THE CORNELL DIGITAL READING ROOM ERGONOMICS CHECKLIST: DEVELOPMENT AND EVALUATION

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ABSTRACT

Currently there exists no strategy for evaluating digital radiology reading rooms. This is of concern since the number of symptomatic radiologists suffering from work related musculoskeletal problems seems to be on the rise. Work related musculoskeletal complaints have been shown to be related to workstation set up, chair settings, monitor placement and other issues related to the computer workstation. Due to the visually intensive nature of the work of radiologists working with digital medical images, it is also important to look at factors in the ambient environment, such as lighting.

A checklist was developed to evaluate environmental factors in the work environment of radiologists. The checklist contained 39 questions divided into sections on display screens, input devices, workstation and workstation accessories, chair and ambient conditions. The items in the checklist were taken from checklists and educational material published for example by independent researchers, the Occupational Health and Safety Administration (OSHA) and the Canadian Standards Association. Answer options for each item consisted of factual statements, measurements, rating or a simple description. Some answer options included images for postural comparison. The checklist was not accompanied by a scoring sheet, but items that, if answered in a particular way, could be classified as “Ergonomic Issues” were identified in the checklist instructions and layout.

To evaluate the checklist, a mailing survey was sent to practicing radiologists, hospital administrators, ergonomists and other health and safety professionals. In the survey, respondents were asked four questions, both open ended and closed-ended, relating to the usability, layout and overall comprehensiveness of the checklist. The experts were also encouraged to provide general comments on the checklist. Twelve

non-factual items or items that required rating or subjective scoring were tested with multiple rater agreement (interrater reliability) and by percent agreement between participants and between participants and an ergonomist. The individual items were tested by asking participants to base their answers based on a series of standardized images depicting a model radiologist performing various tasks, such as reading an image from a computer monitor, use a computer mouse and telephone.

Twenty one participants, aged 18-58 years old completed the Interrater reliability - Individual Item Test. Six were male and 15 female. Eight participants were experts, or had background in ergonomics, facility planning and management or similar human-environment relations fields. The Interrater reliability of the items tested was .50 ($p < 0.05$) for the experts, and 0.10 for the novices ($p < 0.05$). When the results of participant agreement for individual items were analyzed, four items had consistently lower agreement. Three of these items were modified in accordance with expert feedback and one was excluded from the final version of the checklist. The final version of the checklist contained 43 items.

Limitations to this study include the design of the individual item test, not utilizing realistic situation with participants actually observing a radiologist at work, but basing their ratings off images that were not consistent in terms of posture and content. Further limitations also include the limited number of expert feedback received. In spite of the idea that invested experts would provide good feedback, it would prove beneficial to know why some experts chose not to participate.

Future research directions include a more comprehensive test of the checklist, both including the entire checklist as well as testing the checklist in actual digital reading rooms. An interesting application of this type of environmental checklist is to adapt it for computer based use, utilizing either portable hospital computer workstations or palm pilots would enable synchronization of information in a centralized facility database as well as instant access to results and possibly feedback. It would be very interesting to see an interactive version of this checklist developed and tested in the future. This is particularly relevant with hospital environments becoming increasingly a digital workplace.

BIOGRAPHICAL SKETCH

Hrönn Brynjarsdóttir grew up in Reykjavík, Iceland. After getting a Bachelor's degree in Psychology from the University of Iceland in 1999, she decided to take a break from academic pursuits. It was not until she happened to take an introductory class in Human Factors Engineering with Prof. Alan Hedge in the fall of 2002 that she realized that there actually existed a profession dedicated to some of Hrönn's favorite ideas and observations. Observing the interaction between people, machines and systems in general has been a favorite pastime of Hrönn from the early days of sorting her mother's button collection by color, size, shape and texture. This master's thesis is the culmination of Hrönn's work at the Department of Design and Environmental Analysis, from which she graduated in October of 2006. Hrönn currently works as a Human Computer Interaction research specialist with the Information Science department at Cornell. Her favorite color is red.

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CHAPTER 1 – INTRODUCTION

With the introduction of digital medical imaging technology there have been many changes both to the work and to the work environment of the radiologist. One of the more commonly mentioned changes this transition brings is the improvement in workflow (Reiner and Siegel, 2002). The time it now takes for a simple x-ray to be processed could potentially be as short as it takes for the computer or network to save and file the image and for the radiologist to download and view or read that image. With software support like "Picture Archiving and Communication Systems" (PACS), radiologists can even attach diagnostic comments directly to the medical image file, eliminating the time spent arranging meetings or one–on–one consulting with other radiologists or clinicians (Siegel and Reiner, 2002; See also Reiner, Siegel, Hooper and Glasser, 1998). Other benefits from this technology include lower radiation doses and fewer exposures needed due to technical errors (Lee, Siegel, Templeton, Dwyer, Murphey, Wetzel, 1991).

These changes and improvements in the work of radiologists have, however, brought about problems. In general, these concerns have to do with the reading room environment such as the layout of the reading room, the design of the workstation, lighting, acoustics and air quality (Fratt, 2005; Harisinghani, Blake, Saksena, Hahn, Gervais, Zalis, Fernandes and Mueller, 2004; Siegel and Reiner, 2002). More specifically, however, researchers are finding a direct relationship between these working conditions and physical complaints from radiologists. Ruess, O'Connor, Cho, Hussain, Howard, Slaughter and Hedge (2003) found that the incidence rate of carpal tunnel syndrome in one radiology department was 8.3%, which is roughly a 100% higher than the incidence rates of carpal tunnel syndrome in administrative and clerical staff reported by Nordstrom et al. (as cited in Ruess et al., 2003). In observing the work environment of these radiologists, Ruess and her colleagues (2003) found that there were significant deficiencies in all areas of the radiology department. All of the workstations were standard size, configured for right handed use only. There was limited availability of keyboard or mouse trays in addition to limited availability of alternative input devices (roller ball mouse). The chairs used were only adjustable in height and provided limited arm support. An occupational hygienist made a total of 93 recommendations for improvements in the work area of radiologists alone, which is significant considering that the number of radiologists on staff at this particular department is just under forty people. Ruess et al. (2003) conclude that this is only an indication what the situation is like in radiology departments in general.

In spite of the above-mentioned development, little research of these environmental factors in digital reading rooms has been done, and it seems that the majority of today's digital reading rooms are poorly designed for the required tasks (Horii, Horii, Mun, Benson, & Zeman, 2003). Hospitals with top of the line digital reading equipment are facing an upsurge in complaints of eye fatigue and strain, blurred vision, headaches and general musculoskeletal issues from radiologists on staff (Kolb, 2005; Prabhu, Gandhi and Goddard, 2005). These problems have all been shown to be related to work with visual display terminals (VDT) in the ergonomic literature. See for example Carter and Banister (1994) for a review on musculoskeletal problems related to VDT work. Fagarasanu and Kumar (2003) focus on carpal tunnel syndrome in relation to keyboard and mouse usage and Grandjean (1983) discusses the effects of working with VDT in relation to constrained posture and how this can lead to severe physical problems.

One way to evaluate and prevent work related problems like the ones discussed above is to use a checklist. Pencil and paper checklists are a well known tool in the field of ergonomics. Brodie and Wells (1997) describe checklists as the simplest form of observation, where the observer will answer a list of questions with either "yes" or a "no". As such, the checklist will have the advantage of being fast, easy to learn, use and analyze. An example of an ergonomic checklist is the Quick Exposure Check (QEC), developed by Li and Buckle (1999). The QEC addresses risks for work-related musculoskeletal disorders by presenting a one page questionnaire with items pertaining to the back, shoulder/arm, wrist/hand and neck. The observer's answers are supplemented with a workers' assessment as well.

One major disadvantage with simple checklists like the QEC is that the data collected can potentially be very simple and not as detailed as data collected by more complex methods. Given the pressures of finance and time limitations in industrial context, checklists are considered to be a feasible ergonomic tool, providing a quick estimation or an indication of problems or risk factors in the environment or work process itself (Dempsey, McGorry, & Maynard, 2005). The design of the Cornell Digital Reading Room Ergonomics Checklist proposed in the current study deviates from the simple "yes/no" format by providing answer options in the form of images of a radiologists' working posture or requiring the observer to provide measurements of air velocity, temperature or workstation dimensions. This approach is believed to be a more thorough evaluation, with the possibility of documentation for follow-up comparison. As such this instrument will be a feasible possibility for hospital administrators, looking to improve the work environment of their staff without a major financial investment.

Dempsey, McGorry and Maynard (2005) surveyed 308 professional ergonomists and found that 70.5% of the respondents used checklists in their work. Interestingly, the majority of these professionals used a custom made checklist (by self or company of employment). This is understandable in the context of differences between companies, work related tasks and the fact that a non-specific checklist might not be sensitive enough in situations that are highly varied.

The need for checklists, customized or not, becomes more evident in the case of digital radiology reading rooms, considering that there are currently no standards, documentation tools or systematic strategies in place that apply to this environment as a whole.

Objectives

The purpose of the current study was to create and evaluate a concise ergonomics checklist, custom designed for the work environment of radiologists. The checklist was evaluated both in terms of expert feedback from radiologists and practicing ergonomists as well as independent raters. A revised version of the checklist is presented, as well as ergonomic guidelines for users of the checklist.

CHAPTER 2 - THE WORK ENVIRONMENT OF RADIOLOGISTS

This chapter presents a brief description of the history of digital radiology technology and an overview of some of the ergonomic problems arising due to the technological changes in the radiological work environment.

A brief history of digital radiology technology

Technology for digital medical imaging has existed since the early seventies, but it was not until in 1979 that Lemke, Stiehl, Scharnweber and Jackel (as cited in Horii, 1999a) presented one of the earliest PACS that made the synchronization of image viewing, sharing and editing possible. Since then, the development of the digital network for image processing has undergone several evolutionary cycles, where the main focus remains user interfaces, the system integration with other information systems and an understanding of the work and tasks performed by radiologists (Horii, 1999a). According to Hendee, Brown, Stanley, Thrall and Zylak (1994), the drive for this change in the work for radiologists came from positive reporting of the technology and the potential for its advances, the desire of the profession to be on the cutting edge, possibilities for career advancement, financial benefits and pressure from physicians and patients for radiology to be on the leading edge with state-of-the-art technology.

Currently the number of radiology facilities that utilize digital imaging technology is on the rise and the practice of film-based viewing, or "hard copy" viewing, is consequently being reserved more frequently for archival research and comparison studies (Lund, Krupinski, Pereles & Mockbee, 1997). The switch from hard copy to soft copy viewing is considered a revolution in the field of radiology, being labeled a "paradigm shift' by decision makers and practitioners in radiology (Andriole, 2003). This revolution took place within the course of only one decade, and by now new problems related to the organizational context of change and financial obstacles are a very real issue for the field of radiology.

Bennett, Vaswani, Mendiola and Spigos (2002) describe the process of digitizing a radiology department and compare the viewing techniques of the radiologists before and after this change. It is interesting to note their observation of the tendency of radiologists to approach these two different work processes in the same way, requiring a multiple monitor set up for viewing one image on each monitor instead of utilizing an image stacking capability with the digital technology. With increased exposure and experience to the new technology, Bennett et al. (2002) saw the work habits changing and conclude that the efficiency of the department is much better.

The rapid switch and acceptance of the new technology would not have been possible had it not been for the speed at which technological advancements were being made to support these new procedural efforts. Horii (2002) points out that the demands of the work of the radiologists would have quickly ruled out any technology that was not helpful or caused delays. Further, he states that the impetus to switch from hard copy to "soft copy" (digital imaging) would have been weak or nonexistent had the technological follow-through not been available to improve the work.

Problems related to the new technology

The change from hard copy reading to soft copy reading in radiology has brought about several issues. These are an increase in viewing time spent in front of the computer monitor, organizational resistance to change, physical complaints and decreased satisfaction of the work environment.

The time spent in front of the computer viewing the computer monitor has increased dramatically. The time previously required to acquire the images, hang them on the light boxes in concert with doing the accompanying paperwork could also be seen as rest time, that is time not spent intensely viewing images for diagnosis and reporting purposes. Horii (1999b) speculates if this is why Krupinski and Lund (1996, as cited in Horii, 1999b) found that radiologists were viewing non image areas for a significant amount of time during each image viewing session in their study. That is, they were using the non image areas as resting points for their eyes.

Another problem encountered during this transition was of organizational nature, and is reported in a study by Horii et al. (2000). According to Horii et al. (2000), the new technology changed work flow processes significantly by delaying the process of image acquisition to diagnosis by a considerable amount of time. It's not unusual to expect problems related with new work procedures however, and researchers have reported on the successful integration of new work processes (Bryan, 2003; Thrall, 2005). Bramson and Bramson (2004) offer an overview of this problem and state that even though the financial justification for a new work system can be easily argued, and that the technology being developed is efficient and advantageous in many ways, the focus needs to be on the workforce, the employees themselves and how people react and deal with change.

Other, and more acute problems are eye strain, fatigue, backache, shoulder and neck pain as well as other musculoskeletal problems that are being reported more frequently in public literature on digital radiology as well as research literature (Dakins & Page, 2004; Harisinghani et al., 2004; Ruess et al. 2003). It is very likely that this problem is underreported, as suggested by Siegel (as cited in Dakins & Page, 2004) since the issue of ergonomic design of digital reading rooms seems to be very popular in the public literature on digital radiology (see for instance (www.healthimaging.com, www.imagingeconomics.com). However, relatively little research has been done to address this directly. In fact, the only study published to date is Ruess et al's (2003) article in the American Journal of Roentgenology. In their report, they describe four symptomatic radiologists working for the same radiology department at a hospital in Hawaii. These radiologists all suffered from carpal tunnel syndrome or cubital tunnel syndrome, the two most common musculoskeletal neuropathies that can be traced to computer usage. Ruess et al. also wanted to identify possible risk factors in the radiology work environment and conclude that given the shortcomings of the study (a retrospective review of four people), the intensity of the work of radiologists as well as work habits and environment will increase the risk for work-related upper extremity musculoskeletal disorders for radiologists.

In 2003, Rumreich and Johnson conducted a radiologist satisfaction survey in which nearly half of their respondents were either "dissatisfied" or "very dissatisfied" with the soft copy reading environment. The factors that contributed to overall dissatisfaction were items such as "workspace ergonomics", "noise level", "chairs", and "temperature" as well as "room layout". It is interesting to note that satisfaction in relation to layout and appropriate lighting were highly correlated to the overall satisfaction score. Van Ooijen, Koesoema, and Oudkerk (2006) found very similar results in their study of radiology workspace satisfaction in the Netherlands. One of their main findings was that workstation functionality parameters such as software performance, image quality, report generation, et cetera. were rated as far superior to the workspace ergonomics and comfort. Van Ooijen and his colleagues (2006) conclude that much more effort needs to be focused on the reading room design as well as ergonomics.

The findings from the satisfaction studies by Rumreich and Johnson (2003) and Van Ooijen's and his colleagues (2006) apply only to the location of the participants in each case, however, the issue of reading room design and how this affects the performance of the radiologists is evident in the literature (see, for example: Harisinghani et al., 2004; Horii, et al., 2003; Prabhu et al., 2005).

Radiology reading room redesign efforts

Thus far, the efforts of digital radiology reading room redesign can be categorized in two ways. The first category relates to the argument of the radiologists' workstation being very similar to a typical VDT workstation. The digital technology requires a workstation set up similar to other office type work and so the reading room is designed as an office space (Harisinghani et al., 2004). In the second category we see radiology redesign efforts where the only change is that instead of using light boxes for film viewing, they are now used as ambient light sources (Siegel, & Reiner, 2002). However, neither one of these approaches work completely, as we can see by the number of health-related complaints and general concern within the field of digital radiology.

Further, Pomerantz, Protopapas, and Siegel (1999) argue against this kind of an approach, pointing out that given the added editing possibilities and flexibility of digital medical imaging, relying on the same design for room layout as for hard copy reading would result in a very poor utilization of all that PACS has to offer. Thrall (2005) similarly states that the pressure from hospital management is immense, and the challenge for radiologists is to live up to high expectations from administration having "*high expectations for both appropriate returns on their investments and the productive management of the increased institutional resources devoted to radiology*" (p. 790). In other words, it is up to radiologists to prove that the cost of digital imaging technology is really warranted by increases in productivity and efficiency. It is becoming clearer that this will not be accomplished with a poorly designed work environment.

But what is really entailed in the work environment of radiologists utilizing digital imaging technology? Aside from computer monitors, input devices, tables, chairs and other workstation accessories, Horii (1999b) defines the radiologists' workstation as consisting of

> *all the elements of the reading room plus the heating, ventilation, air conditioning (HVAC), and communications systems and electrical power supplied from outside. Aside from the physical layout, the workstation environment is also dynamic and needs to account for the movement of personnel and access to the workstations and the people using them*." (p. 291).

Figures 1 and 2 show typical reading room workstations, both individual and shared, for radiologists utilizing digital imaging technology. These images highlight the

Figure 1. Digital radiology reading room individual workstation.

similarities of the work environment of general office workers and radiologists, the radiologists use computers, keyboards, mice and other typical office equipment. These images do not highlight the differences in these work environments in relation to the actual tasks that radiologists perform or the work processes that are involved.

Figure 2. Digital radiology reading room shared workstation

In spite of these superficial similarities, the work of a radiologist is different from that of general office workers in several important ways. For example, it is very common for radiologists to read images from two or more monitors at a time (Siegel and Reiner, 2002). Commercial literature indicates that the shift from a dual monitor set-up to a monitor set-up with three or more monitors is well under way (see for example www.healthimaging.com, www.anthro.com and www.biomorphdesk.com). This makes the likelihood for postural deviation different and perhaps greater, since a set up with more than one monitor will result in no one specific monitor being central field of vision. Further research is needed to determine whether this difference is significant, and if so, harmful.

What also differentiates the work of a general office worker from radiologists' work is that although radiologists utilize the same workstation set up as regular office workers, the lighting requirements and considerations are vastly different.

The level of light needed for computer and paper tasks are different than for intense image viewing. The difference between the luminance of a monitor displaying an x-ray image versus a text processing document varies in the level of contrast of the display. The problem is further complicated when the reading room has lighting design that is optimal for light box reading and not for reading from computer monitors. Lighting requirements for the digital radiology reading room will be discussed further in Chapter 3, *Elements in the digital radiology work environment.*

The radiologists' work consists almost entirely of intense image viewing with minimal work done in other computer applications (Prabhu et al, 2005). As reported in Horii (1992), a radiologist can spend up to four hours reading a single image per session. There are two important issues here. First, the increased potential for stationary work posture of the radiologist. Second, the visual intensity of the work is different and possibly more, since these medical images contain very small but significant information bits that require high contrast in order to be noticed.

