing the lag between the mouse and keyboard to the PACS interface. There were also complaints by the radiologist about the mouse placement and comfort at the radiologist workstations. To compensate, the department ordered padding for hand placement on the mouse and to help guide the mouse better. There is still a need to educate and train users of the reading room on the purpose of the concierge service and all of the features that the reading room offers. This will also aid in the design of radiology workspaces in the future.

Conclusion

The survey results indicate that overall the users of the system are satisfied with the new workstations, lighting, concierge service, and image interpretation theater but not satisfied with the reading room pod. The concierge service requires more education on its purpose as many did not understand its key functions.

Historically, radiology departments and the spaces where radiologists read films were designed around basic determinants: space needed, lighting, and room location. More recently, digital technology has replaced conventional film and this has changed the reading room design requirements. A more current design model must consider different determinants: work process, relationship between design and process, ergonomics and technology needs, radiologists' comfort, health and productivity, and flexibility to accommodate future needs. Many healthcare organizations are trying to adhere to this new model pertaining in the design of their reading room environments. The future reading room design concept at the UVa Health System aims to improve upon current radiology reading room designs by incorporating features designed to address these factors.

Results from this study suggest that an evaluation of a reading room space from the actual users can lead to improved design in terms of increasing radiologist satisfaction and productivity and establishing baseline evaluation data. By evaluating a fully functional testbed, healthcare administrators can examine potential problems with the testbed design before actually implementing the designs on a larger planning infrastructure. This helps in associated cost for hospitals to save money on new designs by evaluating a small-scale implementation. An optimal radiology reading room design will depend on input and feedback from actual users of the system in order to be efficient and effective.

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