Environmental Designs for Reading from Imaging Workstations: Ergonomic and Architectural Features

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Despite the rapid progress made in the electronic design of imaging workstations for medicine, much less effort has gone into the design of environments in which such systems will be used. Based on studies of radiologist film reading sessions, considerable time will be spent working at such viewing systems. If the rooms in which the workstations are placed are not conducive to comfortable work, it will certainly not favor electronic viewing over film reading. In examining existing reading environments, it is also apparent that they are not optimum, even for film. Since some of the problems for film and electronic viewing overlap, such as heat generation (by the alternators, viewboxes, or workstation electronics) and glare from light sources, it should be possible to develop solutions which are applicable to both environments or to rooms which will feature both viewing systems. This paper will discuss some of the approaches to designing environments in which viewing of images is supported by the room architecture and engineering and not degraded by it. To illustrate these points, a design based on the constraint of a real room size and available architectural materials will be developed.

INTRODUCTION

AT THE SPIE MEDICAL IMAGING MEETING last year, we presented a paper which examined ergonomic features of radiology workstations and reading environments.¹ Both prior to and since that time, extensive work has been done on the design of such workstations to better suit the tasks which medical imaging specialists perform, and to make such performance more efficient from human factors and productivity viewpoints.²⁻¹⁰ In particular, analysis of the work patterns of radiologists⁷⁻⁹ have been combined with advances in person-computer interaction (user interfaces) resulting in viewing and reading systems which are far ahead of older approaches.^{6,8,10}

In addition to the workstation itself, we also examined the environment in which such equipment will be used. Unfortunately, aside from the paper by Bart ter Haar Romeny *et al.*,¹¹ little attention has been given in the medical imaging literature to such environmental design. The problem has both architectural and engineering concerns, and requires not inconsiderable use of human factors design principles. We have had the opportunity to work on design of a reading area within the Department. This area will support conventional film as well as PACS workstation reading, and will be used by the Abdominal Imaging Division. As such, a combination of plain film, CT, MRI, and ultrasound cases will be interpreted. This new reading room is a renovation of an existing space, and so is subject to the constraints of existing bearing walls, columns, and major ductwork.

We will examine the design for this space with discussion of the principles employed.

FACTORS IN WORKSPACE DESIGN

There are two excellent books on designing radiology departments,^{12,13} and both discuss some elements of reading room design. Both

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volumes were written before electronic PACS became a serious alternative to film-based operation. However, some of the basic design considerations are not altered by switching to softcopy reading.

Often a first consideration is to determine the amount of **available space** to house the reading area. Finding space is a problem in any health care facility we have seen. Even if a new structure is being built, space may be at a premium because of high construction costs or available lot size. More commonly, one will be faced with finding space in an existing facility, or modifying what facility is available. Scott¹³ recommends about 8 by 10 feet (2.6 by 3 meters) for each person reading. Since a four-panel viewbox array, an alternator, and a four-monitor PACS workstation have about the same width (5 to 7 feet or 1.6 to 2.3 meters) this estimate is a reasonable one. It certainly allows for the one or two other people usually present in a teaching hospital setting, and can accommodate more for shorter periods of time. The room we will be working with consists of two spaces, the larger 20 by 24 feet (6 by 7.3 meters) and the adjacent smaller space 7 by 10 feet (2.1 by 3 meters). The outer perimeter of the space is constrained by bearing walls and existing other services which cannot be relocated. Figure 1 shows the plan of the existing space.

Fig 1. Floor plan of the existing reading room.

