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Work-Related Injuries of Radiologists and Possible Ergonomic Solutions: Recommendations From the ACR Commission on Human Resources

Gordon Sze, MD, Edward I. Bluth, MD, et. al., *J Am Coll Radiol 2017;14:1353-1358*

Use of PACS and digital imaging technologies can lead to repetitive strain injuries, many of which can be exacerbated by specific features of a radiology practice environment. Ergonomic approaches, such as proper reading room structure, lighting, temperature, noise, and equipment setup, can help decrease the frequency and severity of repetitive strain injuries and improve radiologist productivity. However, ergonomic approaches are complex, include all aspects of the radiology practice environment, and are best implemented along with proper training of the practicing radiologists.

The Agony of It All: Musculoskeletal Discomfort in the Reading Room

Rebecca L. Seidel, MD, Elizabeth A. Krupinski, PhD, *J Am Coll Radiol 2017;14:1620-1625*

The survey was completed by 99 radiologists. The majority of respondents spent greater than 7 hours per workday at a diagnostic workstation. The neck, lower back, upper back, right shoulder, and right wrist were the areas where radiologists most frequently reported ache, pain, or discomfort at least once per week. More than 7 hours per day at a computer workstation was significantly associated with higher total pain.

Tired in the Reading Room: The Influence of Fatigue in Radiology

Waite, S., Kolla, S., et. al., *J Am Coll Radiol 2017;14:191-197*

Fatigue in health care providers and any secondary effects on patient care are an important societal concern. As medical image interpretation is highly dependent on visual input, visual fatigue is of particular interest to radiologists.

Factors Associated with Repetitive Strain, and Strategies to Reduce Injury Among Breast-Imaging Radiologists

Thompson, A., Kremer, M. et. al., *J Am Coll Radiol 2014;11:1074-1079*

In the survey 60.2% of respondents reported RSI symptoms, and 33.3% reported prior diagnosis/treatment. Results showed a statistically significant trend for the odds of RSI symptoms to increase with decreasing age or increasing number of daily hours spent working, especially in an awkward position. Respondents recalled a significant increase in pain level after implementation of PACS, and a decrease in pain after ergonomic training or initiating use of an ergonomic mouse, adjustable chair, or adjustable table.

Musculoskeletal symptoms amongst clinical radiologists and the implications of reporting environment ergonomics—a multicentre questionnaire study

Rodrigues, J.C., Morgan, S., Augustine, K. et. al., *J Digital Imaging. 2014; 27:255–261*

This multicentre study aimed to assess compliance of the reporting environment with best ergonomic practice and to determine the prevalence of musculoskeletal symptoms related to working as a radiologist. 83% of radiologists responded, and 38% reported radiology associated occupational injury. Lower back discomfort was the commonest radiology associated musculoskeletal symptom (41%).

Work-Related Injuries of Radiologists and Possible Ergonomic Solutions: Recommendations From the ACR Commission on Human Resources

SA-CME

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Abstract

Increasingly, radiologists' workplaces revolve around PACS and digital imaging. Use of these technologies can lead to repetitive strain injuries, many of which can be exacerbated by specific features of a radiology practice environment. Ergonomic approaches, such as proper reading room structure, lighting, temperature, noise, and equipment setup, can help decrease the frequency and severity of repetitive strain injuries and improve radiologist productivity. However, ergonomic approaches are complex, include all aspects of the radiology practice environment, and are best implemented along with proper training of the practicing radiologists. The ergonomic approaches considered most important by members of the ACR Commission on Human Resources are presented in this report, and this information may serve as an aid in departmental planning.

Key Words: Repetitive strain injuries, workplace optimization, ergonomics

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INTRODUCTION

The roles of radiologists continue to evolve and broaden. Increasingly, radiologists not only interpret imaging examinations but also perform additional activities, including consulting with referring clinicians and ancillary staff members, prioritizing and protocoling studies, conducting interdisciplinary patient care and teaching sessions, and performing image-guided procedures [1]. All of these activities of radiologists, both the traditional interpretation of imaging examinations and the new multidisciplinary responsibilities, revolve around the use of computers. Because of the advent of fully digitized radiology departments centered around PACS and digital imaging, many radiologists now spend their careers at computer workstations [2,3].