Wang and Langer (1998) give an excellent account of what is involved in the perceptual processes of viewing medical images, from the initial "quick scan" of the image to generating the accompanying diagnostic report. They point out that the performance of the radiologist depends not only on the monitor quality but also on the quality of the image being viewed and environmental conditions such as background lighting. A good environment for radiologists would not only ensure efficient reading and minimize errors, but also minimize fatigue.

It can thus be concluded that a moderate to a high stress load accompanies the work of a radiologist. The pressure to do the work quickly and accurately becomes tangible when we think about what the repercussions can be from an incorrect reading. The environmental factors in conjunction with the level of stress can thus amount to a very unpleasant, if not unhealthy work environment for radiologists. Efforts to mitigate this level of pressure include an examination of the work processes that take place within the work environment, a concerned effort from human resources and employee health. A close look at tangible factors in the work environment itself will very likely abet the situational effects as well.

The following chapters discuss several important areas in the work environment of radiologists and how these areas can be examined and adjusted to support the important work that this profession performs. The chapters on the work environment of radiologists are followed by a chapter on evaluation tools in ergonomics and why an observational checklist of the work environment of radiologists is a feasible approach in the journey to a healthier workplace.

CHAPTER 3 - ELEMENTS IN THE DIGITAL RADIOLOGY WORK ENVIRONMENT

This chapter describes the elements of a digital radiology work room. The display screens in digital radiology have been researched extensively, both in terms of monitor quality and monitor height, distance and viewing angle. Following the discussion about the display screens is a general discussion about the radiologists workstation, chair and input devices used in digital radiology. Lastly, factors in the ambient environment are discussed in relation to the radiologists' work, productivity and efficiency. Recommendations on each of these elements are given based on existing research and standards.

Display Screens

Historically, cathode ray tube (CRT) monitors have been the basis of the image workstation (Horii, 1999a). They have presented problems related to the limited time they remain functional and display non-distorted images. Another problem related to CRTs is that the curvature of the screen contributes to specular glare. Flat panel liquid crystal display (LCD) monitors are traditionally considered to be less susceptible to glare but they were initially less common in the digital reading room due to questions about the resolution and quality of image display and also due to the fact that this type of computer monitor was much more expensive than the traditional CRT monitors.

Elizabeth Krupinski and her colleagues at the radiology department at the University of Arizona have authored a number of articles on monitor quality and reading performance of both radiologists and non-radiologists. Krupinski and Roehrig

(2002) compared the visual search behavior patterns and task performance of six participants (radiologists) using a color monitor, a P45 monochrome monitor or a P104 monochrome monitor. The radiologists were instructed to indicate whether or not an image contained an abnormality and how confident they were in their decision. Their eye movements were tracked and recorded with eye tracking equipment that included a video camera that captured their eye position and software that translated their relative eye position at any time onto the image being viewed. What Krupinski and Roehrig (2002) found was that participants made on average significantly fewer errors when viewing images on the P45 monochrome monitor than the other two monitors. Use of this monitor also resulted in shortest dwell times for each image on average, both for true-positive conditions (abnormality present) and false-positive conditions (abnormality not present). This indicates that the use of a monochrome monitor is more efficient and likely to produce more accurate readings by radiologists.

In another study, Lund et al. (1997) concluded that there were no statistically significant differences in the observer performance depending on the viewing method (CRT monitor versus a traditional light-box). The CRT monitor images did however receive higher quality ratings and it took observers longer to view images on the traditional light-boxes.

It appears that the initial debate on the diagnostic accuracy of monitors versus light boxes has been resolved, but Horii (2002) points out that in order for the accuracy to be equal or superior for computer monitor reading, environmental factors such as lighting play a big role and, if improperly designed, can have degrading effects on reading performance.

Currently the focus has been on determining whether there is a difference in accuracy reading from CRT monitors versus LCD monitors. In general an LCD flat monitor is considered to be better in terms of space requirements, weight, energy expenditure and radiation emissions, whereas CRT monitors have a bigger viewing angle. The bigger viewing angle allows for image viewing by more people at the same time than the operator sitting directly in front of the monitor (Harisinghani et al., 2004). Harisinghani et al. (2004) recommend the use of a high brightness, active matrix LCD monitors for general purposes. This is supported by several studies that have been conducted by researchers in digital radiology. A recent study by Usami, Ikeda, Ishigaki, Fukushima, and Shimamoto (2006) indicates that the two types of display devices are for the most part comparable when looking at observer performance.

The American Association of Physicists in Medicine (AAPM) published an extensive report in 2005 giving not only guidelines for the assessment of the monitors used for medical imaging, but also the illuminance level in the reading room and the placement of the monitors. Their recommendations on monitor placements are somewhat vague, though, and there is need for further quality assurance from an ergonomic standpoint to ensure that the monitors are placed at a height, distance, and angle that is minimally harmful for the person viewing them.

Monitor Height and Viewing Angle

Babski-Reeves, Stanfield, and Hughes (2005) highlight gaps in the literature regarding research results and recommendations about optimal monitor height. High monitor placement is beneficial for viewing angles, neck mobility and lower muscle load in the shoulder and upper back as well as fewer reports of discomfort (Kumar; Straker & Mekhora, as cited in Babski-Reeves et al., 2005). Conversely, Babski-Reeves et al. (2005) report on several studies that indicate that lower monitor placement results in overall better posture and lower muscle loads in the neck. Babski-Reeves et al. conclude that this represents a compromise between the visual and the musculoskeletal systems. Due to the nature of functioning for each system, it is virtually impossible to get one setting of monitor height that will be beneficial for both. It is thus evident that having a monitor that will adjust in height is essential for people working intensely with VDTs. Being able to adjust the monitor throughout the day will ensure non-static posture and prevent discomfort that will eventually lead to musculoskeletal problems. The monitor height is not only dependent on the actual monitor settings, though, and the complex relationship between the monitor height, the chair and desk height settings as well as the task at hand are explored by Babski-Reeves et al. (2005), Karlquist (1998), Laville (1983) and Lu and Aghazadeh (1998), among others.

Viewing angle is a complicated parameter that is affected not only by the height of the monitor but by the type of monitor used as well. The luminance, color and contrast can change depending on what the angle is. Flat panel displays will in most cases not be visible from a side angle, whereas the CRT technology will allow for deviation in the horizontal plane. From an ergonomic standpoint, Ankrum and Nemeth (1995) state that the "common practice" of placing the top of the monitor at eye level or lower will be suboptimal for the VDT operator as this could potentially constrain the neck posture. This is further supported by Fostervold (2003) who proposed a lower monitor setting that enabled viewing angle of 30-45° below the horizontal line on the center of the monitor in his review of ergonomic research on monitor settings. The HFES Computer Workstations Draft Standard for Trial Use (2002) specifies an optimal viewing angle ranging between ±20° in the horizontal and vertical planes with respect to the display screen, whereas the Canadian Standards Association (CSA) Guideline on Office Ergonomics (2000) recommends the range to be 30° from the horizontal and vertical line of sight (0°).

A further consideration is the worker's visual correction (glasses) and age. Users of bifocals or trifocal (progressive) corrective lenses benefit from having the monitor lower than people without corrective lenses, since they view the monitor through the bottom portion of the lens (CSA, 2000).

Viewing Distance

Carter and Banister (1994) point out that, in essence, the optimal viewing distance depends on legibility and operator preference. In this sense, flat panel monitors are preferable, since they have a smaller footprint on the operator desk, are lighter than the traditional CRT monitors and thus easier to adjust in distance. This becomes more evident when a workstation is designed for alternating sitting or standing posture. According to Nylén (2002), an operator at a standing workstation will tend to lean forward, resulting in a need to move the monitor back for viewing comfort. In their review of the literature on musculoskeletal problems and VDT work, Carter and Banister (1994) recommend a range for monitor distance to be from 41-93cm, or roughly 16-36in. According to the HFDS, the minimum distance should not be less than 33cm or about 13in (Ahlstrom & Longo, 2003).

Short note about document holders

With an upright document holder, the same parameters for viewing distance and height apply as with monitor displays. The CSA (2000) recommends that if needed, a stable and task-appropriate document holder should be placed at the same height and distance as the computer monitor, preferably right next to the monitor. This reduces unnecessary head and neck movement as well as eye movements, including extreme focus adjustments between the monitor and document.

Workstation

For most of the recommendations in the literature on workstations, the work is based on the US Army Anthropometric data reported by Gordon et al (CSA, 2000) and by military standards developed by the US department of Defense (Ahlstrom & Longo, 2003). Basic recommendations like reach and clearance can be derived from these measures, but specifications like optimal monitor placement, keyboard angle and design and chair specifications are harder to derive from this data, because of the complex interaction between the posture of the user, workload and other environmental factors that will either mitigate or worsen the overall effects (Lu & Aghazadeh, 1998).

The best fit for an individual will be achieved by adjusting the height and angle of the desk or keyboard tray as well as the chair. Ergonomic standards (HFES, 2002) and educational literature in ergonomics (Sanders & McCormick, 1993) recommend that when designing for more than one individual that the anthropometric data used is the range from the fifth percentile female to the 95^{th} percentile for males. This way, the majority of the population is accounted for as far as versatility, flexibility and reach are concerned. It is important to note that the measurements for the anthropometric data apply for a single dimension only, such as reach or elbow height, and that when several dimensions are being used, there is potential for error. This error is not systematic, since people have varying body dimensions that will not be correlated. One person might have long legs and a short trunk, whereas another person that is equally tall might have shorter legs and a long trunk. These two people will require different setups for their workstations. Sanders and McCormick (1993) cite an example where this type of error excluded 52% of the population, based on using the 5^{th} and the 95^{th} percentiles in a combination for several dimensions (Bittner, as cited in Sanders & McCormick, 1993). One way to counter a problem such as this is to design for adjustability.

Sufficient clearance for legs, reach and adjustability are among the necessary features mentioned by Sanders and McCormick (1993). Other important considerations are whether or not the workstation will be used by more than one individual, what the workspace lighting design is, as well as proximity to other necessary equipment and materials (CSA, 2000). The HFES (2002) stresses that the adjustability function should be accessible from the relevant posture (seated or standing) and that it not interfere with the work intended. An example of this is where the controls on an electronically height adjustable table are located within easy reach of the operator, yet out of the way to prevent accidental activation. The option of adjusting the height of the work surface to allow for seated position as well as a standing position would be beneficial in terms of avoiding a static posture for prolonged periods in addition to allowing the workstation to be used by more than one user if needed.

Figure 3 shows some of the CSA (2000) and the HFES (2002) guidelines for seated work surface dimensions and clearance for feet, thighs and legs with or without a keyboard tray.

Other specifications for the work surface include sufficient support for the equipment being used, such as display, keyboard, other input device, a document holder and other material (CSA, 2000).

Similar to many other areas within the reading room design, minimal attention has been paid to the design of the work tables or desks of radiologists. In fact, it appears that radiologists have taken this responsibility upon themselves in order to

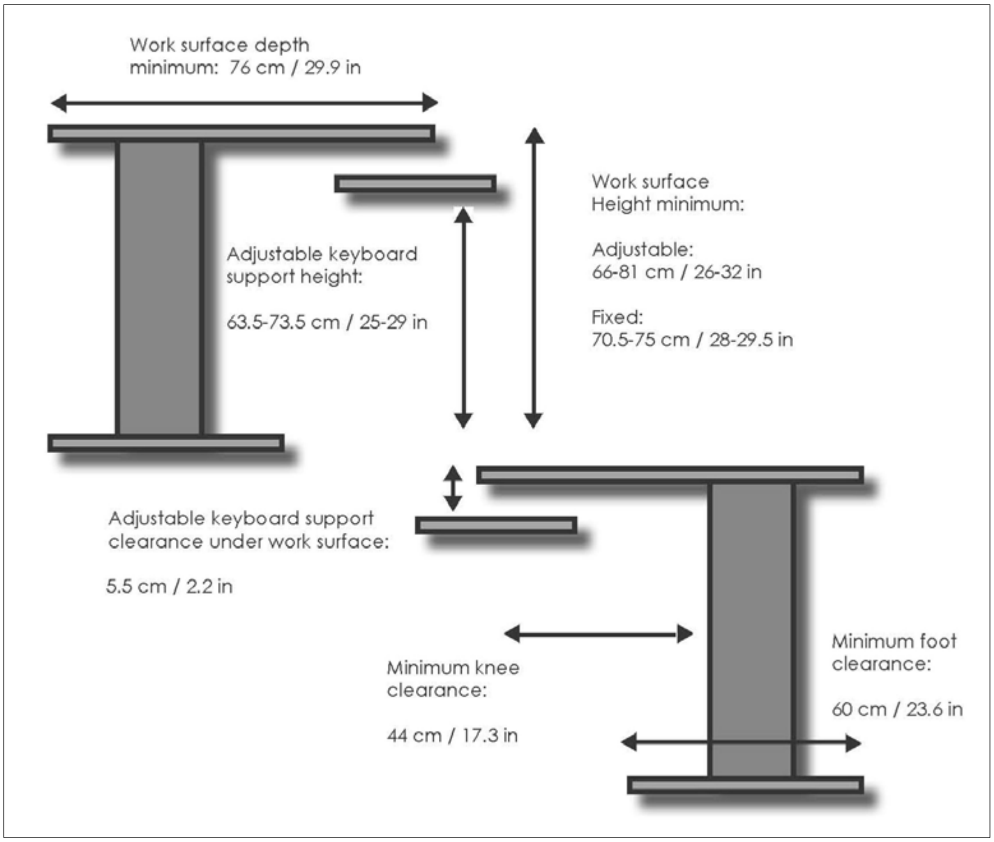


Figure 3. CSA and HFES (2002) guidelines for seated work surface dimensions and clearance for feet, thighs and legs.

make their work environment better. Haramati and Fast (2005) describe a prototype of a cart to be used while interpreting radiology images. Haramati and Fast wanted a cart that would be suitable for interpretation of digital images for any radiologist that would chose to use it. They further wanted a design that would allow for users of different heights and weights as well as the possibility of reading while standing in addition to sitting. What Haramati and Fast (2005) realized in this undertaking was that when changing one part of the reading room, other factors in the environment were affected and needed to be re-evaluated in turn. One important aspect of Haramati and Fast's report is that users of progressive lenses needed different workstation set up in terms of monitor height, angle and distance from the reader. They allow for this with mounting the monitor on arms that attach to the workstation, that are easy to adjust and move around.

Horii (1992) summarized studies showing the amount of work done by radiologists and what the implications were for the design of their work environment. The fact that on average, a radiologist can read about 150 patient cases per day (each containing 3-4 images), interacting with illuminators and other workstation equipment as well implies that the computer equipment used is very powerful and fast. It is thus logical to conclude that the design of the supporting work environment, i.e. the work surface of the computer desk, keyboard tray and other peripherals be available in a direct and efficient manner to help the radiologist maintain a neutral posture throughout the day.

Chair

According to Carter and Banister's review (1994), sitting has been studied more than any other area in relation to musculoskeletal problems and VDT work. The overall conclusion is that a major cause of musculoskeletal problems and pain during VDT usage and other general office work is the fact that most people spend the bulk of their workday sitting. Technological advances and increased office automation will further this trend, since office workers now have the option to complete all of their tasks without having to stand up at all during the workday. Coupled with a chair design that is not sufficient to support the posture, the potential for musculoskeletal problems will undoubtedly increase.

When it comes to identifying what constitutes a good chair design, it is complicated by disagreement among experts on what the optimal seated posture should be as well as the fact that people don't necessarily sit the way experts have traditionally prescribed, with right angles at the hips, knees and ankles (Carter & Banister, 1994; Gerr, Marcus, Ortiz, White, Jones, Cohen, Gentry, Edwards, Bauer, 2000). For instance, Grandjean (1983) found that most VDT operators tended to lean back in their chairs, extending their legs and neck forward. This puts a tremendous load on the neck muscles as well as possibly flattening the lumbar lordosis, adding pressure on the lower back. This is evidenced in the incidence of "daily pains" in the neck and shoulder areas for VDT workers (Grandjean, 1983) as well as EMG activity and intervertebral pressure being lower when the backrest is tilted backwards between 90° to 110° (Andersson, as reported in Carter and Banister, 1994).

Ultimately, the ideal seated posture depends on the task and the working conditions. Upright seating will be problematic in the long run due to the static load on the spine, especially if the chair does not have a backrest in the lumbar region. The argument for using a chair without a backrest (also known as a kneeling chair) to facilitate a forward tilt of the hips and natural curvature of the back can be countered with the overall cumbersome nature of the design. Carter and Banister (1994) point out that getting seated and standing up from this type of chairs tends to be difficult, compression on the knees can cause discomfort and that in general spinal load will be higher than when the person sits in a chair with a backrest. This is also supported by Grandjean's findings from 1983, VDT operators might not prefer this kind of a posture for work, regardless of whether the preferred posture is better or less harmful. Leaning backwards in a chair that offers back support will not prove to be more beneficial either, since the operator will have to crane their neck in order to view the computer monitor properly.

For the type of work that radiologists perform when viewing digital imaging, it is safe to assume that a supported upright posture would be most beneficial given the visual intensity and that there will also be a need for the radiologists to type and other tasks that will require that input devices and other implements are within easy reach on the work surface. Leaning backwards will be problematic due to this, as well as the forward tilting posture, since it is more focused on writing and reading from paper (Dainoff & Mark, as cited in Carter and Banister, 1994).

Regardless of what posture the radiologist will choose, it is essential that they have the type of chair that will accommodate every person's preference as well as body dimensions. Table 1 details the features that are recommended for a good chair design, these features were compiled from Carter and Banister (1994), HFES (2002), the CSA (2000) and Sanders and McCormick (1993). There is some agreement on the majority of these specifics, but where there is disagreement, the recommendations are presented in ranges. The ranges shown will include the lowest recommended dimension to the highest dimension. It is interesting to note that as a general rule, the most recent literature, the HFES (2002) recommended the biggest or widest ranges, which is not unusual if we take the trend in weight and obesity in the United States into consideration (Flegal, Carroll, Kuczmarski, & Johnson, 1998).

Table 1. Basic features, dimensions and ranges recommended for office chairs.

Basic features	Dimensions and ranges
Seat	
Height	38-57 cm / 15-22.1 in
Depth	Adjustable: 42-46 cm / 15.5-18.1 in
	Non–adjustable: Within a range of 38-43 cm / 15-16.9 in
Width	≥ 46 cm / 18.1 in
Backrest	
Height	45-55 cm / 17.7-21.7 in from upper surface of seat cushion
Width	≥ 36 cm / 14.2 in
Angle	90-120 °
Lumbar support	

Table 1 (*Continued*)

Adjustable	15-25 cm / 5.9-9.8 in above seat
Non-adjustable	Within a range of 15-25 cm / 5.9-9.8
Armrests	
Height	18-27 cm / 7.1-10.6 in
Width	≥ 46 cm / 18.1 in

References: Carter and Banister (1994), CSA (2000), HFES (2002), Sanders and McCormick (1993).