The **use** to which the room will be put has a great impact on the space required as well as a number of other considerations. For a reading room, the main activity is interpreting examinations. Often, however, such rooms may be used for short conferences, consultation with referring physicians, and teaching. Unless there is a requirement to provide services other than for those associated with film reading, it is simpler to design based on the predominant use. Combination use rooms often, but do not always, involve some compromise of one or the other function. For example, in a reading room also used for lengthy conferences, slide projection requirements may preclude optimum placement of viewboxes or light-baffling walls. The room we are renovating will be used primarily for film reading. Associated teaching and consultation is supported at the reading stations at present and in the future. Despite the common picture of radiologists relatively fixed at their reading stations, in fact, there is a lot of movement of people in and out of the reading area. The radiologist may move to another reading area for consultation, leave temporarily to attend to a patient having a procedure done, or move to a different place to make or answer a phone call. Similar actions are done by the housestaff, and different ones by referring physicians and fileroom personnel. All of this points to a high-traffic area, so that in these ways, the use defines the required **access**.

Fire and building codes will fix the number and placement of exits from a space. In addition to emergency egress, though, access is also involved with movement of people to other areas as they do their work. A facility such as a main or large satellite reading room needs to be accessible to virtually anyone in the department. It should not, however, be located so as to serve as a general traffic corridor, nor should such use be encouraged, as it is disruptive to the work of the radiologist. Aside from the radiologists working in the room and referring physicians coming in to look at examinations, there are technologists, clerks, transcription personnel, secretaries, administrators, and housekeepers (this list being based on access frequency and not on job importance, though cynics might assume otherwise) who regularly need to go to the reading area. It is impossible to make such a

facility easily accessible to all of these people. Rather, since the radiologists are most dependent on the space, some thought should be given to optimizing the location of the room for access to the areas they need to reach often. In the instance of our reading area, it is located proximate to the CT rooms, the ultrasound laboratory, and the Abdominal Division offices. In fact, it is relatively central to these, with CT across the north corridor, ultrasound to the west side, and the offices south. The MRI facility is located remotely, owing to the usual siting problems of such facilities, but is a short walk and elevator ride away.

In support of the uses of the reading room, we need to consider supporting **services**. Heating, ventilation, and air conditioning (HVAC), electrical power, communications, illumination, and acoustic control are typical factors which we will include with services. All of these will be discussed in more detail in subsequent sections of this paper. While all of these are part of the environment, electrical power requirements and communications systems have less of an immediate impact on bodily comfort than the other listed items. Providing these services for a workspace requires the coordination of several types of designers and contractors. A good architect will work with the client and the client's contractors so that the construction proceeds as smoothly as possible. In our design stage, we have evaluated the services necessary and will be proceeding with additional engineering detail needed for actual construction.

At the base of any workspace design, be it new or renovation, is the **budget** allotted for the project. This may determine what kinds of solutions to problems can be realistically implemented. Again, a good architect serves the client by being able to provide a number of possible solutions to any problem, so that an optimum design can be achieved for any budget level.

TASKS AND ENVIRONMENT

The major task to be supported in a reading room is the interpretation of medical images. However, this consists of a number of smaller tasks. A number of these were described in a very detailed fashion in the paper by Rogers

*et al.*¹⁴ and in a more general fashion by Mun *et al.*¹⁵ Aside from looking at images on alternators or workstations, a large amount of writing is done, results are dictated, and teaching is often incorporated into these processes. This means that facilities to support these activities must be provided, and features of the room should not hinder any task to a significant degree, or preferably not hinder any task at all. Some of these actions have requirements which are contrary to others. For example, image reading is best done with as little ambient light as possible, but some light is needed for writing and for searching through film folders.

The devices which need to be located in the room are also based on the work to be done. Film alternators and workstations are the equipment we have designed for. However, report generation requires some form of dictation system, and consultation requirements force heavy dependence on telephones. Because we have found that telephone use may be quite frequent, it would benefit users if the phones were located on the workstation or alternator tables, or were at least within reach without standing up.