In this article, we discuss the impact of the digital radiology environment on the occurrence of repetitive strain injuries (RSIs) among radiologists and possible ergonomic solutions. We also present the results of a survey of ACR Commission on Human Resources members regarding prioritizing ergonomic solutions; this information may help in departmental planning.

THE PROBLEM OF RSIs IN RADIOLOGISTS

RSIs, also known as repetitive stress injuries and occupational overuse syndromes, are any injuries, generally musculoskeletal or neurologic, that result from continual repetitive motion, vibrations, or sustained or awkward movements [4]. Although PACS and digital imaging systems permit increases in efficiency and improvements in patient care, they also have the deleterious effect of producing RSIs [5-7]. For example, Boiselle et al [8] documented that in their department, the majority of radiologists reported spending more than 8 hours a day at computer terminals, 58% reported symptoms of RSI, and 38% had actually been diagnosed with RSIs. Furthermore, these injuries have become more common as the workloads of radiologists have increased.

Radiologists work under conditions that precipitate RSIs in multiple ways. First, use of a computer mouse can result in tenosynovitis, carpal tunnel syndrome, and

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cubital tunnel syndrome. Ruess et al [9] documented work-related carpal tunnel syndrome and cubital tunnel syndrome in four symptomatic radiologists. Brusin [10] suggested that tenosynovitis is particularly associated with the use of handheld devices and texting.

Second, radiologists' prolonged positions at computer terminals can result in neck and low back pain. Boiselle et al [8] showed that 55% of surveyed radiologists reported spending more than 2 hours per day in awkward positions. Harisinghani et al [11] showed that when hospitals move to a filmless environment, radiologists become more sedentary.

Third, certain specialties of radiology are associated with particular RSIs [12]. For example, ultrasonographers in particular are prone to develop shoulder symptoms due to the forces exerted by pressing the ultrasound probe on the area of interest on the patient's body with an extended arm [10]. Neck, elbow, and low back pain are also common in ultrasonographers. Thompson et al [13] found that 60.2% of breast imagers reported RSIs and found a significant increase in pain level after the implementation of PACS. As expected, this correlated with an increase in the number of hours spent working per day and with awkward positioning. Interventional radiology is associated with musculoskeletal problems associated with protective gear, as discussed by Klein et al [14].

FEATURES OF RSIs UNIQUE TO RADIOLOGY

Robertson et al [15] performed a work systems analysis of the typical work environment of radiologists and found that complex, prolonged pointing and handheld device activities constituted the majority of PACS-related activities. These researchers compared the actions of radiologists and nonradiologists during their time using computers and found that compared with nonradiologists, radiologists spent more time using a mouse (69% versus 42%) and less time using a keyboard (2% versus 22%).

ERGONOMIC APPROACHES TO MINIMIZE THE RISK FOR RSIs IN RADIOLOGISTS

The term *ergonomics* comes from *ergos* (work) and *nomo* (natural law). The science of ergonomics encompasses all of the methods that can decrease discomfort and RSIs to maximize productivity [16]. To minimize the risk for discomfort and RSIs in radiologists, a wide range of parties must be involved, from biomechanical experts, who can analyze problems, to equipment designers, who can improve on existing platforms and hardware, to administrators, who must implement the necessary changes.

The digital workplace in radiology presents many ergonomic challenges. Although the shift away from hard copies to PACS and digital imaging has become almost universal in the United States, radiology departments have lagged in realizing that these changes create conditions that mandate changes in the work environment. Ergonomic issues range from the structure of the reading room to background lighting and noise to chair and monitor positioning to mouse and keyboard design and placement [12].

Reading Room Structure

In a film-based environment, a reading room requires view boards, which provide lighting, both for the films and for background lighting; storage facilities for films in the queue to be read and films the radiologist has finished reading; and conference areas for film display and to facilitate consultations with clinicians. The switch to a digital environment has drastically altered the structure of the reading room [3,17]. View boards have been replaced by a number of computer screens for workflow and for image display. This creates a need for alternative lighting sources. Storage facilities for films are no longer necessary. Similarly, areas for conferences with clinicians can be reduced because face-to-face meetings are no longer as frequent, having been replaced by telephone interactions, in which clinicians view images at their desks while consulting by phone.