Other recommended features for chairs are that they have a five legged base, preferably with casters, that the backrest be contoured to go with the natural curvature of the back, that the edge of the seat pan be rounded to prevent unnecessary pressure on the thighs, and that the chair swivel to prevent unnecessary bending or rotating of the trunk (Carter and Banister 1994; CSA, 2000; HFES, 2002; Sanders and McCormick, 1993). In general it is also considered advisable that footrests are made available in order to counter adjustments made so that the person sitting cannot rest the feet flat on the floor (CSA, 2000).

In a workplace that caters to many individuals of different sizes and shapes, like a busy radiology department, it is not only beneficial, but a necessity to make sure that each and every person can work efficiently and comfortably by providing these adjustment features and support. A fully adjustable chair will be an easy way to accomplish this, especially since according to Babski-Reeves, Stanfield and Hughes (2005), there appears to be no difference between high-end office chairs versus cheaper models that have the same characteristics in terms of muscle activity, perceived level of discomfort and postural shifts. Given that hospital administrators face the task of balancing budgets and justifying expenses, the argument that Babski-Reeves, Stanfield and Hughes (2005) make, might prove to be very helpful.

Input devices

According to Sherbondy, Holmlund, Rubin, Schraedley, Winograd and Napel (2005) not a lot of work has been done to look at the most efficient ways to navigate datasets of digital medical images. In fact, their study seems to be the only one published to date that compares input devices in relation to efficiency and comfort of the user in digital medical imaging navigation, although Harisinghani et al. (2004) discuss general issues in keyboard usage in radiology specifically.

Sherbondy and colleagues (2005) compared a pen tablet, trackball, a jog shuttle wheel and a scroll wheel mouse with artificial and real tasks that were typical for the work of radiologists. Their participants were five radiologists with three or more years of experience. Their main finding was that even though a trackball device is the most commonly used navigation device in medical imaging, it may not be the most optimal one, especially when navigating large data sets. The input devices that were favored by the participants were the pen tablet and the jog shuttle wheel. In spite of some limitations to Sherbondy et al's study (i.e. sample size, task specificity, participant's previous exposure to some input devices and not others) and limited support by other research in the field, their results give some indication as to what radiologists might prefer. It is interesting to note that none of the participants considered the mouse to be useful as a navigation tool, and yet this is the input device that most commonly is distributed with computer workstations. Sherbondy et al. (2005) suggest a design of a hybrid input device that will combine velocity control with a fine position control of the cursor along with haptic feedback similar to that of the jog-shuttle wheel. They further discuss the implications of using a pen tablet as opposed to scrolling devices with tasks that require the user to navigate large longitudinal distances on the monitor. For the pen tablet to be useful in such instances the scrolling function could be located on the pen or pointing device or a function similar to finger tapping could replace the pen.

According to the 2004 conference proceeding website for the Society for Computer Applications in Radiology (SCAR), there was another study conducted on input devices by David Weiss. Weiss compared eight devices, adding a five button mouse, a joystick controller, a gyroscopic mouse and a “twiddler”, a device that is strapped onto the controller’s arm and can be programmed with over 1000 functions. Weiss reports that his participants showed strong preference for simpler input devices such as the five button mouse, which also offered fine tuned control of the cursor. He further reported that the five button mouse might have been preferred due to the fact that it was most familiar to the participants as opposed to the other devices. Weiss’ findings are not surprising if guidelines for general usability are consulted. Fitt’s law of human performance in relation to time, size of target and distance to target might help explain these results. However Accot and Zhai (1997) argue that Fitt’s law might not help explain the performance in tasks that are different than pointing tasks. The maximum number of functions that can be efficiently controlled by an operator has not been established with research as of yet (Sanders & McCormick, 1993).

From an ergonomic standpoint, the main concern might not be what input device is used per se but rather whether or not the input device of choice puts the arm or hand in a harmful position for an extended time period. The only published study on the working conditions of radiologists in relation to work related musculoskeletal disorders by Ruess et al. (2003), looked retrospectively at the work environment of four symptomatic radiologists. Ruess and her colleagues found that their study subjects spent on average more time overall at the VDT in comparison to non-symptomatic radiologists. Further, they had inadequate workstation set up, with keyboards and computer mice placed either too high, or at an angle that invoked poor posture and increased pressure on the ulnar and median nerves. Ruess et al conclude that the current technology of digital medical imaging renders radiologists at risk for work-related, upper extremity musculoskeletal disorders (WRMSD) such as carpal and cubital tunnel syndromes.

In their study of a small technological company in Israel, Shuval and Donchin (2005) identified a number of risk factors contributing to the prevalence of WRMSDs in the company. Women in the company were more predisposed for neck and shoulder problems, whereas men were more prone to have problems related to the wrists and hands. Employees that worked more than ten hours a day were at risk, and in particular, those who spent more than seven hours a day specifically at a VDT. People with more work experience similarly were more predisposed to WRMD than less experienced employees. What is important here is that these workers were working with a dual monitor set-up which relates directly to the working situation for radiologists. Further, the working hours and the intensity of the VDT work match the described working habits of radiologist.

In their review of carpal tunnel syndrome in relation to keyboard and mouse use, Fagarasanu and Kumar (2003) mention that in most applications, mouse usage accounts for roughly 66%, increasing with drawing applications. Although there are no studies on this particular topic in radiology, it can be assumed that due to the nature of the radiologists' tasks, navigating images, scrolling and zooming with minimal keyboard use, that this percentage is higher with radiologists than regular office workers. It is thus safe to conclude that in spite of the scarcity of studies on the work environment of radiologists that these professionals are at risk for serious work related musculoskeletal disorders.

The Ambient Environment

Thermal Conditions

When the first digital reading room began operating in 1993, it soon became evident that an important environmental factor had been missed in the planning and design stages. The thermal output by the equipment associated with the digital reading technology overloaded the existing air conditioning and ventilation system and, at times, the temperature in the reading room at the Baltimore VA Hospital reached 38 degrees Celsius (100F) (Siegel & Reiner, 2002). Some of the consequences were reduced productivity and increased fatigue among the radiologists, in addition to expensive equipment being compromised. Siegel and Reiner conclude that for a proper thermal design of any digital reading room there would need to be special allowances for the thermal output of the equipment as well as the people, and that individual temperature controls at each workstation would ensure each reader's comfort. Harisinghani et al. come to the same conclusion in their conclusive review of altered workplace ergonomics in digital radiology reading rooms (2004). More recently, Prabhu et al. (2005) published a review of their observations of digital reading rooms in the United Kingdom, confirming the observations of their American counterparts.

The Human Factors Design Standard specifies the temperature ranges required for comfort as 21-27°C (70-80°F) for warmer climates or summer and 18-24° (65-75°F) in a colder climate or winter (Ahlstrom, & Longo, 2003). Since thermal comfort is influenced by relative humidity, it is important to consider how, as temperature increases, the relative humidity should decrease to maintain comfortable and safe environment for work. The HFDS recommends the relative humidity level to be maintained at 45% at 21°C (70°F) (Ahlstrom, & Longo, 2003). However, according to CSA's Guideline on Office Ergonomics (2000), the influence of humidity on sedentary work in moderate temperatures in the range 20-26°C (68-78°F) is slight. Further, humid environments might be harmful to the technology used in digital radiology reading rooms as well as the air quality in general. Observations of stuffy air as well as condensation and mold growth are all direct results of environments that are too humid (CSA, 2000). Taking the number of factors that contribute to comfort and safety of the individual in relation to thermal conditions can prove to be increasingly complicated, and HFDS (Ahlstrom, & Longo, 2003) does recommend individual control as a general practice. This way, the problem of the relationship between heat transfer, equipment and human beings becomes manageable and can be maintained within the range of human tolerance and safety. It is safe to assume that the recommended practices by the HFDS and CSA will apply to the working environment of radiologists, even though the study of their environments specifically has not been conducted. However, further studies in this regard are recommended.

Lighting

Not a lot of research has been done on the optimal digital reading room lighting environment for radiologists (Horii et al., 2003). Krupinski, Roehrig and Furukawa (1999) mention that even though the field of digital medical imaging is expanding, one serious impediment is that optimal display design and performance factors have yet to be determined. The Illuminating Engineering Society of North America (IESNA) very recently published *An IESNA Recommended Practice: Lighting for Hospitals and Health Care Facilities* (2006). This guidebook does not specify lighting for digital radiology reading rooms, other than by referring to the standards for office lighting. As discussed in chapter 2, this recommendation will not result in a reading environment for radiologists that will be sufficient.

Illumination levels

Ishihara et al. (2002) looked at the influence of monitor brightness and room illuminance on observer performance in two studies. In the first study, 6 participants viewed images on computer monitors and were asked to diagnose and indicate their confidence levels for each image. The viewing conditions were two levels of monitor luminance, 50 and 400 cd/m^2 (14.59 and 116.75fL) and three levels of room illuminance, 20, 120 and 480 lux (1.86; 11.15 and 37.16fc). The participants did significantly better at 20 lux (1.86fc) than at 480 lux (37.16fc) in both low and high luminance conditions. For the second study, ten participants viewed images that were displayed at 50, 200 and 5500 cd/m^2 (14.59; 58.37 and 1605.25fL) luminance, with room illuminance being 20, 120 or 480 lux (1.86; 11.15 and 37.16fc). Here, the worst performance occurred with room illuminance at 480 lux (37.16fc), regardless of the luminance conditions. The authors concluded that the optimum room illuminance levels were at the intermediate level, and that illumination level at 480 lux (37.16fc) with monitor luminance at 50cd/m^2 (14.59fL) should be avoided.

These findings were supported by the study done by Goo, Choi, Im, Lee, Chung, Han, Park, Kim and Nam (2004). Like Ishihara et al (2002), Goo and his colleagues looked at the effect of ambient light and monitor luminance on performance in reading digital medical images. Participants were asked to review images with three different types of abnormalities (lung nodules, pneumothorax, interstitial disease) under three different monitor conditions, luminance set at 25, 50 and 100 fL (85.66; 171.31 and 342.63cd/m^2) and three different ambient lighting conditions with illuminance set at 0 lux, 50 lux, and 460 lux (0; 4.65 and 42.74 fc). These researchers found that monitor luminance did not have a statistically significant effect on performance for detecting any of the abnormalities. The ambient light level did affect the participants' performance in detecting nodules. The higher the light level the worse the performance becomes. Whether these results apply to other digital imaging needs to be determined, but the American Association of Physicists in Medicine (AAPM) recommends the illumination levels at diagnostic reading stations be as low as 2-10 lux (0.19 – 0.93fc) (AAPM, 2005).

Charles et al. (2004) state that looking at the illumination level only tells half the story. Considerations about the task at hand and other factors in the surrounding environment need to be addressed as well. They further state that "*Any single illuminance value is likely to satisfy only half of the occupants*" (Charles et al., 2004, p. 40). Findings from individual research (Aarås et al., 2002 ; Charles, Danforth et al, 2004) as well as standards (Ahlstrom and Longo, 2003; Human Factors and Ergonomics Society, 2002) define the optimum range of illumination levels for office work with visual display units as ranging from 200 lux to 755 lux (18.58-7014fc). The Illuminating Engineering Society of North America (IESNA) however recommends that the ambient illuminance throughout the office space should not exceed 500 lux (46.45fc) (2000). The lower the illuminance is, the better, according to IESNA's Lighting handbook: Reference and Application (2000), since the low illuminance level will reduce reflections or glare on the computer monitors, only affecting the screen contrast minimally.

Individual control

In order for any recommended range of illuminance to be beneficial, researchers agree that adjustability and individual control is important (Harisinghani et al, 2004; Hedge, 2000; Prabhu et al., 2005). Further research support for individual lighting control and office work can be found in the publication Workstation Design for Organizational Productivity from the National Research Council and Institute for Research in Construction, Canada (Charles et al, 2004).

Glare

The minimization of glare is another important recommendation for optimal lighting conditions that is well supported by research. As an example, Lu and Aghazadeh (1998) found that ocular discomfort related to glare is a significant variable in their model of risk factors in VDT workstation systems. The recommendations for reducing or minimizing glare can roughly be categorized in three ways. First, minimization of glare can be accomplished with layout or space related changes, such as facing the visual display unit away from the source of the glare or using window coverings (Harisinghani et al., 2004). Second, common changes or applications related to the monitor itself, such as applying a glare filter or tilting the unit have been known to minimize glare (Sanders and McCormick, 1993). Third, a change in lighting conditions can help with this issue and the combination of direct and indirect lighting is commonly recommended in research and other scholarly publications (for example, see: Aarås et al., 2002; Horii, 1992; Prabhu et al., 2005). The IESNA (2000) recommends that the maximum luminance in a workplace with VDTs should not be more than $850 cd/m^2$.

Lighting Uniformity

One of the arguments for recommending the lighting environment to be uniform or having low contrast ratio stems from the notion of the transient adaptation of the eyes. An example of this is what happens when one goes from a well lit area into a dark room or vice versa. The analogy Sanders and McCormick give is going into a dark movie theater (1993). As the color receptors (cones) and the black/white receptors (rods) adapt to the change in light levels, a temporary blindness sets in. This phenomenon is called the Purkinje Shift (Sanders and McCormick, 1993). Charles et al. (2004) claim that frequent adaptations, even if they are not as drastic as a complete darkness adaptations, will increase fatigue and discomfort. In a recent study, Sheedy, Smith and Hayes (2005) found that their participants' performance was significantly affected by surround luminance. Beginning at very low surround luminance that was increased stepwise, the participants' task performance improved as the surround luminance approximated the computer monitor luminance at 91cd/m^2. The improvements leveled off when the contrast ratio was approximately 1:1. They also found significant differences in performance by age. Older people seemed to perform best when the ratio was close to equal, whereas for younger people, optimal performance occurred at 50cd/m^2. These results lend support to recommending uniformity in lighting conditions, but discussion about this concept is unclear in other literature. Statements, such as "*The ideal is a consistent level between the monitor and background surface*" (Fratt, 2005), do not discern what this level should be. Does "consistent" mean uniformly consistent, or consistently set at 3:1, for example? In 1996, Veitch and Newsham expressed frustration at the lack of set recommendations in this field, arguing that if an interesting, non-uniformly lit environment still allowed occupants to see and perform the tasks needed then the "conventional wisdom" of uniformity might not hold. Research done by the Institute for Research in Construction in Canada has since led to the uniformity recommendations in Table 2, reproduced from *Workstation Design for Organizational Productivity* (Charles et al., 2004).

Table 2. Lighting uniformity recommendations by IRC and IESNA

Uniformity/Task description	IRC	IESNA
Paper tasks on desktop and adjacent surroundings or vice versa	1.5 : 2.1	3 : 1
Computer screens and adjacent surroundings or vice versa	1.2 : 1	3 : 1
Between near and remote surfaces or vice versa	20 : 1	10 : 1

References: Charles et al. (2004)

In this table we also see the recommended uniformity levels by IESNA. Here, as with illumination recommendations previously stated, we see a range of recommendations that conflict. In the case of digital radiology and reading performance, it is vital that the lighting conditions support the work that is to be performed; having conflicting or non-specific recommendations is discouraging at best.

Noise

The sources for noise at the radiologists' workstation include the equipment, ventilation and air conditioning system, other radiologists as well as general traffic if the reading room is centrally located within the department (Haringsinghani et al., 2004; Horii, 2002). Phone usage, radiologists dictating or conferencing and hospital public announcement systems can be further sources of interruption (Siegel & Reiner, 2002). None of these can be classified as harmful according to work safety and health standards, as pointed out by Horii et al. (2003), but with prolonged exposure or improper mitigation of this environmental sound the effects can be harmful. According to the HFDS (Ahlstrom, & Longo, 2003), sound levels for work areas should not exceed levels that interfere with necessary voice, telephone or radio communication. Fatigue or injury-invoking noise levels should be avoided as well as levels that will degrade the overall effectiveness of the work process. In defining what these levels are, the HFDS give two criteria, the A-weighted sound level (dß (A)) and the speech interference level (SIL). The SIL is a measure in the effectiveness of noise in masking. The A-weighted sound level is sound pressure level in decibels measured using a sound level meter with an A-weighting network. The HFDS further specify that the dß (A) is the desired measurement (Ahlstrom & Longo, 2003).

The results from Rumreich and Johnson's (2003) and Ooijen et al.'s (2006) satisfaction surveys indicate that most radiologists would prefer the noise levels to be controlled to a certain extent, but it is also implicitly understood that for some tasks that go with digital image reading this will be hard. Harisinghani et al. (2004) looked at a digital radiology reading room and found that the number of radiologists sitting next to each other while reading and reporting, the absence of acoustic dampening materials and location of freestanding reading consoles in high traffic areas all contributed to a noisy and distracting environment for image reading. In fact, Banbury and Berry (2005) found that even though defined as low-level sound, background noise such as people talking and phone ringing, not only affected concentration but were also 'bothering' and 'greatly disturbing'. What is interesting about these results is that Banbury and Berry's study was conducted in a working environment that closely matches most current radiology reading rooms, that of open office layout, without specific individual offices but workstations in a shared space. For noise mitigation, sound absorbing panels, carpeting, as well as removable partitions between workstations are well known solutions (Sanders & McCormick, 1993).

CHAPTER 4 - EVALUATION TOOLS IN ERGONOMICS

This chapter provides a brief overview of current debate in ergonomic measurement theory, the rationale for posture based observational tools and a description of successful observational tools as well as limitations to observation based research and data collection.

In spite of what has been established about musculoskeletal problems and how certain aspects of posture, force, repetition and time will contribute to these problems, it is still debated in what particular way these factors work together and what other factors in addition will moderate or exacerbate the effects (Babski-Reeves, Stanfield & Hughes, 2005; Lu & Aghazadeh 1998; Wells, Norman, Neumann, Andrews, Frank, Shannon & Kerr, 1997). According to Spielholz, Silverstein, Morgan, Checkoway and Kaufman (2001), one reason for this debate is that there is a lack of well-defined exposure assessment methods within the field of ergonomics. Lowe (2004) further states that there is a lack of standardization in operationalization and scaling in exposure assessments as well. As a result, Spielholz and his colleagues (2001) conclude, the existing data might not be all-conclusive.

Rationale for Posture Based Observational Tools

Most postural based observational tools in ergonomics are centered on the notion of a "neutral zone" or a neutral posture (Hedge, 2004). This neutral zone is the posture that will not invoke stress or strain on the muscles sufficient to initiate injury. The idea is then that when a person is in a posture that will deviate from the neutral zone, the chance for an injury becomes greater; the greater the deviation, the greater the risk. It can be assumed that some discomfort will accompany the deviation if held for a prolonged time or repeatedly and thus risk and the severity of a postural deviation can be measured by looking at the posture and the level of discomfort the person experiences (Hedge, 2004).

