

Evaluating Ergonomics Risks for Digital Radiologists

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Abstract. Modern radiology is digital and the work of the radiologist now shares many features with that of other high technology computer work. Many digital reading rooms are poorly designed in terms of ergonomics and how they accommodate computer technology. Lighting is typically inadequate resulting in visual health problems of eyestrain and headaches and inadequate lighting also adversely affects image reading performance. The prevalence of musculoskeletal symptoms among radiologists often exceeds levels seen among other computer workers. An innovative reading room design is briefly described that incorporates some ergonomic design features and this has resulted in high levels of workplace satisfaction. Finally, the Cornell Digital Reading Room Ergonomic Checklist is presented which aims to give guidance on the ergonomic design of future reading rooms.

Keywords: Digital radiology, Ergonomics checklist, Innovative Reading Room, Musculoskeletal symptoms, Visual health.

1 Introduction

Radiology was one of the first medical specializations to undergo rapid technological change as film-based reading rooms were replaced by computer-based picture archiving and communication systems (PACS). The first installation of a PACS was at the University of Kansas in 1982, and more widespread development and use of PACS began in the 1990s [1]. The widespread introduction of digital medical imaging technology in the past twenty years has dramatically changed the nature of the work of the radiologist, and changed the design of the work environment to support this work. Film based radiology reading rooms often required the radiologist to stand and look at x-ray film on a light box reader, moving from physical image film to physical image film to assess a case. However, PACS allows for more sophisticated analysis and precise diagnosis, and electronic sharing of the x-ray image. In the digital world, images can be easily manipulated, allowing the radiologist to move around the image, zoom in and out, annotate the image, and in some systems even see the image in color and 3D. Advocates for the transition to PACS argued that this would result in significant improvement in workflow [2]. Modern computer-based reading rooms now resemble high-technology offices in many respects, and reading x-rays has is now much more sedentary work than in the past. As such, users of these reading rooms report a variety of issues comparable to those found in other computer work

environments. In general, these concerns have to do with the reading room environment such as the lighting, acoustics and air quality, the layout of the reading room, and the poor ergonomic design of the workstation, [3-5]. Some of these factors are examined below.

2 Digital Reading Room: Lighting and Visual Health

Designing appropriate lighting for a digital reading room remains a concern, especially with the move from film to cathode ray tube (CRT) display to liquid crystal display (LCD). Research has shown that typical office lighting designs and levels can reduce the efficacy of radiologic diagnoses when compared with lower levels of ambient lighting. A study [6] tested whether five ambient light levels (480, 100, 40, 25, and 7 lux: 44.6 fc, 9.3 fc, 3.7 fc, 2.3 fc, 0.7 fc) affected the decisions of 79 experienced radiologists reading 30 posteroanterior wrist images and determining whether or not a fracture was present. Reading images at 40 and 25 lux resulted in fewer false-positives and false-negatives compared with 480, 100 lux or 7 lux. Radiologists specializing in reading musculoskeletal trauma images were only partly able to compensate for inappropriate lighting levels.

In part agreement with the previous study, when four chest radiologists read 100 radiographs (50 normal and 50 containing a subtle nodule) under two different ambient light levels: low illuminance of 1 lx (0.1 fc) and elevated illuminance of 50 lx (4.65 fc), there was no statistically significant performance difference, although there was a trend for faster average selection times, for decreased false positive identification times (35.4 ± 18.8 to 26.2 ± 14.9 s) and for true positive identification times (29.7 ± 18.3 to 24.5 ± 15.5 s) at 50 lx [7].

A rise in the prevalence of visual health symptoms may be expected as the work of radiologists increases and becomes near work involving long periods staring at one or more computer screens. A study of 3 radiologists and 3 radiology residents, who worked at a computer an average of 5.7 hours per day, assessed the accommodative ability of the eyes at the start and end of the workday [8]. Results showed that accommodation ability is significantly reduced after a day of radiology near work on a computer screen, with readers becoming more myopic, and the duration of reading correlated with reports of headache, eyestrain, difficulty focusing, and blurry vision. Long workdays have also been shown to significantly reduce accommodation accuracy, increase visual fatigue and oculomotor strain, and reduce the ability to detect fractures [9]. The prevalence of headaches among Swedish radiologists and nurses in one hospital increased from around 25% to over 60% after the construction of a new PACS reading room, and remained high at around 70% in another hospital after renovation of the reading room to accommodate PACS workstations [10].