Studies have examined the qualities of an optimal digital reading room [18]. Factors needing consideration include "architectural planning, room layout, workstation design, and general environmental concerns" [18-20]. Hugine et al [18] found that the most popular layout was an open environment, allowing easy interaction with other radiologists, with soundproof walls and sound-absorbing clouds above, as well as individually controlled lighting. Also popular was a separate image interpretation center with state-of-the-art touch-screen technology for conferences and interactions with a clinical team. Individual enclosed reading pods were unpopular.

Lighting, Temperature, and Noise

Other general environmental factors are also important [21,22]. Individual lighting needs can vary, depending on personal preference and age. Mild ambient lighting should be indirect and overhead, to avoid glare. At the same time, individualized lighting control in the immediate individual reading space is also required when written materials or notes on paper must be read.

Equally important are maintenance of appropriate temperature and ventilation, both to benefit readers and to prevent damage to sensitive electronic devices.

It is also important to facilitate noise reduction. Ambient noise levels in a reading room can come from mechanical sources, such as the imaging equipment or terminals, or from human sources, such as other radiologists' phone consults, staff members giving patients instructions, or crying children. Noise from human sources has been found to be more distracting than mechanical noise and should be minimized to the extent possible [12]. Speech recognition systems are more sensitive to noise than classic Dictaphones, which is another reason to reduce noise in the reading room.

Equipment Setup

Finally, as far as specific workplace tools are concerned, the monitors, keyboard, and mouse must be optimized [23-25]. The ideal number of monitors is controversial, but a three-monitor approach is popular, with one low-resolution monitor to view worklists and hospital electronic medical records and two high-resolution monitors to review imaging examinations. The use of three monitors also reduces the need for body movements compared with setups in which more monitors are used.

The ideal distance from the radiologist to the screen is believed to be 50 to 75 cm, with a 5-mm font size [26]. Computer visual syndrome, a set of symptoms including eye strain, headaches, blurred vision, and eye pain, has been found in 90% of users who spend three or more hours per day in front of a terminal [27,28].

The keyboard and mouse are particularly important in minimizing stress to the hands and wrists. The keyboard and mouse should be placed in a convenient location and at a comfortable height, with plenty of desk space available around them and few obstructions, to allow fluid movements [29]. Ideally, these devices should be thin and flat to reduce wrist extension. The mouse should be configured to minimize long and repetitive movements down the screen.

Raising Radiologists' Awareness of Best Ergonomic Practices

Just as important as optimization of the work environment is raising awareness among radiologists of best ergonomic practices [30]. Training with respect to potential ergonomic adjustments and personalization of the reading area is also helpful in reducing work-related injuries. Rodrigues et al [30] found that even when ergonomic adjustments were available, in terms of monitor, chair, desk, and armrest height, chair back support, ambient light and temperature, and mouse and keyboard optimization, few radiologists made adjustments before beginning read-out. Yet individualizing the workplace is crucial. Thompson et al [13] showed that radiologists experienced a significant decrease in workplace injuries after ergonomic training. Even more successful is participatory ergonomics, in which radiologists themselves develop personalized ergonomic measures [31].

Need for Further Research

Further studies directed at the specific work patterns of radiologists have great potential to further clarify the risks for RSIs in imaging professionals. For example, according to the study by Robertson et al [15], the computer mouse was believed to contribute more to RSIs than any other single factor, including table height, monitors, keyboards, and others, suggesting that concentrated effort on specific improvements may prove particularly beneficial. However, the study of Boiselle et al [8] demonstrated that typical ergonomic interventions did not deal with the computer mouse, diminishing the value of improvements. Further studies in conjunction with occupational health specialists are especially recommended.

SURVEY RESULTS TO GUIDE DEPARTMENTAL PLANNING

In a time of potentially limited resources, our commission attempted to determine which of the potential ergonomic improvements cited in the literature might be particularly preferable to radiologists. We polled our members to determine which individual ergonomic adjustments they deemed most important. Our questionnaire and the polling results are shown in Table 1. Respondents were asked to rank individual factors on a scale ranging from 1 to 5, with 1 the least important and 5 the most important. Although some of the results were predictable, many were not, as shown below.

Rating 4.5 to 5

Unsurprisingly, the amount of light and noise at the reading station, as well as the accessibility of phone and Internet, were considered of paramount importance, with ratings of 4.5 to 5. Also ranked in this highest category were wheeled chairs of adjustable height.