The environment can be thought of as a combination of the physical space or structure, the services provided, and the equipment and people within. In addition to the size and layout of the room we are working with, there are ceiling constraints (fixed ducting) and flooring systems (raised flooring) to be considered. The fixed ducting to some extent affects placement of lighting fixtures. The raised flooring is an advantage in that it allows for very easy re-routing of cables, but does require more maintenance than plain flooring (the supports may get out of alignment, resulting in panels which rock a bit). The floor plan of our existing space with the equipment as located is shown in Figure 2. The changes made to the layout will be to move the existing neuroradiology reading area to a different location (which will probably not involve equipment relocation), moving GI/GU into the room, and relocating the two IMACS workstations for better user access. Figure 3 shows the changes to be made in the walls and alternator locations. Not shown are a number of storage shelves and cabinets to be used to house books, selected films, and other items

Fig 2. Existing reading room with major equipment.

used by the radiologists. This design is felt to be adequate given that approximately the same number of people will be using the room, and no new equipment is being added. This latter factor means that new electrical power and HVAC changes are not required for the larger reading area. The IMACS workstation (an A T & T CommView EDW4) for ultrasound is in a new location, and its heat load of 8500 BTU/hr (2144 Kcal/hr) will be considered.

Structural requirements may also have to include floor loading and vibration studies, and some local building codes will affect the impact of these issues on any design. Addition of heat sources or expanding a facility for a larger number of people will have to take these into account when considering HVAC requirements.

COMFORT FACTORS

Most important to the users of any given space is how comfortable they will be when

Fig 3. Reading room redesign with equipment placement.

using it. Quite separate from the user interface issues raised by electronic workstations are those things which directly affect comfort. These factors include seating, heat, noise, and light. Though people can operate within wide ranges of these variables, adverse values will impair function either temporarily or permanently (chronic exposure to high noise levels, for example, can do both). In some instances, the degree of impairment may not be noticed by the person working, but various measurements will show distinct performance losses.¹⁶

We have found that reading sessions may last from fractions of an hour to four hours,¹⁷ so that comfortable seating is a must. The "ergonomic" design chair has become quite popular in offices in which video display terminals (VDTs) are used. The major features of these chairs are adjustability, good low back (lumbar) support, arm rests (for keyboard users), and good padding. There are apparently a set of ANSI standards for such chairs, though the authors have not seen them. We have found this type of chair to be acceptable to the radiologists, and are presently in use in some reading rooms and offices.

The HVAC design should, having taken into account the equipment and personnel heat load, maintain the room temperature in a comfortable range. For most people, this range changes with seasons, but is approximately 63-71° F (17.2-21.7° C) in winter, and 65-75° F (18.3-23.9° C) in summer.¹⁸ The relative humidity of the air affects perceived temperature, and the most comfortable range is from about 20 to 60 per cent at 75° F.¹⁹ Electronic equipment is also constrained by temperature and humidity, but will generally operate well in the same ranges as those for which people are comfortable.

Sound is one of the environmental factors which is highly subjective. Most of us know that sounds may be irritating or not depending on the context. A newborn's first cry is probably music to most ears, but a child's cry which wakes one in the middle of the night is hardly so. It is sound quality as well as loudness and context which alter its perception. Noise is thought of as sound which is unwanted. Despite these problems defining noise, most designers think that an office-type workspace has a noise threshold of about 58dBA.²⁰ There are specific

OSHA limits for sound exposures, but these are for sound levels far above what should be encountered in any reading room environment. Standard methods for noise control are in a selection of materials for ceiling, floor, and walls. Acoustical ceiling and carpet are excellent sound absorbers, and matte wall finishes or even acoustic absorption panels on the walls are better than plain gloss or semi-gloss wall treatments.

Lighting is, we feel, one of the most critical issues to be faced in reading room design. This is particularly true for rooms in which CRT displays will be read as their brightness is usually less than that of film on a viewbox. As described previously, the tasks of reading images and writing notes will have opposite lighting requirements in a radiology reading room. Aside from general room illumination and task lights, the image displays themselves (whether CRT or alternator) are a source of additional light. The problem is that the lighting may result in glare from CRT screens or from film, and this may impair reading by reducing contrast sensitivity of the eye or by fatiguing the iris.²¹ The curved screens of CRTs are an additional complication in that they reflect light sources from a wider angle than a flat screen or film. In our reading room at present, most task lighting is stray light from the alternators. All the ceiling lights are usually turned off. This poses some problem for the IMACS workstation as some illumination is needed to see the keyboard and control panel.