Self reported discomfort is a valuable notion when it comes to the early stages of muscular injury. As Hedge (2004) points out, the sensation of discomfort is not to be ignored, and changes in the levels of discomfort can potentially give feedback on whether an implemented change in work processes or methods has made a difference for better or worse. However, the concept of self-reported discomfort is problematic due to the level of error or variability between people and how differences in interpretation and analysis will influence this measurement option. As a result, more common risk analyses and evaluation tools will be based on posture as the main focus.

Existing Tools

Li and Buckle (1999) give an overview of the existing techniques used in the field of ergonomics to evaluate risk factors related to musculoskeletal problems. Among these, the majority are posture-based observation tools. Up until 1974, any kind of posture recording was made with drawings or photographs with supplementary narratives, and it wasn't until Priel developed the first known systematic observational tool in 1974 (as reported in Li and Buckle, 1999), including an index of upper and lower limb positions in relation to three orthogonal planes. This was supported by a drawing of the posture by the observer. Other similar observational tools followed, such as the Ovako Working Posture Analysing System (OWAS) developed in Finland in 1977, assessing the magnitude of postural risk and posture targeting, developed by Corlett, Madeley and Manenica in 1979 (Li and Buckle, 1999). The Rapid Upper Limb Assessment (RULA) was developed in 1993 by McAtamney and Corlett, and is based on different segments of the body being rated on the scale of 1 to 3, indicating the level of postural deviation from the neutral zone. A total score for each body section (head, trunk, upper and lower arm and wrists) will contribute to the overall or grand score for the whole body that can be assessed with an action list (McAtamney & Corlett, 1993). Another well known tool is the Rapid Entire Body Assessment (REBA), developed by Hignett and McAtamney (2000). This tool was developed as a response to a need in the field for evaluations that would take unpredictable postures accompanied with force, movement or repetition into account. These kinds of postures are frequently found to happen in hospitals and other institutions where employees lift or manipulate heavy and animate loads a regular basis (McAtamney & Hignett, 2005). Since this was a new kind of an evaluation tool, Hignett and McAtamney (2000) had to look to a combination of other tools that would provide a baseline for each of the concerns and design goals. The REBA was based on the range of limb positions offered in the RULA, as well as concepts from the OWAS and work at the National Institute for Occupational Safety and Health (NIOSH) (Hignett & McAtamney, 2000). The REBA is scored based on the philosophy of the "neutral zone" mentioned previously where the final score will indicate the level of risk and action needed for improvements.

The above-mentioned tools as well as most other observational methods not discussed here (See Hedge, 2004, for a complete discussion on more methods, as well as chapters 3–16 in the Handbook of Human Factors and Ergonomics Methods, edited by Stanton, Hedge, Brookhuis, Salas & Hendrick, 2004) all offer the advantage of being relatively simple paper and pencil observational techniques. As such they are inexpensive to carry out and mostly don't take a long time to complete. One disadvantage of this type of exposure assessment is however that these methods will have limited use where postures are not held for a long time. The QEC developed by

Li and Buckle (1999) is supposed to be sensitive to this limitation and studies of this measurement tool indicate that before and after changes can be detected with it as well. This tool is relatively new, and as such, more research is needed for further validation. Li and Buckle (1999) also state that the score system associated with the QEC is largely hypothetical, since again, the concept between exposure and risk needs to be studied further.

Comparison of observation based methods

In an attempt to evaluate the measures most commonly used in ergonomic fieldwork in this aspect, Spielholz and colleagues (2001) conducted a study where they compared self-report, video observation and direct measurement. Not surprisingly, Spielholz et al. (2001) found that self reports were the least precise method in the sense that they had the most variability or error. Their participants overestimated the amount of repetition, force and posture duration as well as velocity of movement. Direct measurements, such as an electro-goniometer, were found to be the best measures for wrist flexion/extension duration, repetition as well as forearm rotation duration repetition, grip force and velocity in Spielholz et al.'s study (2001). In general direct observational methods are considered to provide more accurate data than self-reports; however, as with any type of measure, there is the possibility for measurement error from the calibration process, for example. Another problematic concern with direct measurement tools is equipment cost and practicality in the field. According to Dempsey et al.'s (2005) survey of tools and methods used by certified ergonomists, roughly one fifth of their respondents use an electronic wrist goniometer, in spite of the majority of their specializations being "Job/task analysis and design" (52.9%), "Health and safety" (42.5%), "Anthropometry/biomechanics" (34.4%) or a combination of these. When asked why they didn't use electronic wrist goniometers, about thirty per cent didn't need this equipment, but roughly 50% claimed that it wasn't available to them or too costly.

Lowe (2004) looked at how experts' ratings of upper limb working postures varied depending on how the observation tool was constructed (3, 6 category scales or a continuous visual analog scale) in relation to direct measurements made with electro-goniometers. Lowe's rating scales were constructed to represent available scales in the literature without directly evaluating existing scales. The main findings from Lowe's study were that the expert participants tended to underestimate the frequency of postural deviation and average wrist extension significantly, especially when using a visual analog scale. Further, the probability of misclassifying a posture used most frequently was higher for experts using the 6 category scale versus experts using a three point scale. This indicates that there is a tradeoff between the level of accuracy and the type of rating scale used. It is also interesting to see that even the expert participants were not very successful at estimating the extent of a postural deviation just by observation. In defense of the experts, the observation estimates were based on video taped excerpts which can potentially be harder to rate than actual observation due to limited range of visibility and angle.

Successful use and design of checklists – Implications for digital radiology

With any observation, there are several sources of error that are well known. An obvious source is how being observed alters one's behavior. Kerlinger and Lee (2000) state "*The major problem of behavioral observation is with the observer*" (p. 728). The observer by definition will affect the observed person's behavior or by virtue of content error or context error, code the behavior inaccurately to a certain degree. In the case of altering behavior by presence alone, it can be detrimental to performance or encourage performance that is superior to unobserved performance (Stanton, Baber, & Young, 2004).

According to Corlett (2002), the use of observation measures such as checklists implies ease of use and interpretation when in fact most observational tools require some training not only for implementation but also for interpreting the results as well as monitoring. How easy a tool is to use depends in large part on how it is designed, the wording of the questions and how the answer options are presented. As Lowe (2004) discovered, there is a difference in how accurately an expert will rate a posture based on how the rating scale is constructed.

Traditionally, tools in which observed behavior or posture is matched with images on a scoring chart similar to RULA or Rapid Entire Body Assessment (REBA) are favored. These seem to be successful due to the relatively low cost associated with completing them as well as the succinct manner in which the information is presented and the relative short training it takes in order to use them. The opportunity to overcome language difficulties, as well as general comprehension issues is another benefit of tools that use graphic representation of answer options or questions. Other ideal factors for an evaluation tool include: short time for completion (10 minutes or less), limited extraneous data collection, with allowance for flexibility or accommodation for the tasks that are being evaluated (Li & Buckle, 1999).

According to the literature in digital radiology there is not only a lack of standardization of the workplace for radiologists, but also a lack of proper evaluation tools that will both identify risks as well as offer quick and easy indicator of the current state of the digital reading room (Kolb, 2005). This is problematic in part because of the pressure for productivity that is associated with the use of digital radiology technology. Experts in digital radiology (Reiner & Siegel, 2002; Thrall, 2005) state that if this pressure is not alleviated with a properly designed environment, the promise of increased productivity and efficiency will not be fulfilled. Another problem is that there is also a strong demand for financially viable ergonomic environments (Kolb, 2005). Without any indication of whether or not the environment is supporting the work that is supposed to take place in the space, it is hard for hospital administrators to justify any expense for furniture and computer equipment in addition to the software framework (PACS). A short and easy to use environmental checklist of the working environment in a digital reading room, similar to the one proposed in this paper is an ideal tool to begin looking at the working environment of radiologists. It will not only assist the radiologists themselves as well as hospital health and safety enforcers but also hospital administrators as they move towards completely digitizing the radiology work process.

CHAPTER 5 - METHODS

Checklist Development

The goal was to identify items that would represent an intensely used radiology digital reading room workstation, in terms of duration of work and intensity of material viewed. Eventually the checklist will be used by ergonomists and facility planners, so environmental measures such as temperature and air velocity were included as well as basic measures of the work station, for example: size of work surface and types of input devices. Since there is not an existing checklist in place that focuses on the work environment of radiologists, it was further decided to look to literature on ergonomics in radiology as well as commercial material such as brochures by furniture makers for hospital and radiology furniture fixtures.

The Cornell Digital Reading Room Ergonomics Checklist (CDRREC) was devised based on questionnaire items found in thirteen checklists and educational material published by the government, independent researchers and furniture makers. Examples of these sources are the Occupational Safety and Health Administration (OSHA) Ergonomic Solutions: Computer Workstations e-Tool Index for Computer Work, the Canadian Standards Association's Z412 Guideline on Office Ergonomics and the Cornell University Performance Oriented Ergonomic Checklist For Computer (VDT) Workstations from the Human Factors and Ergonomics Society. A complete list of all the resources can be found in Appendix A

The following criteria was used in choosing the initial items for the checklist:

- *The items had to address a work environment with computers, keyboard and mouse set-up.*

- *The items had to address work with visual displays, adjustments and image display quality.*
- *The items had to address postural issues related to working with visual display terminals, input devices, document holders and other computer workstation accessories.*
- *The items had to address issues relevant to office furniture typically used with visual display terminals, such as adjustments and maintenance.*
- *The items had to address postural and usability issues in working with input devices commonly used in digital radiology, such as voice recognition, microphone, headset, joystick, roller ball and foot controlled pedals.*
- *The items had to address ambient environment issues, such as air quality, temperature, noise and lighting.*

The items were arranged in an excel spreadsheet, with columns representing initial item number (from original checklist), new item number, item and item source. This allowed for easy manipulation of the items, arranging alphabetically by items or item source. This arrangement also allowed for easy search of the items as well as side-by-side comparison of items.

After reviewing a total number of 615 items, it was decided to divide the checklist into five sections that were put up on separate sheets within the excel spreadsheet document. These sections can be seen in figure 4.

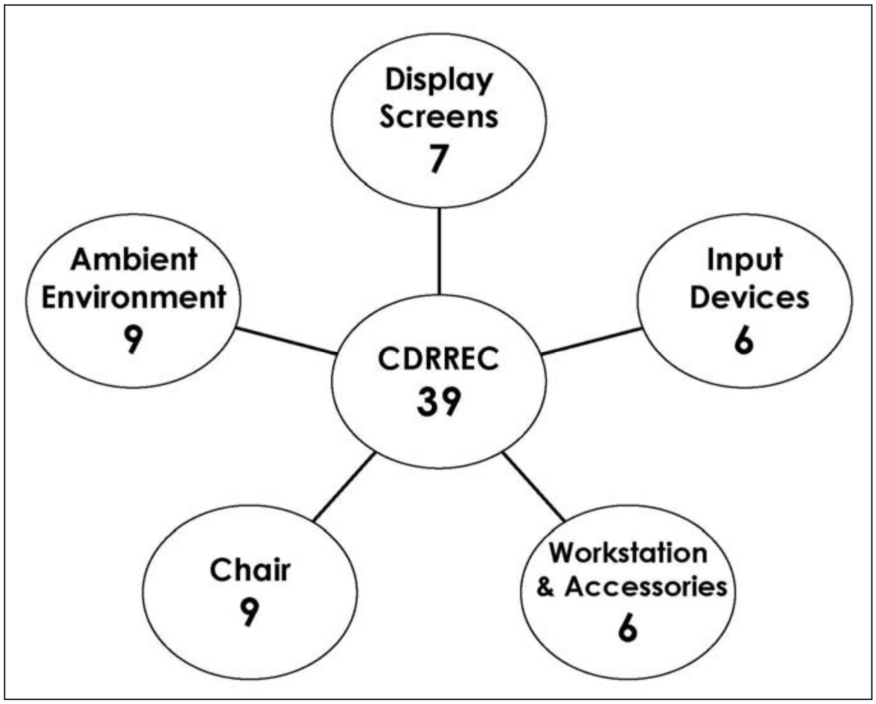


Figure 4. Sections of the CDRREC. The number of items in each section is represented below the section name.

To cut down the number of items for the final checklist, duplicate items were summarized into one and irrelevant items were deleted from the pool of items. Further elimination of items was based on a review of the literature for radiology workstations as well as reviewing commercially available workstations and equipment for radiologists utilizing digital image technology. Based on these eliminations, the final number of items to comprise the list was 84. These items make up the 39 questions on the final checklist. The discrepancy between these two numbers can be explained with a look at question 7 in the initial version of the CDRREC: "Please check circle if the images on the screen are: Fuzzy, Hard to read, or Without visible flicker or jitter". Here, three items from the initial pool of items have been combined into one question. Similarly, most other checklist questions in the CDRREC will contain more than one item from the initial pool of items.

To facilitate understanding of the checklist and its usage, one goal of the creation process was to maximize the number of pictorial cues within the checklist. This was considered especially important for ratings of postures. Images of model radiologists employing various postures while sitting at a desk, using input devices were created using a Canon Digital IXUS 400, 4.0 megapixel camera, using standard automated settings and flash. These images were post-processed using Adobe Photoshop version X for Microsoft Windows XP Professional.

Figure 5. An image created for the CDRREC, before post-processing.

Items in the background were erased and a standard color used to fill the background, ensuring that there would be a minimal level of "noise" within each image, focusing the users' attention to what specifically the checklist question was targeting. The images were saved in a grayscale mode to facilitate a comparable print quality between users, whether they would download the tool off the internet or obtain it via photocopies. An example of an image before and after post-processing for the checklist can be seen in figures 5 and 6.

Figure 6. Same image as in Figure 4, after post-processing.

Most questions in the checklist contain a combination of factual and subjective items that can be answered by checking a “YES/NO” answer-box, a measurement, rating or a simple description. Three questions (6, 8 and 11) have answer options in the form of images that have been processed as described above.

Other answer options that were thought to improve and facilitate the use of the CDRREC were designed for questions 4 and 5. For question 4 “Is there glare on the display screens that affects image reading? If yes, please mark of fill in the screen areas affected by glare:” a diagram representing two computer desktops with monitors was created with an overlay grid for the user to fill in the exact location of the glare on the monitors when viewed from seated position. This was also thought to facilitate the remediation process for glare, since knowing where the glare is showing off the monitor will help locate the sources of it as well. The diagram can be seen below, in figure 7.

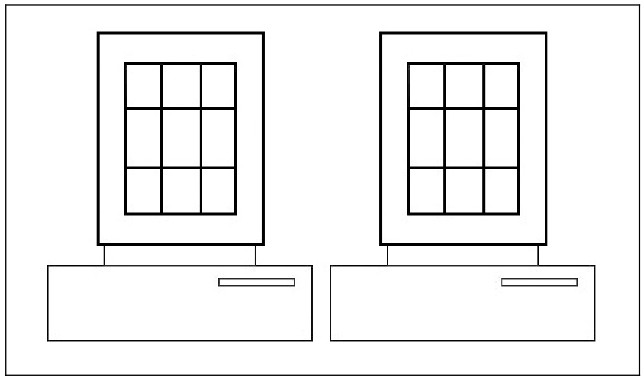


Figure 7. Diagram used as an answer option for question 4.

For question 5 in the checklist, “Check the current screen character luminance of the computer screens by comparing to these luminance examples”, the answer options were designed to display a range in contrast values, going from good contrast

Table 3. Contrast values for Question 5 in the CDRREC

Answer option	Contrast value	
	SI units	USCS units
1	83 cd/m^2	24.22fL
2	73 cd/m^2	21.31fL
3	52 cd/m^2	15.18fL
4	36 cd/m^2	10.51fL
5	26 cd/m^2	7.59fL
6	16.8 cd/m^2	4.90fL

to poor contrast in accordance with the Human Factors Display Standard (HFDS, 2003). This was believed to help the evaluator get a quick idea of whether or not the display quality was sufficient or in need of improvement without doing extensive tests. The contrast value was created with a black background surrounding the answer option with a predefined value, using a light meter positioned 7 inches from the target. In order to accommodate regular printer quality, a series of grayscale test strips were created with the Microsoft Word Version text editing software, choosing colors from the font color palette. These test strips ranged in values from 83 cd/m^2-11.5cd/m^2 .(24.22fL-3.36fL). The values chosen for the answer options can be seen in table 3.

Instead of basing the checklist outcome on a scoring system, it was decided to mark the items that need immediate attention or improvement in the checklist by using the term "Ergonomic Item". The first version of the Cornell Digital Reading Room Ergonomics Checklist can be seen in Appendix A.

Pilot Feedback

In order to test the usability of the checklist, three people (2 male, 1 female) were asked to rate a workstation being used. The pilot participants were graduate students in fields that are not associated with ergonomics or radiology. None of the participants had previous knowledge or exposure to the list or its contents. The participants were asked for feedback on the instructions for the list, if they were clearly written as well as how easy using the list felt in their opinion. They were further asked to give feedback on the overall layout of the list. The results from the pilot feedback were added clarity in wording of some question items. An example would be the change in question 24 from: "*Do the chair armrests restrict workstation clearance?*" to "*Do the chair armrests restrict workstation access?*"

Interrater reliability - Individual Item test

For further evaluation of the first version of the Cornell Digital Reading Room Ergonomics Checklist, a group of experts (human factors and engineering, facility management and human environment research background) and non-experts were asked to complete the checklist using a set of eleven 8.5" x 11" images depicting a person viewing digital radiology images at a two monitor computer workstation. Figure 8 is an example of the images used for this purpose.

Figure 8. A sample image used for the individual item test

In the images, a model radiologist was pictured doing various tasks, such as typing, using a computer mouse and holding a telephone receiver. The images were created using a Canon Digital IXUS 400, 4.0 megapixel camera, using standard automated settings.

A resized version of the images can bee seen in Appendix D. Only items that require a judgment call were tested, since not much variation was expected in items that ask questions of factual nature.

This test was intended to reveal items that might not be good for differentiating between situations that were unclear or demanded more information for clarity as well as looking at the overall variability between raters. Further, this test was also intended to provide data on the level of agreement between observers in terms of interrater reliability and how well the list differentiated between experts and novices as well. The items that were used in this test are listed in table 4. To create a base line of correct answers or evaluation, the images were rated by an ergonomist. This baseline was used to evaluate the ratings by the participants in terms of agreement rates.

Table 4. Items used for individual item test of the CDRREC.