Rating 4.0 to 4.4

Also important but slightly less so (rating 4.0-4.4) were adjustable monitors, adjustable desks, and chairs that swivel and have adjustable armrest height. Access to the electronic medical record from the workstation also achieved this rating.

It should be underscored that adequate space, both at the reading station desk and in the layout of the reading

Table 1. Poll of commission members on importance of factors

	Member											
	1	2	3	4	5	6	7	8	9	10	Total	Average
GENERAL FACTORS, IN TERMS OF CONTRIBUTION TO OPTIMAL READING ENVIRONMENT												
Light	5	5	5	5	4	5	4	5	5	4	47	4.7
Noise	4	5	5	5	4	4	5	4	5	5	46	4.6
Temperature	3	3	5	3	2	3	4	4	3	3	33	3.3
Ventilation	2	3	4	2	1	4	2	4	3	3	28	2.8
LIGHTING												
Dimmers and switches at workstation	4	5	4	5	2	5	2	3	3	4	37	3.7
Individual controls	5	5	3	4	3	4	3	3	3	5	38	3.8
Flexible stems	3	5	1	1	3	2	3	5	3	2	28	2.8
Overhead lighting with dimmers	4	5	4	4	4	4	4	5	3	4	41	4.1
Air conditioning												
Temperature, individually controlled	4	5	4	3	4	3	3	4	3	5	38	3.8
Humidity	3	5	4	1	4	1	3	2	3	3	29	2.9
LAYOUT												
Flexible layout with movable dividers to accommodate different number of people	4	3	1	3	3	2	1	3	3	2	25	2.5
Individual rooms	5	2	3	1	2	4	2	3	3	5	30	3
Open layout in a large reading room	2	4	3	4	3	2		3	3	2	26	2.9
Adequate space	4	5	3	5	4	4	3	5	5	4	42	4.2
Space for personal belongings	4	5	4	2	4	3	2	3	4	3	34	3.4
Headphones	3	2	1	1	2	2	2	3	2	1	19	1.9
Separate consultation area	3	4	1	3	3	1	2	2	2	2	23	2.3
MOUSE												
Traditional mouse	5	5	4	3	4	5	5	4	3	4	42	4.2
Joystick or pen	3	1	1	2	1	2	1	2	2	1	16	1.6
Multiple ways to scroll, such as mouse wheel	5	3	1	4	3	5	3	5	3	4	36	3.6
Wrist support mouse pad	4	4	5	1	3	3	3	5	3	3	34	3.4
Wireless	4	4	5	1	3	2	2	4	3	2	30	3
NOISE												
Acoustic ceiling and carpeting	5	5	3	4	3	2	5	4	3	5	39	3.9
Absorption panels on walls	4	5	3	4	3	4	4	4	3	4	38	3.8
Clouds over each station	3	2	3	3	2	2	2		3	2	22	2.4
CHAIRS												
Swivel	5	5	3	1	4	5	5	5	5	2	40	4
Adjustable height	5	5	5	5	4	5	4	5	5	5	48	4.8
Adjustable back support	5	5	1	3	2	5	3	5	5	5	39	3.9
Armrests	5	5	4	2	3	5	5	3	5	1	38	3.8
Adjustable armrest height	5	5	3	3	3	4	4	4	5	4	40	4
Wheels	5	5	4	4	4	4	5	5	5	4	45	4.5
Footrest	3	5	1	1	2	3	1	4	3	1	24	2.4
Neck rest	3		1	1	2	2	1		2	3	15	1.9
MONITORS												
Adjustable angle superior-inferior	5	5	5	2	3	3	2	5	5	3	38	3.8
Adjustable angle right-left	5		5	1	3	2	2	5	5	3	31	3.4
Adjustable distance	5	5	5	2	3	4	4	5	5	3	41	4.1
Adjustable height	5	5	5	3	3	4	4	4	5	3	41	4.1
Adjustable brightness	5	5	5	4	3	4	3	4	5	3	41	4.1

(continued)