3 Digital Reading Room: Workstation Ergonomics and Musculoskeletal Disorders

Within radiology there are subspecialties with higher risks of developing occupational musculoskeletal injuries associated with maintaining poor postures over long periods, with the added load of wearing protective apparel [11] and with the poor ergonomic design of the radiology reading room [12].

A study of 12 radiologists in a department of some 40 people at the Tripler Army Medical Center, Honolulu, found that the incidence rate of carpal tunnel syndrome was 8.3%, which is around double the normal incidence rates in administrative and clerical staff, and 33% were clinically symptomatic with either carpal tunnel syndrome or cubital tunnel syndrome [14]. Significant deficiencies were observed in all areas of the radiology department and an occupational hygienist made 93 recommendations for work area improvements. There was limited availability of keyboard or mouse trays, the chairs used were only height adjustable and provided limited arm support, workstations were a standard size and were not adjustable. The symptomatic radiologists were found to spend more time on computers and they experienced their symptoms when using the PACS workstations.

The impact of introducing PACS in 2 large Stockholm hospitals was investigated [10]. In one hospital 27 radiologists and 68 nurses were surveyed before-and-after moving to a new building with a new PACS. The % of their sedentary work (>50% of workday seated) increased from ~50% to 80% of the work day. In another hospital 42 radiologists and 81 nurses were surveyed who remained in existing but renovated radiology space. When a PACS was implemented the prevalence of their seated work postures for >50% of the day increased, especially among radiologists, from around 70% to over 90% of the day. In both hospitals there was a high prevalence (>60%) of very frequent neck/cervical spine, shoulder, upper arm and lower back musculoskeletal pain associated with reading activities. The prevalence of musculoskeletal symptoms among radiologists was studied for a sample of 30 radiologists from the Henry Ford hospital in Detroit [15]. For diagnostic radiology work all radiologists worked at shared computer workstations with the same equipment, set-up and adjustment capabilities. Results showed that 67% reported neck discomfort from the computer screen position, 50% had wrist problems from use of their computer mouse, 43% complained of neck and low back discomfort from their chair, and 40% experienced headaches when reading images. Discomfort ratings were not associated with the frequency of adjustments but rather the work postures of the radiologists.

Researchers at Massachusetts General Hospital randomly surveyed 28 radiologists and found that only 7.2% were free of musculoskeletal symptoms, whereas 70% had seen a physician for a musculoskeletal injury associated with PACS use, and some radiologists experienced multiple symptoms. Neck pain was reported by 43%, low back pain by 39%, shoulder pain by 32%, headache by 32%, and 17% did not adjust their chairs and these individuals experienced 3 or more symptoms [16].

A survey of 107 faculty members, fellows, and residents working in a PACS-based radiology department found that 68% reported working more than 8 hours per day at a personal computer or PACS monitor, and 58% reported musculoskeletal symptoms [17]. Fifty four people subsequently received ergonomic chairs and 70% reported

improvements in their musculoskeletal symptoms. Fifty five people subsequently received an ergonomic workstations and 80% of them reported improvements. Twenty people underwent ergonomic training and 80% of them also reported improvements. The researchers concluded that although there is a high prevalence of musculoskeletal symptoms among radiologists working in a PACS-based environment, these symptoms are responsive to ergonomic interventions and ergonomic initiatives to reduce the risk for musculoskeletal injuries in radiology departments.

4 Innovative Digital Reading Room Evaluation

The previous sections have shown how digital reading room design can have a major impact on the health and performance of radiologists. A study of an innovative digital reading room design evaluated radiologists' satisfaction with the ergonomic furniture and workstation design, lighting, and collaborative spaces [19]. The innovative reading room incorporated ergonomic workstation design features, such as easily adjustable multi-screen flat panels PACS displays, multiple CPU's in holders, adjustable height work surfaces, negative tilt adjustable height keyboard trays with a mouse platform, wire management, sound absorbing panels between and above stations, textured sound absorbing walls, music and white noise systems for speech privacy, and variable lighting. Results for all aspects showed high levels of satisfaction with the reading room design, especially for the furniture and ergonomic workstations (Table 1).