Glare is a problem for at least two reasons. The first is that the glare light will cause the pupil to constrict more than it would if there were no glare. This results in less of the information illumination getting to the retina. Secondly, the glare source can result in veiling glare within the eye itself. This results from the scattering of light by the vitreous portion of the eye, and is increased with extraneous light entering the eye.

Lighting design is often aimed at achieving some brightness on the work surface and is adjusted for the task to be performed. This rarely takes into account the problems posed by glare, but with increasing use of VDTs, some lighting manufacturers are designing systems which control the output light beam. Figure 4 is

Fig 4. Screen glare from a diffuse luminaire.

a schematic illustration of the glare problem posed by a diffuse light source, and Figure 5 shows how this is reduced by using a directional luminaire (the term for a lamp plus fixture). Tilt and swivel monitors help relieve the glare problem to some degree, but may not be practical for all workstations.

Other methods of reducing the reflection from CRT screens include etching the envelope glass, coating the glass, and placing filters or screens over the tube. Etching the glass reduces specular reflection, but also blurs the image on the phosphor, reducing the apparent spatial resolution. Antireflection coatings work well, but suffer from sensitivity to fingerprints and smudges. Frequent cleaning of such screens is a must. Filters work by attenuating the light reflected off the tube more than the light coming from the tube, since the reflected light passes through the filter twice. Filters themselves are subject to reflection from their surfaces. Screens

Fig 5. Reducing glare with a directional luminaire.

act as collimators, but are subject to collecting dirt. For high-resolution displays, the mesh of the screen may be visible. The monitors in our workstations all use antireflection coatings.

One consistent problem we have seen in reading room design is in the placement of viewboxes and alternators. Placement on opposing walls with the reading surfaces facing each other should be avoided if at all possible. Even placement on orthogonal walls can result in glare problems for anyone not viewing normal to the illuminator surface. Unfortunately, even some texts²² violate this principle in example designs. This is not a problem if the two sets of viewboxes or alternators are never used simultaneously, for the unused one is simply turned off.

We have given a great deal of attention to the lighting problem. The overhead ambient lighting plan uses a luminaire design (Lithonia Optimax) which has been widely used in VDT-intensive offices. A number of lighting manufacturers are now addressing this problem, so that architects have a choice of vendors. Overhead lighting on dimmers can further control brightness. Local fire codes may restrict very low illumination levels, and some consideration must be given to special lighting for exits in this regard. Also, good solutions for task lighting at a workstation are difficult to find. One problem is that some task lighting, when bright enough to read or write by, illuminates a user's face or clothing enough for them to become a glare source.

Figure 6 shows the existing reflected ceiling plan and light sources. Figure 7 puts this together with the equipment in the room. None of the ceiling lights is directional, and this is a major reason for turning them all off during reading sessions. Figure 8 shows the proposed reflected ceiling plan using the highly directional luminaires. We would provide separate switch/dimmer controls for the luminaires nearest the equipment so that their brightness could be individually adjusted.

CONCLUSION

We have tried to provide an outline of room design based on conventional architectural principles applied to the problems posed by

Fig 6. Existing reflected ceiling plan.

Fig 7. Existing reflected ceiling plan and major equipment.

Fig 8. Proposed reading room design.

electronic image displays. In addition to the usual concerns about the equipment (powering it, cooling it, and paying for it) the most successful environments for the equipment will be those in which human factors have been given equal or more consideration than equipment requirements alone.