Number	Item description
4	Is there glare on the display screens that affects image reading?
4b	(*contingent on answer to prior question*) If Yes, Please mark or fill in the screen areas affected by glare:
5	Check the current screen character luminance of the computer screens by comparing to these luminance examples.
6	Please check the image that best describes the posture of the radiologist while (s)he is viewing the screens.
8	What is the wrist angle? Please check the image that best fits the posture.
11	What is the wrist position? Please check the image that fits the posture.
14	Does the work surface look cluttered?
16	Does the radiologist have sufficient space for feet underneath the desk?
17	Is the document placed at the same height and distance as the screen?
18	Is the telephone used with the head upright and shoulders relaxed?

In terms of percent agreement, the ratings by each participant were compared to ratings by other participants in, as well as the ergonomists' rating to estimate the level of agreement between participants and between participants and the ergonomist. This method has been used in research to estimate validity and reliability of screening tools by Engkvist et al. (1995). Multiple observer agreement (King, 2004) was statistically analyzed using Minitab 14 for Microsoft XP Professional.

Based on the results from the participant percent agreement on individual items, inconsistent items were excluded in a second round of multiple observer agreement calculations to investigate whether the level of agreement would improve. The Cornell Office of Statistical Consulting was contacted to verify the use of this test and its outcomes. Based on these results, the final version of the Cornell Digital Reading Room Ergonomics Checklist was created (see Appendix G for a complete final version).

Expert Feedback

In order to validate the CDRREC further, expert feedback was solicited in four ways. First, the list, a feedback form and a letter explaining the purpose of the feedback were mailed individually to a list of 19 practicing radiologists that all utilize digital medical imaging in their work. Second, thirty copies of the list and a feedback form were handed out at a major national conference and education seminar on digital medical imaging, attended by radiologists, hospital managers and other imaging professionals. Third, the list and the feedback form were made available on-line at http://ergo.human.cornell.edu/ AHProjects/Hronn06/cudigitalRR.htm. The on-line version of the feedback form was announced at the above mentioned major national conference as well. Visitors to this website were encouraged to download the checklist and the accompanying feedback form and submit electronically. Fourth, a practicing hospital ergonomist was contacted for feedback and comments, using the same feedback form that was sent to the radiologists. The feedback form consisted of four closed ended questions, with a comments section after each question to be analyzed qualitatively by coding and categorizing as well as quantitatively by analyzing the number and types of comments submitted with content analysis. The closed ended questions were analyzed quantitatively. The feedback form can be seen in Appendix B. The letter to the radiologists can be seen in Appendix C.

Validity

Face validity

The purpose of the checklist is to identify and document postural or equipment set-up related problems or problems related to ambient conditions at a radiologist's workstation. Face validity refers to what a test appears to be measuring, whether the instrument appears to be measure the intended construct. This type of validity is not quantifiable (Kerlinger & Lee, 2000). It was assumed that since the items all came from validated sources, checklists and standards based on research, that the face validity for the CDRREC would be pretty good.

Concurrent validity - Predictive validity

According to Kerlinger and Lee (2000), concurrent and predictive validity are subcategories of criterion related validity. Concurrent validity refers to the extent that a test or a measurement would agree with another validated test or measure for the same thing. The same applies to predictive validity, but with a different twist. Predictive validity refers to the extent a measurement can be applied to predict a certain outcome in the future. Kerlinger and Lee (2000) argue that this classification of predictive validity is vague, and that in a sense all measurements are predictive by definition. It is helpful to look at these two types of validity when validating a new tool, simply to verify the theoretical foundation of the items within the tool. The predictive and concurrent validity of the checklist should be fairly good, considering that all the items in the CDRREC come from sources that have been validated in practice and theory.

Convergent Validity – Divergent Validity

Kerlinger and Lee (2000) identify construct validity as one of the more important notions in measurement theory and practice. Not only does this concept address the question of whether a tool is actually measuring a construct, or whether hypotheses can be derived from the construct, but also if an alternative hypothesis can be tested. Suggesting an alternative theory in this case would mean another way of looking at problems that arise in a working environment than focusing on the relationship between the worker and their workstation. For this purpose, it is important to look at whether the CDRREC will provide an outcome similar to other observation based tools (convergence) of working environments and postures or if the CDRREC will differ from these measures (divergence). It is suggested that the CDRREC will fulfill the criteria related to convergence and divergence in relation to other measurements due to the theoretical foundation on which the CDRREC is built.

CHAPTER 6 - RESULTS

Individual item test - Interrater Reliability -

Participants

Twenty one people, age 18 – 58 years old completed the interrater reliability and individual item test. Six were male and 15 female. Seventeen had completed an undergraduate or a graduate degree, whereas four had completed high school only. Eight participants had background in ergonomics, facility planning and management, and other human environment relations. Thirteen participants had backgrounds that were not related to human-environment research. The participants were recruited via flyers on campus and were rewarded with $2.00gift certificates for ice cream at the Cornell Dairy Bar for their efforts.

Individual Item test

Table 5 shows the items used for the item analysis with the ergonomist ratings, the participants' maximum percent agreement in ratings and percent agreement between participants and the ergonomists' ratings.

In six instances, the level of percent agreement between participants and between participants and ergonomist is relatively high (71.4% - 95.2%).

In two instances, the level of agreement between participants and between participants and ergonomist is moderate, ranging from 50% to 61.9%.

Table 5. Percentage agreement between participants (P-P) and between participants and ergonomist (P-E).

Number and Item description	Ergonomist rating	P-P agreement (%)	P–E agreement (%)
4.a) Is there glare on the display screens that affects image reading?	Yes	85.7	85.7
4.b) (contingent on answer to prior question) If Yes, Please mark or fill in the screen areas affected by glare:	L[1]: 4,5,7	39	92.7
	R: 4,5,7,8	36.7	100
5. Check the current screen character luminance of the computer screens by comparing to these luminance examples:	L: 1,2	33	66.7
	R: 3,4	38	42.9
6. Please check the image that best describes the posture of the radiologist while (s)he is viewing the screens.	Screen is too far away	71.4	71.4
8. What is the wrist angle? Please check the image that best fits the posture.	Wrist Extension	85.7	85.7
11. What is the wrist position? Please check the image that fits the posture.	Radial deviation	90.5	90.5
14. Does the work surface look cluttered?	Yes	95.2	95.2
17. Does the radiologist have sufficient space for feet underneath the desk?	No	50[2]	50
18. Is the document placed at the same height and distance as the screen?	No	61.9	61.9
19. Is the telephone used with the head upright and shoulders relaxed?	No	90.5	90.5

When looked at in relation to whether the participants agreed with the ergonomist rating or not, the numbers change for four items. Table 5 shows that the most dramatic change is visible in items that had showed a very weak consensus

[1] L= Left monitor, R= Right monitor
[2] Data missing for one participant, total percentage calculated from n=20

between participants. An example is item 4b) "*Please mark or fill in the screen areas affected by glare*:" (Left monitor), going from 36.7% participant-participant agreement to a 100% in participants-ergonomist agreement. For this particular item, participants had the option to mark more than one location on the monitor diagrams options. Eighteen participants rated a total of five areas in left monitor and four in the right monitor that had glare. Figure 5 shows the ergonomists' rating of this glare indicator contrasted with the number of participants rating for each area of either monitor. The shaded areas represent areas that were rated as having glare by the ergonomist. The numbers in the cells represent the number of participants rating each area as showing glare.

Overall, the majority of the participants' ratings for glare matched the ergonomists' ratings for the right monitor, however three participants rated areas as showing glare on the left monitor, whereas the ergonomist had not.

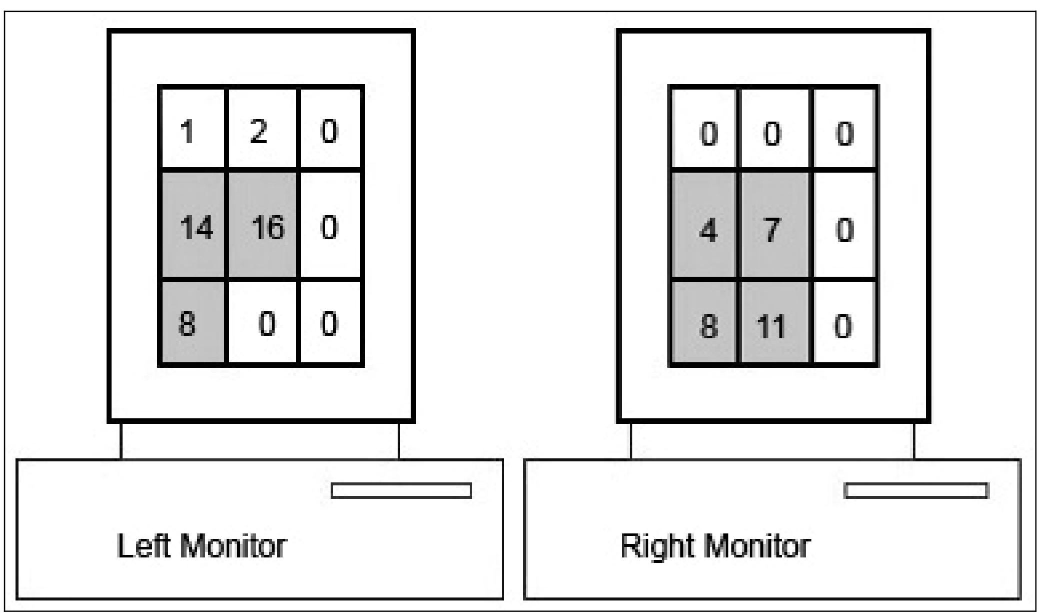


Figure 9. Comparison of ergonomists' and participant glare ratings

The results for Question 5, "Check the current screen character luminance of the computer screens by comparing to these luminance examples" can be seen in table 6. Table 6 also shows the actual contrast values of the test strip in the questionnaire.

Table 6. Number of participant contrast ratings by character luminance

Character Luminance of test strip SI units	Character Luminance of test strip USCS units	Test strip number	Left monitor (number of participants)	Right monitor (number of participants)
83 cd/m2	24.22fL	1	7	3
73 cd/m2	21.31fL	2	7	8
52 cd/m2	15.18fL	3	6	5
36 cd/m2	10.51fL	4	1	4
26 cd/m2	7.59fL	5	0	1
16.8 cd/m2	4.90fL	6	0	0
		Total	21	21

As can be seen in table 6, a majority of the participants (20) rated the Character Luminance for the left monitor to range between 1 and 3, or 83–52 cd/m^2 (24.22-15.18fL). One participant rated the character luminance between 52 and 36 cd/m^2 (15.18-10.51fL). The ratings for the right monitor were more varied, with eight participants rating the luminance at 73 cd/m^2 (21.31fL) and five or less ratings between 52-26 cd/m^2 (15.18-7.59fL) for each value (5, 4, and 1 respectively). Three participants rated the character luminance to be at 83 cd/m^2 (24.22fL)

The items that show a very low agreement between participants (4b, and 5) both had multiple answer options. Item 4b looks at where the glare is showing up on the radiologists' display screens. In each case a participant could check up to nine answer options, leading to the final number of options checked to be 41 for the left monitor and 30 for the right monitor. Overall, these answer options were compared with the ergonomist ratings in terms of whether or not the participants had checked anywhere within a particular area. This explains why the percent agreement between participants and ergonomist (92.7% for left monitor, 100% for right monitor, Table 5)) is much higher than between participants (39% for left monitor, 36.7 for right monitor, Table 5). There is also a problem with the images provided, since they are static and do not give the participants a realistic view of glare and how it can change depending on what the viewing angle is.

It is valuable for the ergonomist doing the reading room evaluation to discern where or what the source of glare is, in order to help with recommendations and amelioration of the problem, however, judging by the agreement levels of this item test, the item is questionable at best and needs further validation. It can be argued that the items will prove to be useful in an actual field test, where the evaluator could situate themselves in the radiologists' chair and experience the glare on the display monitor. An observation of the lighting set up in the reading room was not possible for the individual item test, but this is necessary when looking at glare sources in the environment. Again, an actual observation in the field will likely provide a higher level of agreement between observers than the observation done with the images as was the case here.

Answering item number 5, "*Check the current screen character luminance of the computer screens by comparing to these luminance examples:*" proved to be difficult for some participants and this was expressed to the researcher during data collection. The difficulty appeared to be related to the form of the answer options (test strips with contrast items) and how to arrive at an answer from these, since there were more than one monitor set-up available for testing in the images provided.

This is supported when we look at the agreement between participants and the ergonomist. This value was moderate (66.7%, 42.9% for left and right monitor respectively), indicating that the design for this type of evaluation might be flawed.

It is essential to provide superior display quality for digital radiology image reading. Not only will it result in more accuracy, but also provide the radiologists with work environment that is not harmful to their health, i.e. eyes in this case. An evaluation of this sort of display quality might best be served with the rigorous testing that the American Association of Physicists in Medicine recommends in their standard for the assessment of display performance for medical imaging systems (2005). The problematic items identified with percent agreement were further tested with the multiple rater agreement analysis below.

Interrater reliability

To test whether the checklist was correctly discriminating between experts and novices, the multiple rater agreement was evaluated for the whole group and then for individual subgroups. When the group is tested as a whole the multiple rater agreement is at .18 ($p<0.05$). When looked at in terms of experts and novices, the expert group multiple rater agreement is at .50 ($p<0.05$) and the group of novices at .08 ($p<0.05$), this supports one of the design goals for the CDRREC, that it would be used by ergonomists, facility planners and managers or other health and safety professionals and not untrained people.

The results from the individual item test indicated that there were at least four questions that were problematic, either by design or in the way that they were tested. This prompted a closer examination of the rater agreement by excluding each of these questions to see if there would be a significant change in the multiple rater agreement as a result

Table 7 reveals the multiple rater kappa scores for the group of experts excluding one of the four questions at a time from the analysis.

Table 7. Multiple rater agreement for the individual item test, when problematic are excluded.

Item left out	4b	5	16	17
Multiple rater agreement	0.39	0.52	0.52	0.47
Significance level	$p< 0.05$	$p< 0.05$	$p< 0.05$	$p< 0.05$

As can be seen in table 7, excluding question 4b, specifying the location of the glare, would not be beneficial for the overall reliability of the CDRREC. This can be concluded by looking at how the multiple rater agreement is lowest when this question is left out. The multiple rater agreement is somewhat similar for the other three items, ranging from 0.47-0.52, indicating a slight benefit or harm in leaving those questions out.

Expert feedback

A total of 11 expert feedback questionnaires were obtained via mail and email. Respondents were practicing radiologists (4), hospital administrators (2) or professionals in the field of environmental design and analysis such as architects (1) and ergonomists (1). Three respondents did not disclose their profession.

Expert feedback – Questionnaire

The results to the closed ended questions can be seen in table 8. In general the experts thought that the instructions, questions and layout of the checklist were easy to understand and follow. However, only five out of ten thought the checklist was comprehensive.

Table 8. Results from expert feedback questionnaire.

Feedback survey item	Answer: Yes	Answer: No	Missing data
The instructions were easy to understand and follow	9	2	0
The questions were easy to understand (stated clearly)	8	3	0
The layout of the questionnaire was easy to follow	10	0	1
The checklist was comprehensive	5	5	1

Expert feedback – Comments

The qualitative expert feedback resulted in a total of 39 comments that were categorized into the following categories after coding: *Improvements or changes to current items*, which had 15 comments, thirteen comments were classified as *Recommendations for new items* and lastly, *Questions, general comments and information* had eleven comments.

Improvements or changes to current items

These comments or recommendations focused specifically on layout, the clarity of each item and wording. One example is the recommendation to add a diagram to question 16: "*Does the radiologist have sufficient space for feet underneath the desk?*" to help clarify what the different parameters in that question represent. Another expert suggested substituting "Fore/Aft Distance" with "Depth" for item 20: "*Chair seat pan can be adjusted in: Height – Angle/Tilt – Fore/Aft Distance*". Expert comments regarding improvements or changes to new items can be seen in Table 9.

Table 9. Expert feedback for the CDRREC: Improvements or changes to current items

Section	Expert comments
Display screens	Display type: monochrome, color. Define screen size measurement On page 3, DISPLAY SCREENS, question 6, you may want to consider accounting for screens not directly in line with the input devices that tends to be a problem in healthcare, due to limited space, etc.
Input devices	On page 4, INPUT DEVICES, questions 8 and 11, you may want to consider labeling the photos, similar to page 3, i.e. "correct height/angle", "keyboard/mouse too high", "radial/ulnar deviation", etc. On page 4, INPUT DEVICES, question 10, you may want to include an answer option for when the mouse is on the same platform as the keyboard, but not the desk, such as a Humanscale Big Board keyboard / mouse tray, unless that is what you are getting at with "Platform adjacent to keyboard" – I thought this might be for a separate mouse platform adjacent to keyboard, not over it though.
Workstation and workstation accessories	OK – except for question 17 – Distances (depth, width) are ambiguous. I would suggest defining or illustrating. On page 5, WORKSTATION & WORKSTATION ACCESSORIES, question 17, you may want to consider adding "legs" to the question: "Does the radiologist have sufficient space for legs and feet underneath the desk?"
	On page 5, WORKSTATION & WORKSTATION ACCESSORIES, question 18, you may want to include an answer option under the document holder for "Is the document holder directly in line with the keyboard/mouse and monitor?"

Table 9 (Continued)

	On page 5, WORKSTATION & WORKSTATION ACCESSORIES, question 19, add "headset" to the "Hands free" answer. This will help clarify, because the term headset is used more in work settings, as opposed to hands free, which is used more for cell phones
Chair	On page 6, CHAIR, question 1, the choices may be easier to understand if you include the term "Depth" on the last choice "Fore/Aft Distance", because Depth is the term that chair manufacturers use and practicing ergonomists, etc. are familiar with. On page 6, CHAIR, question 22, I would consider giving people the option of checking more than one circle, because many armrests adjustable in one or more of those features, sometimes all three. On page 6, CHAIR, question 25, you may want to consider separating the question into two questions, one getting at the 5 legged base and one getting at "appropriate" casters, i.e. hard nylon for carpeted areas, and soft rubber for tile/linoleum areas. This comes up frequently in the hospital where hard, nylon casters are used in tile areas, or vice versa.
Ambient environment	OK- except for the ambient noise level. Most of us do not have sound level meters. You could give comparison with common noise levels (in a car, on a subway platform, open-plan office, etc.) My only suggestion would be to add or replace the technical measurements with some "laymen's" terms. Specifically noise level and illuminance. I suspect many hospitals would neither understand nor have access to a sound level meter, light level reader and the like. Also you might include optional noise levels, ambient light levels, etc. ... so we might know what numbers to shoot for. Good survey J
Other	The "Ergonomic Issue" section of the instructions is not entirely clear. Is the person completing the checklist supposed to check the box if an answer falls into that particular division? This should be explained further in the instructions, and maybe bold the connecting lines and boxes so they stand out more on the checklist.