Table 1. Satisfaction Levels with Digital Reading Room Components [18] *(1 - very dissatisfied; 2 - dissatisfied; 3 - neutral; 4 - satisfied; 5 - very satisfied)

| Furniture and Workspace Questions | Average Satisfaction Rating* |
|---|-------------------------------------|
| Adequacy of Desk space | 3.73 |
| LCD Monitor Placement | 3.89 |
| Keyboard & Mouse Placement | 3.45 |
| Dictation Microphone Placement | 3.55 |
| Adjustability of Desk | 3.7 |
| Chair Comfort | 4.1 |
| Sufficient space for personal belongings | 2.93 |
| Fabric portable dividers between workstations | 3.6 |
| Open floor layout of reading room | 3.66 |
| Layout encourages collaboration between radiologist | 3.57 |
| Amount of space in reading room | 3.93 |
| Ease of access to reading room coordinators spaces | 4 |
| Reading room testbed enhances radiology workflow | 3.64 |
| Overall comfort of workspace | 3.8 |

5 Cornell Digital Reading Room Ergonomics Checklist

Digital reading rooms that are designed in accordance with ergonomic principles for intensive computer workplaces seem to be the exception rather than the rule. In part this may be a consequence of simply replacing film in a reading room with PACS workstations without changing lighting or furniture. Partly it may be a result of a lack of ergonomic knowledge. In the design of many socio-technical systems, ergonomists develop checklists to assist the designers and to help provide them with guidance on important ergonomic design considerations. Consequently, the Cornell Digital






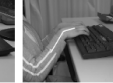
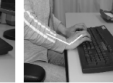
| DISPLAY SCREENS | | | | | | | ERGONOMIC ISSUES | | | | | | | | |
|--|-----------------------------------|-------------------------------------|------------------------------------|-----------------------------------|-------------------------------------|------------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|-----------------------------|----------------------------|----------------------------|----------------------------|---|
| Arm/Wall mounted | | | Freestanding | | | | | | | | | | | | |
| 1. The display screens are: | Left (L) <input type="radio"/> | Middle (M) <input type="radio"/> | Right (R) <input type="radio"/> | Left (L) <input type="radio"/> | Middle (M) <input type="radio"/> | Right (R) <input type="radio"/> | | | | | | | | | |
| <table border="0" style="width: 100%;"> <tr> <th style="width: 50%; text-align: center;">Monochrome</th> <th style="width: 50%; text-align: center;">Color</th> </tr> </table> | | | | | | | Monochrome | Color | | | | | | | |
| Monochrome | Color | | | | | | | | | | | | | | |
| 2. The display screens are: | Left (L) <input type="radio"/> | Middle (M) <input type="radio"/> | Right (R) <input type="radio"/> | Left (L) <input type="radio"/> | Middle (M) <input type="radio"/> | Right (R) <input type="radio"/> | | | | | | | | | |
| 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 <input type="radio"/> Left (L) <input type="radio"/> Middle (M) <input type="radio"/> Right (R) | | | | | | | | | | | | | | | |
| Distance from person <input type="radio"/> Left (L) <input type="radio"/> Middle (M) <input type="radio"/> Right (R) | | | | | | | | | | | | | | | |
| Angle/Tilt <input type="radio"/> Left (L) <input type="radio"/> Middle (M) <input type="radio"/> Right (R) | | | | | | | | | | | | | | | |
| Twist/Rotation <input type="radio"/> Left (L) <input type="radio"/> Middle (M) <input type="radio"/> Right (R) | | | | | | | | | | | | | | | |
| 5. Is there glare on the display screens that affects image reading? _____ | | | | | | | 1 | | | | | | | | |
| NO <input type="radio"/> YES <input type="radio"/> What are the sources of the glare? | | | | | | | | | | | | | | | |
| Continue to item 6 <input type="radio"/> Overhead lighting <input type="radio"/> Paper <input type="radio"/> Task lights | | | | | | | | | | | | | | | |
| <input type="radio"/> Windows <input type="radio"/> Clothing <input type="radio"/> Other, please specify: _____ | | | | | | | | | | | | | | | |
| <table border="0" style="width: 100%;"> <tr> <th style="width: 33%;">LEFT (L)</th> <th style="width: 33%;">MIDDLE (M)</th> <th style="width: 33%;">RIGHT (R)</th> </tr> </table> | | | | | | | LEFT (L) | MIDDLE (M) | RIGHT (R) | | | | | | |
| LEFT (L) | MIDDLE (M) | RIGHT (R) | | | | | | | | | | | | | |
| Please mark or fill in the screen areas affected by glare: | | | | | | | | | | | | | | | |
|  | | | | | | | | | | | | | | | |
| DISPLAY SCREENS | | | | | | | ERGONOMIC ISSUES | | | | | | | | |
| 6. Is the screen character luminance adjustable? LEFT (L) MIDDLE (M) RIGHT (R) | | | | | | | | | | | | | | | |
| <input type="radio"/> YES <input type="radio"/> NO <input type="radio"/> YES <input type="radio"/> NO <input type="radio"/> YES <input type="radio"/> 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 <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | L <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | L <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | L <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | L <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | |
| | | | | | | | | | | | | | | | |
| 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 <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | Fuzzy | L <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | Hard to read | L <input type="radio"/> | M <input type="radio"/> | R <input type="radio"/> | With visible flicker/jitter | | | | 3 |