Table 1. Continued

	Member											
	1	2	3	4	5	6	7	8	9	10	Total	Average
DESK												
Adjustable height	5	5	3	5	2	5	4	5	5	2	41	4.1
Adequacy of desk space	5	5	4	4	4	4	2	5	5	4	42	4.2
Keyboard tray	3	5	1	1	3	3	1		3	4	24	2.7
READING STATION												
Phone	5	5	5	5	5	3	4	5	5	5	47	4.7
Internet	5	5	5	5	5	4	5	5	5	5	49	4.9
Paging	5		5	3	2	1	2	5	3	4	30	3.3
Electronic medical record	5	5	5	5	2	3	5	5	5	4	44	4.4
Hands free dictation	5	5	3	1	2	2	3	3	3	2	29	2.9
READING STATION												
Number of monitors: 2, 3, 4, more	4	3	3	4	More (5)	3	4	4	4	4	33	3.7

room, was a high priority. Space is often sacrificed in an effort to cram as many reading stations as possible into the limited space of the reading room. This has become a particularly important issue in recent years with the increased workloads of radiologists and the need for increased staffing.

Rating 3.0 to 3.9

Among the factors with ratings of 3.0 to 3.9 was individualization of the workplace. Individualization took the form of individual controls for lighting and temperature, back support for chairs, and angulation of monitors. Individualization of the workplace also took the form of space for personal belongings and even individual reading rooms. Also important at this level were optimization of the mouse to allow individual preferences in terms of scrolling and other computer manipulations.

Unexpected Results

Some of the results were unexpected and differed from recommendations or discussions often cited in reviews of best ergonomic practices. For example, the number of monitors preferred by respondents in our poll was four, with three coming in as second choice. Two monitors were not believed to be adequate by any of the respondents. Similarly, although mouse design is frequently discussed as a significant factor in RSIs, our respondents were primarily in favor of the traditional mouse. Ventilation requirements and humidity were also not ranked highly, nor were footrests on the reading room chairs.

Of course, some of the criteria that were not considered high priorities may have received low ratings because their impact on and direct connection to highly rated factors were not considered by the respondents. For example, elimination of distracting sources of noise was one of the highest priorities, achieving a score of 4.6. However, the installation of acoustic clouds over each station was not given a high rating, perhaps because respondents did not realize that this intervention is actually very effective in reducing noise levels. Similarly, a separate consultation area was not considered a high priority although it could be vital in reducing noise in the other reading areas.

TREATMENT AND PREVENTION OF RSIs

Once symptoms of an RSI appear, the best initial treatments, in addition to ergonomic approaches, are rest and anti-inflammatory agents [32]. Other treatments, such as splinting, physical therapy, and appropriate directed exercises to strengthen the muscles at risk, are also widely used. Although the vast majority of cases of RSI in radiologists are self-limited, it is important to acknowledge and treat these injuries because progression to chronicity, even to the point of requiring surgery, can occur.

With respect to prevention, it is widely known that ergonomic training and devices can substantially decrease the incidence and prevalence of RSI in radiologists. However, implementation is still incomplete in radiology departments in the United States, despite formal guidelines from the offices of the Occupational Safety and Health Administration and the American National Standards Institute and despite studies showing that ergonomic improvements can not only decrease RSIs but also result in myriad other benefits, including improved diagnostic accuracy and efficiency.

TAKE-HOME POINTS

- Radiologists' professional lives increasingly center on PACS and digital imaging.
- The implementation of the digital workplace has resulted in an increase in RSIs.
- Radiology work practices in general and practices common to certain radiology subspecialties in particular are especially prone to RSIs.
- Ergonomic approaches can reduce the frequency and severity of RSIs and improve radiologists' productivity but are multifactorial and involve nearly all aspects of the radiology workplace.
- A poll of our commission members with respect to prioritization of frequently mentioned ergonomic approaches revealed members' preferences that may help in departmental planning.

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The Agony of It All: Musculoskeletal Discomfort in the Reading Room

Rebecca L. Seidel, MD, Elizabeth A. Krupinski, PhD

Abstract

Purpose: The purpose of this study was to determine the extent and severity of musculoskeletal discomfort in radiologists using a standardized tool, the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ). In addition, we evaluated the influence of demographic factors on the frequency of symptoms, degree of discomfort, interference of symptoms with ability to work, and overall pain.

Methods: The CMDQ was distributed via an anonymous link to all radiology trainees and faculty at our institution. The questionnaire assessed frequency and location of pain, severity of symptoms, and degree to which discomfort interfered with work. In addition, demographic data were collected.