Recommendations for new items

These recommendations included more extensive checking of the current situation in the radiology reading room, by addressing the history of existing employee health issues related to the workstation. One expert thought it would be beneficial to add a section on general satisfaction with the working environment. An example from these comments is: "*Include questions on individual controls of lighting and heating/cooling*". Expert recommendations for new items can be seen in Table 10.

Table 10. Expert feedback for the CDRREC: Recommendations for new items.

Section	Expert Comments
Display screens	What screens do you use? Vendor, resolution, size? Are monitors on freestanding pedestals or on mounted brackets?
Input devices	N/A
Workstation and workstation accessories	You might want to ask if anyone has developed any musculo-skeletal problems using the workstation Is height of work surface easily and quickly adjustable from seated height to standing height? What is lowest and highest heights? Can angle of counter be altered? Is your work surface one that was constructed on site or from a commercial vendor? If commercial vendor, company and model number? Has the height of the desk to floor been assessed adequately?
Chair	Ask for vendor and model of chairs being used.
Ambient environment	Include questions on individual controls of lighting and heating/cooling
Other	Have any of your radiologists suffered any injuries? If so, describe. On a scale of 0 to 10, how pleased are you with your reading room? Remediation attempts: For any item selected that is a problem, you might ask what (if any) remediation steps were taken.

Questions, general comments and information

This category consisted of comments similar to: "…*question 2, the display screen size is not entirely clear. Are you looking for a display size measurement (pixels), or a diagonal screen size measurement?*" There were also informational comments about the number of monitors used, types of monitors as well as comments about the ambient environment measures to be used in the checklist.

The expert questions, general comments and information in total can be seen in Table 11.

Table 11. Expert feedback for the CDRREC: Questions, general comments and information.

Section	Expert Comments
Display screens	On page 2, DISPLAY SCREENS, question 2, the display screen size is not entirely clear. Are you looking for a display size measurement (pixels), or a diagonal screen size measurement? At present most diagnostic workstation will have 3 monitors - 2 monochrome, 2-3 mpixel, and one color. Typically 1-2mp's for RIS and color images. This requires redesign of display screen page. You should talk with some of the PACS vendors or ergonomic workstation vendors for help and also funding for your research. It is very important.
Input devices	N/A
Workstation and workstation accessories	On page 5, WORKSTATION & WORKSTATION ACCESSORIES, question 20, I don't agree that not having a footrest is necessarily an "Ergonomic Issue" if the workstation and accessories are adjustable, one may not be needed.
Chair	On page 6, CHAIR, question 28, I'm just curious why a "NO" response to this answer wouldn't generate an "Ergonomic Issue".
Ambient environment	On page 7, AMBIENT CONDITIONS, just a general comment on this page, practicing ergonomists in hospitals/healthcare facilities, may not necessarily have access to all of this specialized equipment, due to budget constraints, etc. I know our Environmental Health and Safety Office has some of this equipment, but this may make the checklist not qualify as a "quick evaluation" as you indicate in the beginning of the instructions. You may want to consider having an option that the evaluator could answer the questions without having to give all the quantitative data.
Other	I have found few sites that can verbally describe many of the issues you wish to obtain, but hope some of the comments I have made will be of use to you Great checklist. Would like to see how it is assessed/reviewed/reported

Table 11 (Continued)

	Thank you. We have 3 radiologists' reading rooms. This tool is very helpful to us. I'm not sure how readily available a goniometer is in radiology – especially if it has gone digital. #23 is missing or numbering is out of order While our radiologist would not care to participate, this is a good frame of reference for a correctly designed and comfortable reading environment.

To gauge the strength of each section within the CDRREC, the expert comments were arranged in a numerical fashion. The section that had the fewest comments was "Input Devices" (2), whereas "Workstation and Workstation Accessories" had a total of eleven comments. Table 12 shows the number of comments for each section of the CDRREC.

Table 12. Number of expert feedback comments by sections in the CDRREC

Section	Improvements or changes	New items	Questions, comments information	Total
Display Screens	3	2	2	7
Input devices	2	0	0	2
Workstation and workstation accessories	4	6	1	11
Chair	3	1	1	5
Ambient Environment	2	1	1	4
Other	1	3	6	10
Total	15	13	11	39

The expert feedback questionnaire revealed that the majority of the participants felt that the CDRREC was easy to understand and follow and that the layout was easy to follow (Table 8.). The final version of the CDRREC has the same overall look and layout as the checklist version submitted to the experts.

Half of the respondents felt that the checklist was not comprehensive. Table 12 reveals that the section most in need of improvements was the section on the workstation and workstation accessories.

Summary of changes to the CDRREC

Display Screens

Based on the recommendations from the expert feedback, all the questions in the Display Screens section were changed to reflect a three monitor setup as opposed to two monitor set up as was done in the first version of the CDRREC. Further, question number 5 “Check the current screen character luminance of the computer screens by comparing to these luminance examples:” was eliminated based on the results from the individual item test and the multiple rater agreement analysis. A new question addressing the type of screen display (monochrome versus color) was added (new number 2).

Input Devices

Images in questions 8 and 11 were provided with descriptive labels for identification of wrist posture and angle based on expert feedback recommendation.

Workstation and Workstation Accessories

Two new questions were created for the Workstation and workstation accessories section. These questions address the angle of the workstation surface (new number 18) and the adjustability of the workstation height (new number 19). Question 17 (same new number) was changed to represent sufficient clearance under the desk, ensuring that the issue of clearance for feet and legs would be addressed. Similarly, question 18 (new number 20) was split into two items; one regarding the distance of the document holder from the radiologist and one to represent the height of the document holder. If a document holder is at the same height as the monitor but at a different distance, it will be logically impossible to answer this question in any other way than negatively and the question will be rendered useless unless it addresses both of these dimensions separately. This was considered to be the cause of the participants' confusion in their ratings for the individual item test for both items initially numbered 17 and18.

Out of six suggested new items or questions for the section on workstation and workstation accessories, only three were added to the final version of the CDRREC. The remaining three were considered to be outside the scope of the checklist, pertaining to furniture model types, user satisfaction and health history. While questions like these would provide valuable information, the scope of the CDRREC is not to evaluate the workplace on a macroergonomic level, where the whole organization is scrutinized in relation to work design and management, or to evaluate different types of workstations available commercially. Rather, the CDRREC is intended to identify problem areas for the users, and to provide a quick overview of the work environment.

Chair

The wording for question 21 (new number 23) was changed from “fore/aft distance” to “depth”. For question 25 (new number 26), “…casters that are appropriate for the flooring material?” was added.

Ambient Conditions

To address the issue of individual control, two new questions were created for the section on Ambient Conditions. New question number 42 pertains to individual control for heat in the reading room and new question number 43 addresses individual control for lighting. See Appendix G for the revised version of the CDRREC.

CHAPTER 7 - DISCUSSION

Research has shown that when digital reading rooms are not designed to support the type of work that takes place there, the risk of work related musculoskeletal problems and medical misdiagnosis is greater (Dakins & Page, 2004; Harisinghani et al., 2004; Horii et al., 2003). The evaluation of design factors such as the workstation set up, ambient room condition and the type of monitor display settings were addressed in the development of the Cornell Digital Reading Room Ergonomics Checklist. The results from individual item testing, interrater reliability and expert feedback indicate that the design goals for the CDRREC were accomplished. Further research and design opportunities are discussed

Checklist development results and previous research

The first version of the CDRREC that was created was tested and found to yield an interrater reliability kappa at .50 (p<0.05). This indicated that this version of the CDRREC was a fairly strong evaluation tool but also there is room for improvement. In their evaluation of different work demands in a hospital setting and how the human factors review process could be improved, Janowitz et al. (2006) combined the REBA and selected items from the UC Computer Use Checklist to use as their main evaluation tool. This is similar to the approach taken with the development of the CDRREC, where previously validated measures are taken and adapted to the specific environment in which the evaluation will be used. With the combination of REBA and five items from the UC Computer Use Checklist, Janowitz et al (2006) wanted to capture the entire working experience of hospital staff in an environment that requires considerable amount of time spent sedentary working with computers as well as patients. After adapting the scoring algorithm to account for the new items, Janowitz et al. (2006) divided their tool into two sections, addressing the upper body (UBA-UC) and lower body (LBA-UC) separately. This was done to prevent an overall score to be affected by extreme ranges and negating severe issues identified. Janowitz et al. (2006) found that their inter-rater reliability kappa ranged from 0.54-0.66, depending on what body regions were being evaluated. Janowitz et al. (2006) also found a strong correlation in ratings between REBA and the combined measurement tools (UBA-UC and LBA-UC). This indicated that adding the items from the UC Computer Use Checklist did not negatively affect the performance of REBA. Janowitz et al. (2006) conclude that this type of assessment methodology is well suited for large-scale observations of complex environments.

In terms of further validation of the CDRREC, theoretically, it would be feasible to evaluate the interrater reliability in a similar way as was done by Janowitz et al. (2006), looking at the different sections of the entire checklist. However, this was not possible here, due to the uneven number of items within each section that was tested. Similarly, this type of analysis would need to be done for the CDRREC as a whole, and not only for select items as was done here. Looking systematically at the interrater reliability by excluding problematic items based on percent agreement, showed that the interrater reliability could be improved by excluding questions 5 or 16 (see table 6). This improvement is slight (.02) and does not warrant exclusion of these questions without further support from either research or theoretical work. Question 5 ("Check the current screen character luminance of the computer screens by comparing to these luminance examples ") was eliminated from the final version of the CDRREC due to problems related to sufficient printing quality of the test strips that could result in a bias towards lower image quality. As was discussed in the introduction, the optimal working conditions for radiologists working with digital medical images are not only critical for occupational health and safety reasons, but the weight and seriousness of the task at hand for these professionals needs to be factored in. Any compromise in terms of image display quality is not an option. Further, the AAPM (2005) recently published strict guidelines on how display quality should be tested and evaluated. In terms of indications of low monitor display quality, it is also believed that question 8 (previously number 7), “Please check the circle if the displayed images on the screen are: Fuzzy, Hard to read or With visible flicker/jitter” would be sufficient. It is believed that elimination of question 5 in the final version of the CDRREC will add to the overall validity of the checklist.

Janowitz et al. (2006) discussed other significant improvements to the work processes and how this was facilitated with a customized checklist evaluation. Some of these factors pertain to the design of the checklist and how it was created to give a quick overview and feedback on the work environment. Again, this is similar to the design goals and development process for CDRREC. Utilizing this type of approach is cost efficient in terms of time and manpower. Janowitz et al.’s (2006) results will support further use and development of the CDRREC, especially because of these findings. This is also supported by Li and Buckle’s (1999) findings, defining successful design criteria for checklist design by practitioners to include low cost, minimal extraneous data collection and graphic representation of answer options or questions. In the commercial literature related to digital imaging, there is already a steady influx of articles where the focus is on how the model in hospital administration has been to focus on the current economic situation and the limitations therein. Providing an evaluation tool that will be supported by other research in the field as well as careful design will prove to be successful due to the aforementioned concerns.

One of the major issues with the first version of the CDRREC were: word choice, how questions were structured, and how, in some cases, the specificity of the questions could be improved. These concerns were the result of the expert feedback, obtained with a close ended and open ended questionnaire. This feedback is as valuable as any other statistical analysis in terms of highlighting issues that might contribute to poor interrater reliability or other measures of checklist validation. In their study of checklist usage in a car manufacturing environment and how these lists predict health outcomes for employees, Brodie and Wells (1997) discovered a great variability in individual scores. As a result, they concluded that in general the checklists evaluated (RULA; Occupational Safety and Health Administration (OSHA) draft risk factor checklist; and the Posture and Upper Extremity checklists) were not reliable and needed to be greatly improved in order to be a feasible option in health and safety management. One of the areas they pinpointed as needing further improvement was the wording of the checklist questions and how using site specific examples might facilitate understanding of the environment or work processes in question. Issues similar to Brodie and Wells' (1997) concerns were addressed in the creation of the CDRREC, both in terms of making the checklist specific for the work environment for radiologists working with digital medical images. Further, certain checklist items were modified upon results analysis. The expert feedback received for the CDRREC indicates that the site specificity of the checklist was accomplished and that it will be successfully applied in digital reading rooms.

Limitations of the present study and future directions

As was discussed previously, there was a problem with how the interrater reliability and individual item test was conducted and designed. The information in the images used was in some cases not consistent, causing error in participant's observations that in turn decreased the value of individual items. However, the indications gauged from the individual item test do give some insight into how the checklist will perform and this first step in validating the instrument will provide focus for future work.

In spite of the number of commercially available articles that have been written about the shortcomings of the ergonomic environment for radiologists, the expert feedback received was limited. The low feedback rate from experts might indicate a disinterest within the profession, but the positive nature of each expert's feedback indicates otherwise. There is a concern that there is a self-selection bias in the expert feedback. It is believed, however, that each expert that participated in this study is interested and invested in making the work environment for radiologists the best it can be. These people are all either practicing radiologists, or other professionals that will benefit from this instrument being valid and useful. As such, the self selection bias is a positive influence on the initial development of the CDRREC. For further evaluation and optimization of the CDRREC, it would be beneficial to get expert feedback from health and safety professionals that will be using this instrument. An interesting idea to further evaluate the CDRREC would be to subject it to usability testing that would be more rigorous than what was attempted in the expert feedback currently, evaluating the instructions for the whole checklist and for individual questions. It is possible that the failure of question 5 could be due to the lack of specific examples or directions as to how to use the test strips.

The possibilities for future directions with the CDRREC include a complete evaluation of the checklist in an actual digital reading room. This would include all of the checklist questions and allow for a full evaluation of each item as well as an overall analysis of the checklist. Similarly, this full evaluation might provide data for an individual look at each of the sections within the CDRREC to determine strengths and weaknesses of each. For instance, the section on the Ambient Environment does not contain graphic representations of answer options similar to the section on Display

Screens. In some cases it is virtually impossible to come up with a graphical representation of a question, but determining an optimal way to represent checklist items by way of comparing different types of representations will be valuable both for further development of the CDRREC.

The information on how best to represent questions in the CDRREC in a succinct manner will be beneficial for another type of implementation of the CDRREC. With the rate at which information is being digitized in the hospital environment, making an interactive computer-based version of the CDRREC will prove to be a realistic and feasible option. Already, the use of decentralized, portable workstations or computers-on-wheels (COWs) is a reality in the hospital setting. This will allow for the use of a computer-based CDRREC without introducing added cost in terms of new equipment or adjustment to different work processes. Where COWs are not used or part of the work environment within the hospital, the computer based version of the CDRREC could be adapted to be used with palm pilots. An interactive version of the CDRREC could offer immediate results, comparison to previous evaluations in terms of any improvements that were implemented as well as providing guidance priorities and quick fixes. Other features such as easy counts of prior "violations" of the workstation and flagging of areas that have had a considerable amount of quick fixes, and would perhaps require a closer look, are a possibility as well. In a way, this version could easily provide a window into a complete facility management database system on-the-go.

Other validation techniques for the CDRREC that could be done is triangulation, where one measurement or evaluation tool is compared to other tools that are supposed to measure same or similar constructs as the tool in question. For instance, if questions related to posture were extracted from the CDRREC and used in tandem with another postural evaluation tool such as the RULA or the REBA, we could expect there to be a convergence or a similarity in the issues uncovered in the testing environment. Similarly, there should be a divergence between the CDRREC and an evaluation tool that looks specifically at workers' satisfaction with the workplace. In short, the CDRREC should be related to evaluation tools that are measuring environmental properties of a workplace and not to evaluation tools that are measuring psychological or psychosocial aspects of a workplace.

The development of an accompanying guidebook for the ergonomic issues identified with the CDRREC is an aspect that will add value to the checklist and its future use. To do this, considerations about optimal presentation of educational material need to be addressed as well as research into how best to combine the approach of an evaluation and follow-up both in the paper based and computer based versions of the checklist. Due to the time constraints of this project, this was not a feasible option but as a philosophical stance, the author believes that no environmental checklist is really complete without a thorough guidance on how to follow through with the issues uncovered in an evaluation.

As is, the CDRREC will provide guidance on current problems to health and safety professionals but other uses include a supplement to programming documents for architects looking to design or remodel digital radiology reading rooms. With further validation and testing, the checklist will be a valuable addition to the field of ergonomics as well as facility planning and management, and architecture and design. It is also interesting to note that due to the graphic representation of some of the items within the checklist, a translation into another language could be an interesting undertaking. This would render the CDRREC an addition to the field of ergonomics not only in English speaking countries, but also in Europe, where the field of digital radiology is growing rapidly as well.

Conclusion

There are many research opportunities related to ergonomics and digital radiology, one of them is to look at how reading rooms can be evaluated in a quick and accurate way. The ergonomic literature on evaluation tools and the current study support the notion of checklists as a prime candidate for this purpose. One way to make an evaluation of this kind even more successful is to pair it with a follow-up. This can be achieved with organizational infrastructure or even laws that protect the employee. However, a simpler way is to provide simple and easy guidelines, references and suggestions on how to improve on the problems highlighted in the checklist. It is important to include the education of the users themselves in any kind of environmental evaluation, in this case it is available in the form of recommendations for improving the work environment. It becomes the ergonomists' responsibility to communicate this knowledge both to enforce changes and to make the changes permanent. Radiologists recognize value of this approach and Horii (2002) points out that the utility of a well-designed ergonomically correct radiology reading workstation will be counteracted by tables that set the monitors too low or high and by chairs that are too uncomfortable to sit in for more than a few minutes. Completely digital radiology departments are already a reality in some places. It is interesting to see that with the rapid advancement of digital medical imaging, there are huge gaps in the information available to really fulfill the potential this technology has to offer for improvements for professionals and patients. There has not been enough research done on the conditions needed for optimal reading in digital reading rooms. We see that there is a movement within the field of radiology to try and rectify this, for instance Krupinski and her colleagues have been systematically looking at monitor quality and the effects on performance, and the discussion of ergonomics in the digital reading room is present in public literature as well as a growing concern of radiologists (see, for example Haramati, & Fast, 2005; Kolb, 2005; Prabhu, et al., 2005; Reiner, & Siegel, 2002). The relative cost of ill-fitting work environments can be huge, and in the case of radiologists, we have the potential of this cost affecting not only the organization, but patients, as well. It is hoped that the Cornell Digital Reading Room Ergonomics Checklist will be a positive addition to the progress of digital radiology.

APPENDIX A

Resources used for initial selection of items for the Cornell Digital Reading Room Ergonomics Checklist. Number of items used from each source is indicated.