Fig. 1 a. Cornell Digital Reading Room Ergonomics Checklist [19]

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:
 If the workstation keyboard is placed on the desk:

| | | | | | |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| Neutral wrist angle | Wrist Flexion | Wrist Extension | Neutral wrist angle | Wrist Flexion | Wrist Extension |

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

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

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

| | | |
|---|---|---|
|  |  |  |
| Neutral wrist | Radial Deviation | Ulnar deviation |

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

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

WORKSTATION & WORKSTATION ACCESSORIES

ERGONOMIC ISSUES

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

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

17. Does the radiologist have sufficient clearance underneath the desk? YES NO

18. Can the angle of the workstation surface be changed? YES NO

19. Can the desk height be adjusted to accommodate for seated work as well as standing work? YES 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?
 NO YES Is there a stable document holder at the workstation? YES NO

Continue to item 21
 Is the document placed at the same height as the screen? YES NO
 Is the document placed at the same distance as the screen? YES NO
 Height of document holder: _____ Distance from person: _____

21. Does the radiologist need to use a telephone while reading images?
 NO YES
 Is the telephone used with the head upright and shoulders relaxed? YES NO

Continue to item 22
 Please check the circle that best describes the phone usage

| | | | |
|--|------------------------------------|----------------------------------|-------------------------------|
| <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| Hands free / Headset (cell/regular phone) | Shoulder cradle (regular phone) | Regular phone w/o accessories | Cell phone w/o accessories |

22. Does the workstation have a footrest? YES NO

Fig. 1b. Cornell Digital Reading Room Ergonomics Checklist [19]

| CHAIR | | ERGONOMIC ISSUES |
|--|---|--|
| 23. Chair seat pan can be adjusted in: <input type="radio"/> Height <input type="radio"/> Angle/Tilt <input type="radio"/> Depth | | |
| 24. Does the chair have armrests? | | |
| <input type="radio"/> NO | <input type="radio"/> YES Please check the circle that best describes the adjustability for the armrests, if applicable: | |
| <i>Continue to item 25</i> | <input type="radio"/> Height <input type="radio"/> Width <input type="radio"/> Can be removed | |
| 25. Do the chair armrests restrict workstation access? | | <input type="radio"/> YES <input type="radio"/> NO |
| 26. Does the chair have a five (5) legged base with casters that are appropriate for the flooring material? | | <input type="radio"/> YES <input type="radio"/> NO |
| 27. Does the chair swivel? | | <input type="radio"/> YES <input type="radio"/> NO |
| 28. Does the chair have: a height adjustable lumbar support? | | <input type="radio"/> YES <input type="radio"/> NO |
| lumbar support that matches the curve of the lower back? | | <input type="radio"/> YES <input type="radio"/> NO |
| 29. Can the backrest height be adjusted to a comfortable height? | | |
| <input type="radio"/> NO | <input type="radio"/> YES | |
| <i>Continue to item 29</i> | Backrest height: _____ inches Backrest adjustment range: _____ inches | |
| 30. Can the backrest recline angle be adjusted? | | |
| <input type="radio"/> NO | <input type="radio"/> YES Recline range: _____ degrees from 90° angle (upright) | |
| <i>Continue to item 31</i> | Does the chair have a headrest? <input type="radio"/> YES <input type="radio"/> NO | |
| 31. If known from the chair specifications, how much weight can the chair support? _____ pounds | | |