REFERENCES

1. Horii SC, Horii HN, Kowalski P: An eclectic look at viewing station design. Proc. SPIE v. 914, Medical Imaging II, pp 920-928, 1988
2. McNeill KM, Fisher III HD: A model for radiologic workstation user interface design. Proc. SPIE v. 767, Medical Imaging I, pp 713-716, 1987
3. Taira RK: Operational characteristics of pediatric radiology image display stations. Proc. SPIE v. 767, Medical Imaging I, pp 571-576, 1987
4. Schuttenbeld HHW, ter Haar Romeny BM: Design of a user interface for a PACS viewing station. Proc. SPIE v. 767, Medical Imaging I, pp 844-848, 1987
5. Beard D, Pizer SM, Rogers D, Cromartie R, Desirazu S, Ramanathan S, Rubin R: A prototype single-screen PACS console development using human computer interaction techniques. Proc. SPIE v. 767, Medical Imaging I, pp 646-653, 1987
6. Fuchs H, Pizer SM, Creasy JL, Renner JB, Rosenman JG: Interactive, richly cued shaded display of multiple 3D objects in medical images. Proc. SPIE v. 914, Medical Imaging II, pp 842-849, 1988
7. McNeill KM, Seeley GW, Maloney K, Fajardo L, Kozik M: Comparison of digital workstation and conventional reading for evaluation of user interfaces in radiology. Proc. SPIE v. 914, Medical Imaging II, pp 872-876, 1988
8. Beard D, Creasy JL, Symon J, Cromartie R: Experiment comparing film and the FilmPlane radiology workstation. Proc. SPIE v. 914, Medical Imaging II, pp 933-937, 1988
9. Good BC, Cooperstein LA, Gur D: Radiologists' perceptions of and preferences for a concise history form during radiologic interpretation. Proc. SPIE v. 914, Medical Imaging II, pp 970-975, 1988
10. Ratib O, Huang HK: Integration of a desktop image analysis work station based on a Macintosh II computer in a clinical PACS. Scientific Exhibit # 915, RSNA 74th Sci. Ass. and Ann. Meeting, Chicago, IL, 1988.
11. ter Haar Romeny BM, Raymakers J, van Waes JC, Helder JC, de Graaf CN, van Rijk PP, Schuttenbeld H, Zuiderveld KJ, Tiemann J, Scharnberg B: The Dutch PACS project: philosophy, design of a digital reading room and first observations in the Utrecht University Hospital in the Netherlands. Proc. SPIE v. 767, Medical Imaging, pp 787-792, 1987
12. Fischer HW: Radiology Departments: Planning, Operation, and Management. Edwards Brothers, Inc., Ann Arbor, MI, 1982
13. Scott WG (1966) Planning Guide for Radiologic Installations, Second Edition. Williams and Wilkins, Baltimore, MD
14. Rogers DC, Johnston RE, Brenton BC, Staab EV, Thompson BG, Perry JR: Predicting PACS console requirements from radiologists' reading habits. Proc. SPIE v. 536, Medicine XIII/PACS III, pp 88-96, 1985
15. Mun SK, Benson H, Welsh C, Elliott LP, Davros W: Baseline study of radiology services for the purpose of PACS evaluation. Proc. SPIE v. 914, Medical Imaging II, pp 978-987, 1988
16. Sanders MS, McCormick EJ: Human Factors in Engineering and Design, Sixth Edition. McGraw-Hill, Inc., New York, NY, 1987
17. Mun SK, et al.: *op. cit.*, p 985
18. Diffrient N, Tilley AR, Harman D: Humanscale 1/2/3, 4/5/6, and 7/8/9. M.I.T. Press, Cambridge, MA, 1981
19. Sanders MS, McCormick: *op. cit.*, p 432
20. Diffrient N, Tilley AR, Harman D: *op. cit.*, 4/5/6 p 13
21. Sanders MS, McCormick: *op. cit.*, pp 414-415
22. Tuddenham WJ: Rooms for Film Processing and Display, in: Scott WG, *op. cit.*, p 79