Source	**Number of items used**
Accel-Team.com (2005). *The Ergonomics Checklist*. Retrieved on July 6, 2006, from: http://www.accel-team.com/ergonomics/main_06.html	10
Borh, P.C. (2000). Efficacy of Office Ergonomics Education. *Journal of Occupational Rehabilitation, 10*(4), 243-255.	14
Çakir, A., Hart, D.J., and Stewart, T. F. M. (1980). *Visual display terminals: a manual covering ergonomics, workplace design, health and safety, task organization*. Chichester [Eng.] ; New York : Wiley.	31
California Department of Industrial Relations (DIR) (1998). *Four step ergonomics program for employers with video display terminal operators. VDT Checklist*. Retrieved on March 15, 2006, from: http://www.dir.ca.gov/ dosh/dosh_publications/ ergonomic.html	14
Canadian Standards Association International (2000). *Z412 Guideline on Office Ergonomics*.	35
Hedge, A (No date). *Choosing an ergonomic chair*. Retrieved on July 6, 2006, from http://ergo.human.cornell.edu/AHTutorials/chairch.html	6
Hedge, A. (No date). *Computer Workstation Ergonomic Checklist*. Retrieved on July 6, 2006, from: http://ergo.human.cornell.edu/ CUVDTChecklist.html	25
Howarth, A. (1995). Assessment of the visual environment, in Wilson, J.R., and Corlett, E.N. (Eds.) *Evaluation of human work. A practical ergonomics methodology. Second edition.* (pp. 441-445). Philadelphia, PA: Taylor & Francis.	4
NIOSH (No date). *Elements of Ergonomic Programs – Toolbox Tray 5-G*. Retrieved on July 3, 2006, from: http://www.cdc.gov/niosh/eptbtr5a.html	11

North Carolina State University Environmental health and safety (No date on site). *Ergonomic Workstation Guidelines*. Retrieved on March 15, 2006, from: http://www.ncsu.edu/ehs/www99/right/handsMan/office/ergonomic.html#vdt	7
Pheasant, S.T. (1995). Anthropometry and the design of the design of workspaces, in Wilson, J.R., and Corlett, E.N. (Eds.) *Evaluation of human work. A practical ergonomics methodology. Second edition.* (pp. 557-574). Philadelphia, PA: Taylor & Francis.	3
U.S. Department of labor – Occupational Safety and Health Administration (No date on site). *Computer workstations checklist*. Retrieved on May 28, 2005, from: http://www.osha.gov/SLTC/etools/computerworkstations/ checklist.html	18

APPENDIX B

The Cornell Digital Reading Room Ergonomics Checklist – First Version.

Cornell Digital Reading Room Ergonomics Checklist

The Cornell Digital Reading Room Ergonomics Checklist is intended as a quick evaluation of the working environment for radiologists who work with digital medical images. The checklist can be used to document the conditions for one radiologist or several radiologists.

The checklist is divided into five sections:

* *Display Screens,*
* *Input devices,*
* *Workstation and Workstation accessories,*
* *Chair, and*
* *Ambient Environment.*

Each section asks questions about the physical environment (such as the height of the desk or the temperature of the room) and the users (such as the posture of the radiologist and how s/he uses the equipment).

When using the checklist, please read the question carefully as well as the answer options. Each item can be answered with a checkmark in an accompanying checkbox. Some items will have "Continue to item X" depending on the answer given or clarifying questions that will follow directly below the answer.

If an item marked as an "*Ergonomic Issue*" is checked, this indicates a problem area within the workstation.

To complete the Display Screens and Workstation sections, you will need a tape measure. For the Input device and Chair sections, you will need a goniometer. For the ambient environment section you will need a sound level meter, a light level reader and instruments to measure temperature, humidity and velocity. It is also possible that the ambient environment of the facility is electronically monitored; in that case archival readings are fine.

***NOTE**: It is assumed that each workstation will have a dual-screen setup. If there is a single screen setup, please use the answer options for the left screen only.*

1

DISPLAY SCREENS

1. The display screens are:	**Arm/wall mounted** Left screen (**L**) O	**Arm/wall mounted** Right screen (**R**) O	**Freestanding** Left screen (**L**) O	**Freestanding** Right screen (**R**) O

2. What is the display screen size? **LEFT**: Size _________ inches/cm **RIGHT**: Size _________ inches/cm

3. The display screens are easily adjustable in:			
	Height	O Left screen (**L**)	O Right screen (**R**)
	Distance from person	O Left screen (**L**)	O Right screen (**R**)
	Angle/Tilt	O Left screen (**L**)	O Right screen (**R**)
	Twist/Rotation	O Left screen (**L**)	O Right screen (**R**)

4. Is there glare on the display screens that affects image reading?

NO O *Continue to item 5*

YES O What are the sources of the glare?

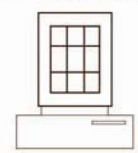
O Overhead lighting O Paper O Task lights

O Windows O Clothing O Other, please specify:

Please mark or fill in the screen areas affected by glare:

LEFT SCREEN (**L**)

RIGHT SCREEN (**R**)



5. Is the screen character luminance adjustable?

LEFT SCREEN (**L**) O YES O NO

RIGHT SCREEN (**R**) O YES O NO

Check the current screen character luminance of the computer screens by comparing to these luminance examples:

11111		22222		33333		44444		55555		66666	
LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
O	O	O	O	O	O	O	O	O	O	O	O

2

DISPLAY SCREENS

ERGONOMIC ISSUES

6. Please check the image that best describes the posture of the radiologist while (s)he is viewing the screens:
INSTRUCTIONS: Ask the radiologist to sit directly in front of and facing the left screen while evaluating the posture. Repeat for the right screen.

L O R O	L O R O	L O R O	L O R O	L O R O
				
Correct distance/height	Screen too close	Screen too far away	Screen too low	Screen too high

7. Please check the circle if the displayed images on the screen are:

L O R O Fuzzy

L O R O Hard to read

L O R O With visible flicker/jitter

INPUT DEVICES

8. What is the wrist angle? Please check the image that fits the posture:

If the workstation has a keyboard tray: O O O

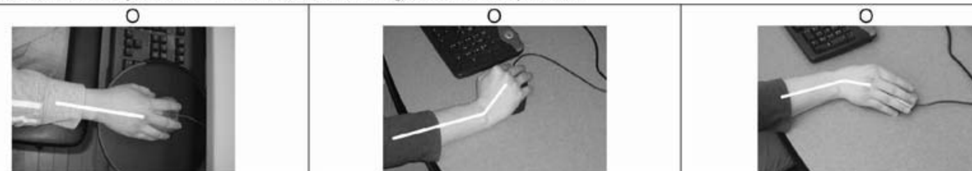
If the workstation keyboard is placed on the desk: O O O

9. Check the circle if the mouse designed for: O Right handed use only O Left handed use only O Use with either hand

10. Where is the mouse used? O On platform over keyboard O Platform adjacent to keyboard O On desk

11. What is the wrist position? Please check the image that fits the posture:

O O O



13. Please check any other hand operated input devices used at the workstation that put the hand or arm in an awkward posture:

O Trackball O Touchpad O Touchpoint O Joystick O Lightpen O Other: ______________

14. Is voice recognition used?

O NO O A hands-free headset O A free standing microphone O A hand-held microphone

ERGONOMIC ISSUES

WORKSTATION & WORKSTATION ACCESSORIES

15. Does the work surface look cluttered? O NO O YES Desktop size: Width: _______ inches. Depth: _______ inches

16. Does the workstation have any sharp edges that could cause compression to either hands or arms? O NO O YES

17. Does the radiologist have sufficient space for feet underneath the desk? O YES O NO

Depth at knee level: _________ inches   Clearance width: ________ inches
Depth at foot level: _________ inches   Desk height: _______ inches

18. Does the work require a document holder for paper?		
O NO	O YES	Is there a stable document holder at the workstation? O YES O NO
Continue to item 19	Is the document placed at the same height and distance as the screen? O YES O NO	
	Height of document holder: _______ Distance from person: _______	

19. Does the radiologist need to use a telephone while reading images?				
O NO	O YES			
Continue to item 20	Is the telephone used with the head upright and shoulders relaxed? O YES O NO			
	Please check the circle that best describes the phone usage			
	O Hands free (cell/regular phone)	O Shoulder cradle (regular phone)	O Regular phone w/o accessories	O Cell phone w/o accessories

20. Does the workstation have a footrest? O YES O NO

5

CHAIR

ERGONOMIC ISSUES

21. Chair seat pan can be adjusted in: O Height O Angle/Tilt O Fore/Aft Distance

22. Does the chair have armrests?

O NO	O YES *Please check the circle that best describes the adjustability for the armrests, if applicable:*
Continue to item 23	O Height O Width O Can be removed

24. Do the chair armrests restrict workstation access? O YES O NO

25. Does the chair have a five (5) legged base with casters? O YES O NO

26. Does the chair swivel? O YES O NO

27. Does the chair have: a height adjustable lumbar support? O YES O NO
lumbar support that matches the curve of the lower back? O YES O NO

28. Can the backrest height be adjusted to a comfortable height?

O NO	O YES
Continue to item 29	Backrest height: ________ inches Backrest adjustment range: _________inches

29. Can the backrest recline angle be adjusted?

O NO	O YES Recline range: __________ degrees from 90° angle (upright)
Continue to item 30	Does the chair have a headrest? O YES O NO

30. If known from the chair specifications, how much weight can the chair support? _______ pounds

6

AMBIENT CONDITIONS

ERGONOMIC ISSUES

31. Is the light level satisfactory for the type of work performed there? O YES O NO Illuminance level: _____fc/lux

32. Is there a task light at the workstation?

O NO O Incandescent O Fluorescent O LED O Other: ___________________

33. Are there natural light sources?

O NO
O Interior window without blinds
O Interior window with blinds
O Exterior window without blinds
O Exterior window with blinds

34. How does the quality of the light source affect the display screen images?

O Not at all O Washes out image O Distorts image O Brightens image contrast

35. Does the reading room noise level interfere with reading performance or verbal communication?

O NO O YES Noise level ______db (A)

36. How does the room feel?

O Comfortable O Hot O Warm O Cool O Cold Measured temperature: _________ °C/°F

37. Is the room drafty? O NO O YES Air velocity: _________ft/min.

38. Does the air feel too dry or too humid? O NO O YES Relative humidity: ______ %

39. Does the air smell or feel stuffy or stale? O NO O YES

7

APPENDIX C

Mailing list and Conference Expert Feedback form

Cornell Digital Reading Room Ergonomics Checklist

Feedback Survey

Please answer the following questions by checking the circle by the answer that best fits your opinion. Please use the backside of this form for more feedback, should you need it.

Upon completion, please return the survey in the pre-addressed and stamped envelope to Hrönn Brynjarsdóttir. If you made your comments on the checklist itself, please remember to mail that as well.

Thank you again for your participation!
Hrönn Brynjarsdóttir.

1. In reading the checklist, I felt that…
   - ○ The instructions were easy to understand and follow
   - ○ The instructions were ***not*** easy to understand and follow. *Please specify your concern – either by writing on the checklist – or using the lines provided below:*

____
____
____
____

2. In reading the checklist, I felt that…
   - ○ The questions were easy to understand (stated clearly).
   - ○ The questions were ***not*** easy to understand (stated clearly). *Please specify your concern – either by writing on the checklist – or using the lines provided below:*

____
____
____
____

3. In answering the Cornell Digital Reading Room Checklist, I felt that…

   - O The <u>layout</u> of the questionnaire was easy to follow.
   - O The <u>layout</u> of the questions was ***not*** easy to follow. *Please specify your concern – either by writing on the checklist – or using the lines provided below:*

4. In answering the Cornell Digital Reading Room Checklist, I felt that…

   - O The <u>checklist</u> was comprehensive.
   - O The <u>checklist</u> was ***not*** comprehensive. *Please specify your concern – either by writing on the checklist – or using the lines provided below:*

APPENDIX D

Letter to radiologists

Cornell University

Department of Design and Environmental Analysis
E104 Martha Van Rensselaer Hall
Ithaca, 14853-4401
t. 607.255.2144
f. 607.255.0305

April 20, 2006

Cornell Digital Reading Room Ergonomics Checklist

Dear Professor Smith,

I am a graduate student in Ergonomics at Cornell University in Ithaca, New York, working with Professor Alan Hedge, PhD. I have developed the *Cornell Digital Reading Room Ergonomics Checklist* as a quick evaluation of the working environment of radiologists utilizing medical imaging techniques, and I am now looking for feedback on this instrument.

Please take a look at this checklist, complete the short feedback form and return to me in the self-addressed and stamped envelope.

I sincerely appreciate your valuable feedback and thank you for taking the time to participate in the creation of the *Cornell Digital Reading Room Ergonomics Checklist*. I would be thrilled to hear back from you via email; hb47@cornell.edu, if you have comments you would like to discuss further with me.

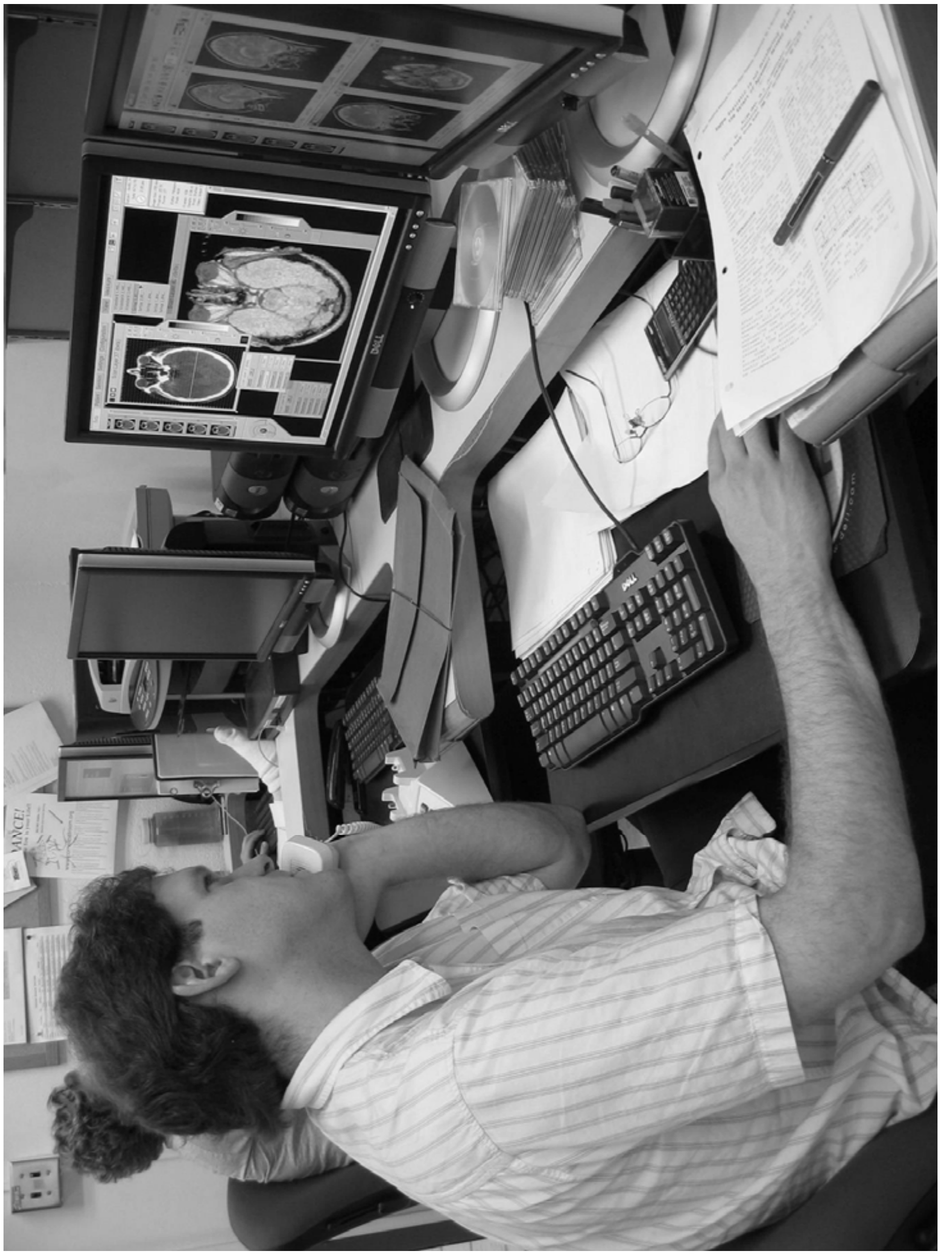
Thank you again.