Fig. 1c. Cornell Digital Reading Room Ergonomics Checklist [19]

| AMBIENT CONDITIONS | | ERGONOMIC ISSUES |
|---|--|---|
| 32. Is the light level satisfactory for the type of work performed there? <input type="radio"/> YES <input type="radio"/> NO Illuminance level: _____ fc/lux | | 19 |
| 33. Is there a task light at the workstation? | | |
| <input type="radio"/> NO | <input type="radio"/> Incandescent <input type="radio"/> Fluorescent <input type="radio"/> LED <input type="radio"/> Other: _____ | |
| 34. Are there natural light sources? | | |
| <input type="radio"/> NO | <input type="radio"/> Interior window without blinds <input type="radio"/> Exterior window without blinds <input type="radio"/> Interior window with blinds <input type="radio"/> Exterior window with blinds | |
| 35. How does the quality of the light source affect the display screen images? | | |
| <input type="radio"/> Not at all | <input type="radio"/> Washes out image <input type="radio"/> Distorts image <input type="radio"/> Brightens image contrast | 20 |
| 36. Does the reading room noise level interfere with reading performance or verbal communication? | | |
| <input type="radio"/> NO | <input type="radio"/> YES Noise level _____ db (A) | 21 |
| 37. How does the room feel? | | |
| <input type="radio"/> Comfortable | <input type="radio"/> Hot <input type="radio"/> Warm <input type="radio"/> Cool <input type="radio"/> Cold Measured temperature: _____ °C/°F | 22 |
| 38. Is the room drafty? | | <input type="radio"/> NO <input type="radio"/> YES Air velocity: _____ ft/min. |
| 39. Does the air feel too dry or too humid? | | <input type="radio"/> NO <input type="radio"/> YES Relative humidity: _____ % |
| 40. Does the air smell or feel stuffy or stale? | | <input type="radio"/> NO <input type="radio"/> YES |
| 42. Are individual controls for heat available? | | <input type="radio"/> YES <input type="radio"/> NO |
| 43. Are individual controls for lighting available? | | <input type="radio"/> YES <input type="radio"/> NO |

Fig.1d. Cornell Digital Reading Room Ergonomics Checklist [19]

Reading Room Ergonomics Checklist (CDRREC) was developed, based on questionnaire items found in thirteen checklists and educational materials published by the U.S. government, independent researchers and furniture makers, and based on empirical observation studies of reading rooms in both the U.S.A. and Iceland [19–20]. The CDRREC is intended as a tool for the 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 has five sections: Display Screens; Input devices; Workstation and Workstation accessories; Chair; Ambient Environment (Figure 1). 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).

6 Conclusions

Designing a successful digital reading room requires consideration of the varied tasks that must be undertaken to encourage and enhance the performance of radiologists and facilitate interactions between clinicians and radiologists. As digital imaging technology improves so the design of reading room facilities should focus on encouraging clinical collaboration, enhancing patient care, and ultimately improving radiologists' job satisfaction and productivity. Above all else, digital reading room design needs to pay attention to ergonomics to optimize the work, comfort and health of radiologists.