Results: The survey was completed by 99 radiologists (39% response rate). The majority (80%) of respondents spent greater than 7 hours per workday at a diagnostic workstation. The neck (66%), lower back (61%), upper back (43%), right shoulder (36%), and right wrist (33%) were the areas where radiologists most frequently reported ache, pain, or discomfort at least once per week. More than 7 hours per day at a computer workstation was significantly associated with higher total pain.

Conclusions: Musculoskeletal discomfort in the week before the survey was reported by the majority of radiologists and was significantly influenced by demographic factors. Further investigation is needed to understand the causes of radiologists' discomfort at work and to evaluate interventions to ameliorate these symptoms.

Key Words: Ergonomics, musculoskeletal discomfort, occupational health, radiology

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INTRODUCTION

Prolonged sitting and repetitive tasks are associated with musculoskeletal injury, fatigue, and poor health outcomes [1,2]. In a study of office workers at a large telecommunications company, 77.5% of respondents reported neck discomfort in the previous week, and musculoskeletal symptoms were most frequently reported in the neck, shoulder, low back, and wrist [3]. Another study showed a high prevalence of discomfort in the neck, upper back, and lower back of occupational notebook personal computer users [4].

In the PACS environment, radiologists spend the majority of their time seated at a computer workstation and, therefore, are also at risk for work-related musculoskeletal injury. Previous studies have demonstrated a high incidence of work-related injuries such as back pain, carpal tunnel syndrome, eye strain, and headaches in radiologists [5,6]. A multicenter study in Great Britain reported radiology-associated occupational injury in 38% of surveyed radiologists [7]. Another study demonstrated a prevalence of repetitive strain injuries in 60.2% of surveyed breast imaging radiologists [8].

Fatigue and discomfort have also been identified as contributors to interpretation errors. Using the Swedish Occupational Fatigue Inventory to measure manifestations of physical fatigue, Krupinski et al demonstrated that radiologists are significantly fatigued after a long day of clinical reading. In addition, they showed that after an average of 8 hours in the clinic, radiologists' diagnostic accuracy decreased by over 4% [9-11].

There have been no studies of radiologists using validated tools designed to assess musculoskeletal discomfort among office workers. The purpose of this study was to determine the extent and severity of

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musculoskeletal discomfort in radiologists using a standardized tool, the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) [12]. In addition, we evaluated the influence of demographic factors on the frequency of symptoms, degree of discomfort, and interference of symptoms with ability to work.

METHODS

This study was approved by the Institutional Review Board of the Emory University School of Medicine. An electronic survey was distributed via anonymous link to all radiology residents, fellows, and attendings (n = 252) at our institution using survey software by Qualtrics (www.qualtrics.com/survey-software/). The survey contained an electronic version of the CMDQ, a 54-item questionnaire about the prevalence of musculoskeletal symptoms in 18 regions of the body during the previous week. This standardized and validated survey tool assessed the frequency of ache, pain, or discomfort in specific areas of the body using a 5-point scale (never, 1-2 times last week, 3-4 times last week, once every day, and several times every day). These scores were weighted according to the survey scoring guidelines with weights of 0, 1.5, 3.5, 5, and 10, respectively, to determine an overall frequency score [12]. The degree of discomfort and the degree to which discomfort interfered with work were evaluated using a 3-point scale. Responses were weighted to calculate a discomfort score (slightly = 1, moderate = 2, very = 3) and an interference score (not at all = 1, slightly = 2, substantially = 3). The frequency, discomfort, and interference scores were multiplied to obtain a weighted score for each body area, which ranged from 0 to 90.

A total pain score was calculated for each individual by summing the weighted scores for each body part. The total weighted scores were dichotomized with those above the median categorized as high pain and those below the median considered low pain. A multivariable logistic regression was then carried out using these categories as the dependent variable and age (≥40, <40), gender (male, female), years of board certification (≥10, <10 years), rank (attending, trainee), shift length (≥7 hours, <7 hours), workstation hours, and percent time standing as independent variables.

RESULTS

The survey was distributed to 252 radiologists (31% women, 69% men; 36% trainees, 64% faculty). It was completed by 99 (39% response rate); 39% of participants were women and 61% were men, and 43% were trainees and 57% were faculty physicians. χ^2 analysis demonstrated that the data were representative of the gender and rank distribution of the population under study. The average age of respondents was 36.94 (SD = 10.19, minimum = 26, maximum = 61). The majority (80%, n = 78) of participants reported spending 7 hours per day or more at a computer workstation, and more than one-half (52%, n = 51) spent 100% of their time in a seated position (Table 1).