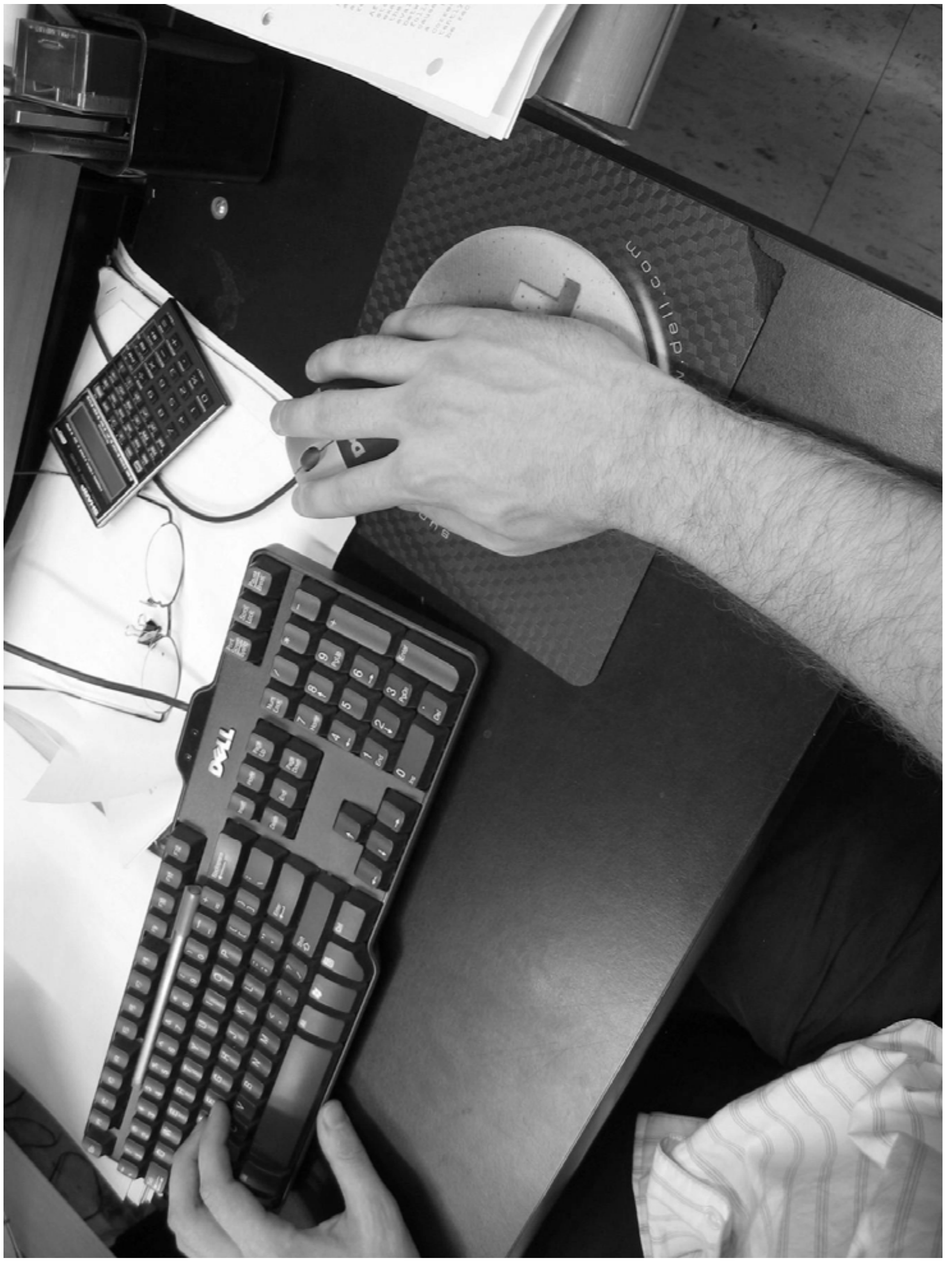
Sincerely,

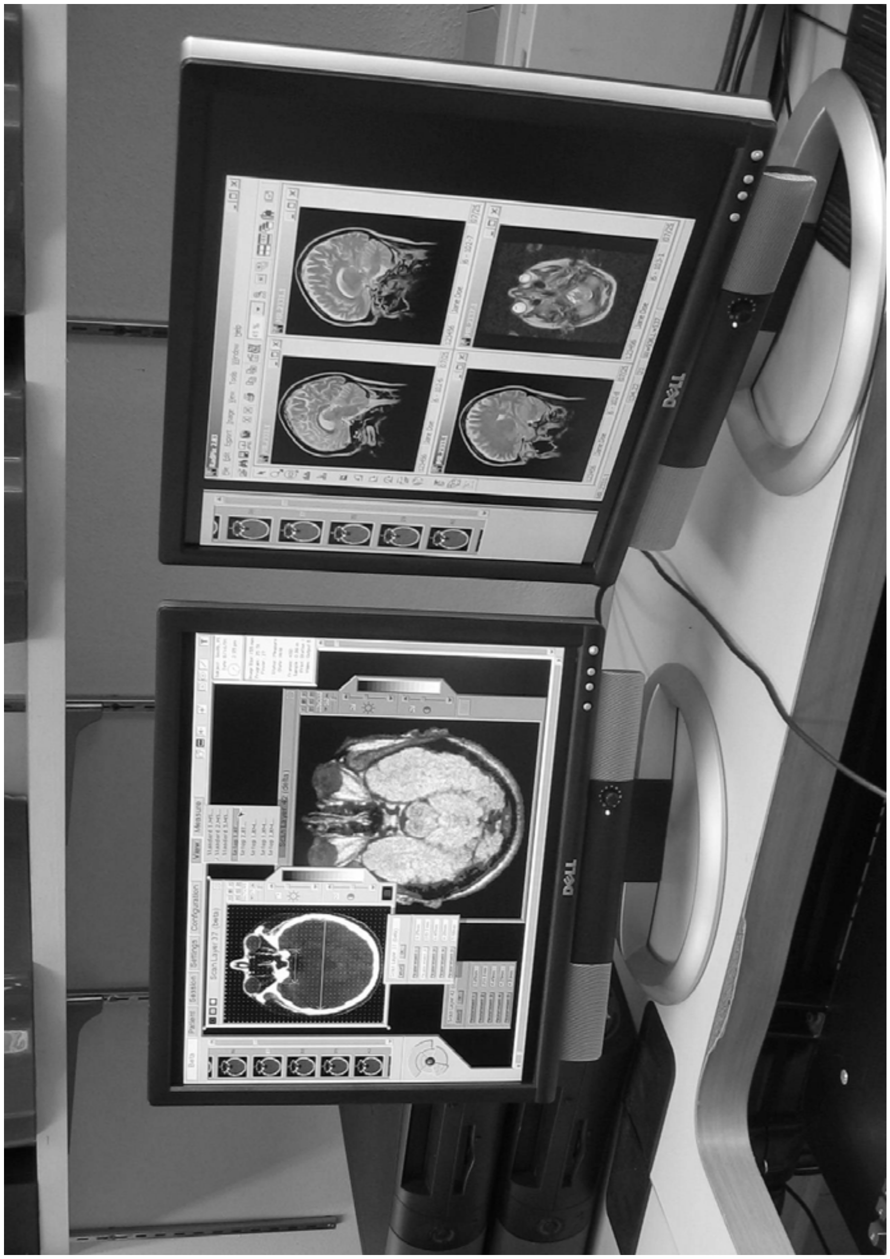
Hrönn Brynjarsdóttir

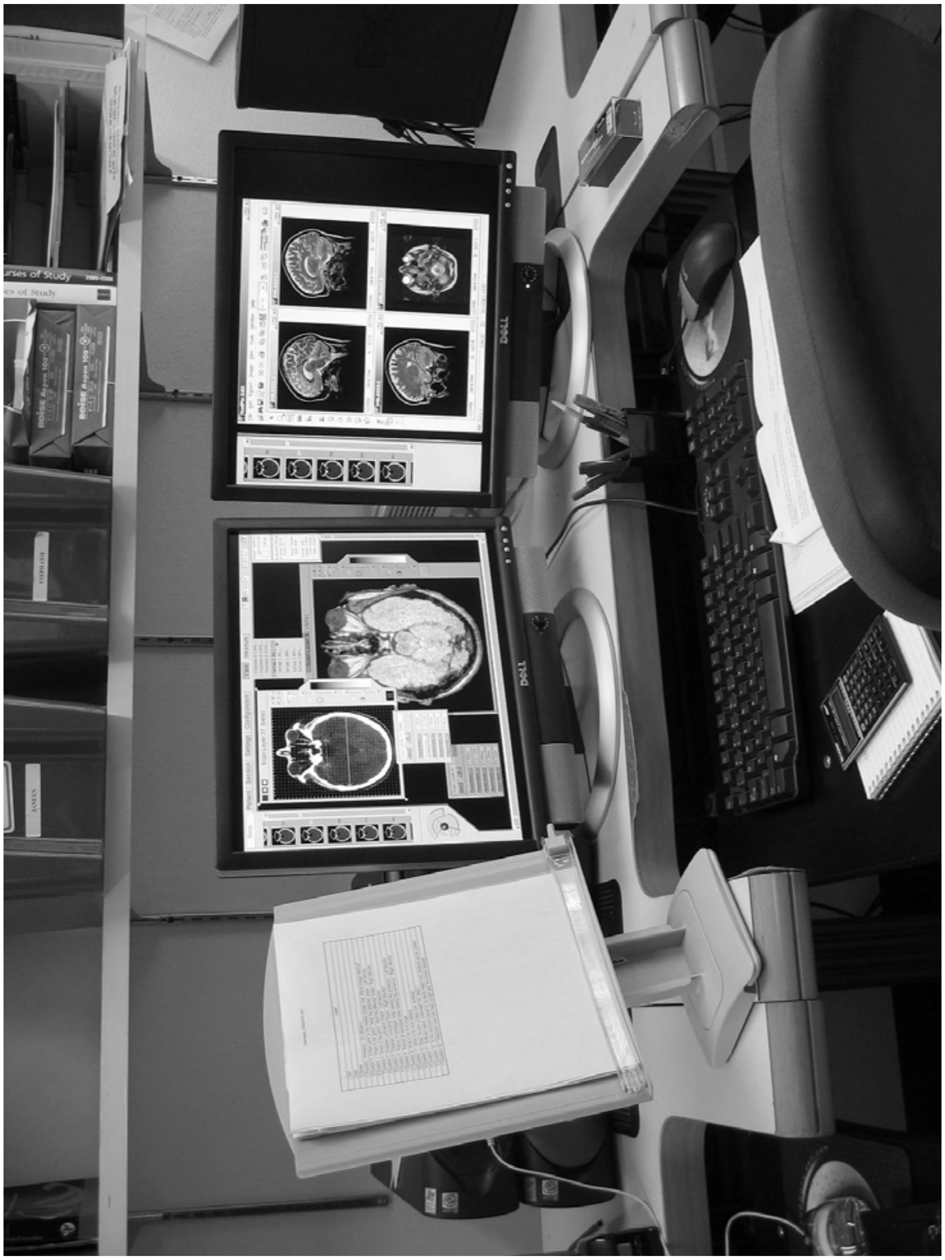
APPENDIX E

Images used for item testing (resized).









APPENDIX F

Instructions for the individual item test

The Cornell Digital Reading Room Ergonomics Checklist

Individual Item Test - Please read these instructions carefully!!

The purpose of this test is to evaluate individual items in the Cornell Digital Reading Room Ergonomics Checklist (CDRREC).

The CDRREC checklist is intended as a quick evaluation of the work environment of radiologists utilizing digital imaging technology.

The attached images are supposed to represent a typical workstation that a radiologist is utilizing while reading digital medical images.

In completing this evaluation please take a look at the checklist and answer the questions in it, based on the information-content in each image.

Please bear in mind that some of the images have information that will help you answer more than one question.

The questions that I want you to answer based on the attached images, are highlighted in the attached checklist. Base your answers on the information in the images only. Please do not answer other checklist items.

In addition to the checklist evaluation, I would also like you to fill out a brief questionnaire, with questions about your age, gender and educational background.

How old are you? ________

What is your gender? Male ☐ Female ☐

What is the highest level of education you have completed (or are about to complete)?

☐ High school

☐ Undergraduate degree (Bachelor's)
Please specify major: ____________

☐ Graduate degree (Masters' or Doctorate)
Please specify concentration: ____________

If applicable, what is your current profession?

____

Thank you!!

Hrönn Brynjarsdóttir

1

APPENDIX G

The Cornell Digital Reading Room Ergonomics Checklist Final Version

Cornell Digital Reading Room Ergonomics Checklist

The Cornell Digital Reading Room Ergonomics Checklist is intended as a quick evaluation of the working environment for radiologists who work with digital medical images. The checklist can be used to document the conditions for one radiologist or several radiologists.

The checklist is divided into five sections:

* *Display Screens,*
* *Input devices,*
* *Workstation and Workstation accessories,*
* *Chair, and*
* *Ambient Environment.*

Each section asks questions about the physical environment (such as the height of the desk or the temperature of the room) and the users (such as the posture of the radiologist and how s/he uses the equipment).

When using the checklist, please read the question carefully as well as the answer options. Each item can be answered with a checkmark in an accompanying checkbox. Some items will have "Continue to item X" depending on the answer given or clarifying questions that will follow directly below the answer.

If an item marked as an "*Ergonomic Issue*" is checked, this indicates a problem area within the workstation. Upon completion of the checklist, please refer to the accompanying guidelines on what steps to take.

To complete the Display Screens and Workstation sections, you will need a tape measure. For the Input device and Chair sections, you will need a goniometer. For the ambient environment section you will need a sound level meter, a light level reader and instruments to measure temperature, humidity and velocity. It is also possible that the ambient environment of the facility is electronically monitored; in that case archival readings are fine.

***NOTE**: It is assumed that each workstation will have a three-screen setup. If your workstation has fewer screens, you can leave extra screen answers options blank. If your workstation set up has more than three screens, you can print out an extra copy of pages 2-3 "Display Screens" to accommodate for this.*

DISPLAY SCREENS

	Arm/Wall mounted			Freestanding		
1. The display screens are:	Left (L)	Middle (M)	Right (R)	Left (L)	Middle (M)	Right (R)
	O	O	O	O	O	O

	Monochrome			Color		
2. The display screens are:	Left (L)	Middle (M)	Right (R)	Left (L)	Middle (M)	Right (R)
	O	O	O	O	O	O

3. What is the display screen size? **LEFT**: _______ inches/cm **MIDDLE**: _______ inches/cm **RIGHT**: _______ inches/cm

4. The display screens are easily adjustable in:	Height	O Left (L)	O Middle (M)	O Right (R)
	Distance from person	O Left (L)	O Middle (M)	O Right (R)
	Angle/Tilt	O Left (L)	O Middle (M)	O Right (R)
	Twist/Rotation	O Left (L)	O Middle (M)	O Right (R)

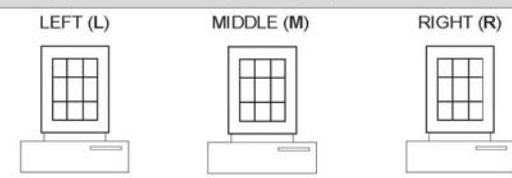
5. Is there glare on the display screens that affects image reading? [1]

NO O
Continue to item 6

YES O What are the sources of the glare?

O Overhead lighting O Paper O Task lights
O Windows O Clothing O Other, please specify:

Please mark or fill in the screen areas affected by glare:



DISPLAY SCREENS

ERGONOMIC ISSUES

6. Is the screen character luminance adjustable?	LEFT (**L**) O YES O NO	MIDDLE (**M**) O YES O NO	RIGHT (**R**) O YES O NO

7. Please check the image that best describes the posture of the radiologist while (s)he is viewing the screens:
INSTRUCTIONS: Ask the radiologist to sit directly in front of and facing the left screen while evaluating the posture. Repeat for the right screen.

L M R	L M R	L M R	L M R	L M R
O O O	O O O	O O O	O O O	O O O

Correct distance/height	Screen too close	Screen too far away	Screen too low	Screen too high

2

8. Please check the circle if the displayed images on the screen are:

L M R		L M R		L M R	
O O O	Fuzzy	O O O	Hard to read	O O O	With visible flicker/jitter

3

3

INPUT DEVICES

ERGONOMIC ISSUES

9. What is the wrist angle? Please check the image that fits the posture:

If the workstation has a keyboard tray:

O 
Neutral wrist angle

O 
Wrist Flexion

O 
Wrist Extension

If the workstation keyboard is placed on the desk:

O 
Neutral wrist angle

O 
Wrist Flexion

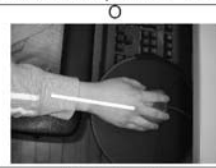
O 
Wrist Extension

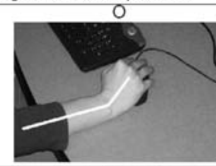
4

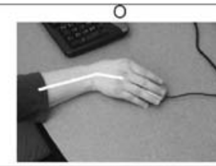
10. Check the circle if the mouse designed for: O Right handed use only O Left handed use only O Use with either hand

11. Where is the mouse used? O On platform over keyboard O Platform adjacent to keyboard O On desk

12. What is the wrist position? Please check the image that fits the posture:

O 
Neutral wrist

O 
Radial Deviation

O 
Ulnar deviation

5

13. Please check any other hand operated input devices used at the workstation that put the hand or arm in an awkward posture:
O Trackball O Touchpad O Touchpoint O Joystick O Lightpen O Other: ______________

6

14. Is voice recognition used?
O NO O A hands-free headset O A free standing microphone O A hand-held microphone

WORKSTATION & WORKSTATION ACCESSORIES

ERGONOMIC ISSUES

15. Does the work surface look cluttered? O NO O YES Desktop size: Width: _______ inches. Depth: _______ inches → 7

16. Does the workstation have any sharp edges that could cause compression to either hands or arms? O NO O YES → 8

17. Does the radiologist have sufficient clearance underneath the desk?	O YES	O NO → 9
18. Can the angle of the workstation surface be changed?	O YES	O NO
19. Can the desk height be adjusted to accommodated for seated work as well as standing work?	O YES	O NO

Depth at knee level: ________ inches Desk width: ________ inches
Depth at foot level: ________ inches Desk height: _______ inches

20. Does the work require a document holder for paper?

O NO	O YES Is there a stable document holder at the workstation? O YES O NO → 10
Continue to item 21	Is the document placed at the same height as the screen? O YES O NO → 11
	Is the document placed at the same distance as the screen? O YES O NO → 11
	Height of document holder: _______ Distance from person: _______

21. Does the radiologist need to use a telephone while reading images?

O NO	O YES			
Continue to item 22	Is the telephone used with the head upright and shoulders relaxed? O YES O NO → 12			
	Please check the circle that best describes the phone usage			
	O Hands free / Headset (cell/regular phone)	O Shoulder cradle (regular phone)	O Regular phone w/o accessories	O Cell phone w/o accessories

22. Does the workstation have a footrest? O YES O NO → 13

5

CHAIR

23. Chair seat pan can be adjusted in: O Height O Angle/Tilt O Depth

24. Does the chair have armrests?			
O NO	O YES Please check the circle that best describes the adjustability for the armrests, if applicable:		
Continue to item 25	O Height	O Width	O Can be removed

25. Do the chair armrests restrict workstation access? O YES O NO — 14

26. Does the chair have a five (5) legged base with casters that are appropriate for the flooring material? O YES O NO

27. Does the chair swivel? O YES O NO

28. Does the chair have: a height adjustable lumbar support? O YES O NO — 15
lumbar support that matches the curve of the lower back? O YES O NO — 16

29. Can the backrest height be adjusted to a comfortable height?	
O NO	O YES
Continue to item 29 — 17	Backrest height: ________ inches Backrest adjustment range: _________inches

30. Can the backrest recline angle be adjusted?	
O NO	O YES Recline range: __________ degrees from 90° angle (upright)
Continue to item 31 — 18	Does the chair have a headrest? O YES O NO

31. If known from the chair specifications, how much weight can the chair support? _______ pounds

AMBIENT CONDITIONS

ERGONOMIC ISSUES

32. Is the light level satisfactory for the type of work performed there? O YES O NO Illuminance level: _____fc/lux — 19

33. Is there a task light at the workstation?
O NO O Incandescent O Fluorescent O LED O Other: ____________________

34. Are there natural light sources?
O NO
O Interior window without blinds
O Interior window with blinds
O Exterior window without blinds
O Exterior window with blinds

35. How does the quality of the light source affect the display screen images?
O Not at all O Washes out image O Distorts image O Brightens image contrast — 20

36. Does the reading room noise level interfere with reading performance or verbal communication?
O NO O YES Noise level ______db (A) — 21

37. How does the room feel?
O Comfortable O Hot O Warm O Cool O Cold Measured temperature: _________ °C/°F — 22

38. Is the room drafty? O NO O YES Air velocity: _________ft/min. — 23

39. Does the air feel too dry or too humid? O NO O YES Relative humidity: ______ % — 24

40. Does the air smell or feel stuffy or stale? O NO O YES — 25

42. Are individual controls for *heat* available? O YES O NO — 26

43. Are individual controls for *lighting* available? O YES O NO — 27

7

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