References

1. Huang, H.K.: Short history of PACS. Part I: USA. *Eur. J. Radiol.* 78(2), 163–176 (2011)
2. Reiner, B.I., Siegel, E.L.: The Cutting Edge: Strategies to Enhance Radiologist Workflow in a Filmless/Paperless Imaging Department. *J. Digit. Imaging* 15(3), 178–190 (2002)
3. Harisinghani, M.G., Blake, M.A., Saksena, M., Hahn, P.F., Gervais, D., Zalis, M., Fernandes, L.S.D., Mueller, P.R.: Importance and Effects of Altered Workplace Ergonomics in Modern Radiology Suites. *Radiographics* 24(2), 615–627 (2004)
4. Siegel, E.L., Reiner, B.I.: Radiology reading room design: The next generation. *App. Radiol. Online* 31(4), 1 (2002), <http://www.appliedradiology.com/Issues/2002/04/Articles/Radiology-reading-room-design-The-next-generation.aspx>
5. Horii, S.C., Horii, H.N., Mun, S.K., Benson, H.R., Zeman, R.K.: Environmental Designs for Reading from Imaging Workstations: Ergonomic and Architectural Features. *J. Digit. Imaging* 16(1), 124–131 (2003)
6. Brennan, P.C., McEntee, M., Evanoff, M., Phillips, P., O'Connor, W.T., Manning, D.J.: Ambient Lighting: Effect of Illumination on Soft-Copy Viewing of Radiographs of the Wrist. *AJR* 188(2), W177–W180 (2007)
7. Pollard, B.J., Samei, E., Chawla, A.S., Beam, C., Heyneman, L.E., Koweek, L.M., Martinez-Jimenez, S., Washington, L., Hashimoto, N., McAdams, H.P.: The effects of ambient lighting in chest radiology reading rooms. *J. Digit. Imaging* 25(4), 520–526 (2012)

8. Krupinski, E.A., Berbaum, K.S.: Measurement of Visual Strain in Radiologists. *Acad. Radiol.* 16(8), 947–950 (2009)
9. Krupinski, E.A., Berbaum, K.S., Caldwell, R.T., Schartz, K.M., Kim, J.: Long Radiology Workdays Reduce Detection and Accommodation Accuracy. *J. Am. Coll. Radiol.* 7(9), 698–704 (2010)
10. Pinto, A., Brunese, L.: Spectrum of diagnostic errors in radiology. *World J. Radiol.* 2(10), 377–383 (2010)
11. Lindbeck, L., Höglund, U.: Ergonomic evaluation of picture archiving and communication system implementations in two X-ray departments. *Ergonomics* 51(2), 98–124 (2008)
12. García-Lallana, A., Viteri-Ramírez, G., Saiz-Mendiguren, R., Broncano, J., Dámaso Aquerreta, J.: Ergonomics of the workplace in radiology. *Radiologia.* 53(6), 507–515 (2011)
13. Moan, R.: Poor ergonomic design plagues reading rooms. *Diagnostic Imaging* 32(5) (2010), <http://www.diagnosticimaging.com/practice-management/content/article/113619/1575035>
14. Ruess, L., O'Connor, S.C., Cho, K.H., Slaughter, R., Husain, F.H., Hedge, A.: Carpal tunnel syndrome and cubital tunnel syndrome: musculoskeletal disorders in four symptomatic radiologists. *AJR* 181, 37–42 (2003)
15. Agarwal, A., Belk, A., Boothroyd, K., Hedge, A.: Radiology Workplace Assessment (2007), <http://ergo.human.cornell.edu/ErgoPROJECTS/2007projects/Radiology%20FINAL.pdf>
16. Ridley, E.L.: Radiologists be prone to work-related injuries (2010), <http://www.auntminnie.com/index.aspx?sec=prtf&sub=def&pag=dis&itemId=90475&printpage=true&fsec=ser&fsub=def>
17. Boiselle, P.M., Levine, D., Horwich, P.J., Barbaras, L., Siegal, D., Shillue, K., Affeln, D.: Repetitive stress symptoms in radiology: prevalence and response to ergonomic interventions. *J. Am. Coll. Radiol.* 5(8), 919–923 (2008)
18. Hugine, A., Guerlain, S., Hedge, A.: User evaluation of an innovative digital reading room. *J. Digit. Imaging* 25(3), 337–346 (2012)
19. Brynjarsdóttir, H., Hedge, A.: Cornell Digital Reading Room Ergonomics Checklist (2006), <http://ergo.human.cornell.edu/CDRREC.htm>
20. Brynjarsdóttir, H.: The Cornell Digital Reading Room Ergonomics Checklist: Development and Evaluation. M.S. Thesis, Cornell University, Ithaca, NY, USA (2007)