Overall, 87% of radiologists surveyed reported ache, pain, or discomfort in at least one body area at least one to two times in the week before the survey. The areas of the body where discomfort was most frequently reported were the neck, back, and right upper extremity (Fig. 1). Respondents reported discomfort one to two times per week or more in the neck (66%), lower back (61%),

Table 1. Demographic characteristics of survey participants

Characteristic	%
Position	
Trainee (resident or fellow)	43
Faculty	57
Gender	
Male	61
Female	39
Years board certified	
<10	29
11-20	12
21-30	10
>30	5
Not yet certified	44
Hours per day at diagnostic workstation	
1-2	7
3-4	2
5-6	11
7-8	44
9-10	33
11-12	3
Time spent standing vs seated	
100% seated	52
90% seated, 10% standing	27
80% seated, 20% standing	8
70% seated, 30% standing	1
60% seated, 40% standing	1
50% seated, 50% standing	3
40% seated, 60% standing	1
30% seated, 70% standing	1
20% seated, 80% standing	1
10% seated, 90% standing	3
100% standing	1

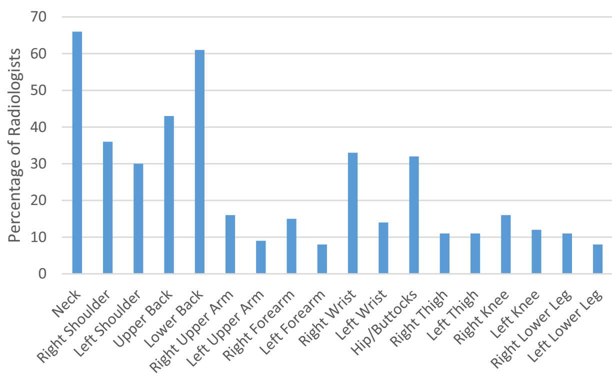

Fig 1. Location of symptoms in radiologists reporting ache, pain, and discomfort in the work week before the survey.

upper back (43%), right shoulder (36%), and right wrist (33%) (Table 2).

In areas where pain was reported, participants were asked, "If you experienced ache, pain, or discomfort, did this interfere with your ability to work?" Of respondents with neck pain, 53% (n = 28) reported that their symptoms slightly or substantially interfered with their ability to work, and 41% (n = 22) of participants with low back pain and 40% (n = 13) with upper back pain reported slight interference with their ability to work. No one with back pain reported that it substantially interfered with their ability to work. Of those with right wrist pain, 11% (n = 3) reported that it substantially interfered with their ability to work (Fig. 2).

The weighted frequency, severity, and work interference scores were multiplied to obtain a total weighted score for each body site. Analysis of the mean weighted scores demonstrated the most severe scores in the neck (mean = 7.88, range 0-60, SD = 15.2), right shoulder (mean = 4.49, range 0-90, SD = 13.85), and lower back (mean = 5.66, range 0-60, SD = 13.38) (Table 2).

Statistically significant gender differences were observed in the location and severity of discomfort. Female radiologists were more likely than male radiologists to report symptoms in the right shoulder ($P = .007$), left shoulder ($P = .0078$), and left forearm ($P = .031$). Female radiologists were more likely than male radiologists to report that their neck ($P = .0346$), lower back ($P = .0354$), and hip or buttocks ($P = .0472$) symptoms were moderately or very uncomfortable. Female radiologists (75%) were more likely than male radiologists (11%) to report that right thigh pain slightly interfered with their ability to work ($P = .015$).

Years of board certification and age of radiologist were associated with statistically significant differences in responses. Radiologists who were board certified for more than 10 years were more likely to report ache, pain, or discomfort in the left upper arm ($P = .044$) and left forearm ($P = .016$). Radiologists that have been board certified for more than 10 years were more likely to report that neck pain interfered with their work than radiologists who were board certified for less than 10 years ($P = .0128$).

Hours at the workstation and percent of day seated were also associated with statistically significant differences in responses. Respondents who spent 7 hours per day or greater at the workstation were more likely to report right shoulder symptoms than those who spent up to 6 hours per day at the workstation ($P = .042$). Those who spent 90% or more of their day seated were more likely to report discomfort in their left shoulder ($P = .01$) and upper back ($P = .0007$).

The total weighted score for each body part was summed for each individual to calculate a total pain score. The mean total pain score was 36.1 (median = 4.75, SD = 60.47). The only variable that was significantly related to a high pain score was > 7 hours at a workstation ($P = .045$) (Table 3). Logistic regression analysis showed that those who worked >7 hours at a workstation were 3.4 times more likely to report high pain.

DISCUSSION

This survey confirmed previously published findings of musculoskeletal pain among radiologists and added new insight into the frequency of symptoms, the degree to which they impact ability to work, and the role of demographics on the location and prevalence of musculoskeletal discomfort. Statistically significant demographic factors included gender, age, years of board certification, time spent seated, and hours at the workstation.

Our data show that the majority of radiologists in our sample spent 7 or more hours per workday at a computer workstation. This variable was significantly associated with an overall higher total pain score. In addition, the majority worked in a seated position 100% of the time. This amount of sedentary time potentially places radiologists at risk of sitting disease [13]. *Sitting disease* is a term that refers to the increased incidence of illness and mortality associated with prolonged sedentary time. Our findings suggest the need to educate radiologists regarding the adverse health effects of prolonged sitting and encourage them to incorporate movement breaks and periods of standing into their workday. In addition, the reading room environment must be modified to allow for changes in work position throughout the

Table 2. Frequency, severity, and work interference of musculoskeletal discomfort

	Frequency of Ache, Pain, Discomfort in the Last Work Week (%)					Severity of Discomfort (%)			Work Interference (%)			
Site	Never	1-2 Times	3-4 Times	Once Every Day	Several Times Every Day	Slightly	Moderately	Very	Not at All	Slightly	Substantially	Mean Weighted Scores (SD)
Neck	34	30	10	7	19	60	28	11	47	51	2	7.80 (15.2)
R shoulder	64	17	5	2	12	57	30	13	53	43	4	4.44 (13.85)
L shoulder	70	13	5	3	9	64	16	20	60	36	4	3.26 (13)
Upper back	57	22	9	4	8	67	24	9	60	40	0	3.34 (9.34)
Lower back	39	39	7	4	11	67	25	8	59	41	0	5.60 (13.38)
R upper arm	84	10	3	1	2	69	31	0	60	40	0	.78 (3.04)
L upper arm	91	5	1	0	3	73	27	0	82	18	0	.23 (1.47)
R forearm	85	7	5	1	2	73	27	0	53	47	0	.84 (3.15)
L forearm	92	5	1	0	2	78	11	11	82	9	9	1.11 (9.14)
R wrist	67	21	5	3	4	56	44	0	46	43	11	2.46 (7.42)
L wrist	86	10	0	2	2	69	31	0	67	27	6	1.18 (5.49)
Hip or buttocks	68	16	8	6	2	58	42	0	69	28	3	1.78 (5)
R thigh	89	7	2	1	1	60	40	0	72	28	0	0.66 (2.91)
L thigh	89	7	2	1	1	80	20	0	79	21	0	0.36 (1.67)
R knee	84	11	3	1	1	80	20	0	78	22	0	0.60 (2.68)
L knee	88	7	3	2	0	83	17	0	81	19	0	0.51 (2.54)
R lower leg	89	8	2	1	0	83	17	0	81	19	0	0.43 (2.48)
L lower leg	92	6	1	0	1	91	9	0	87	13	0	0.32 (1.76)

L = left; R = right.

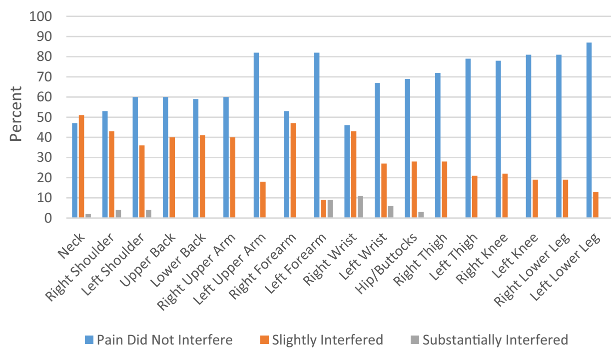

Fig 2. Responses to "If you experienced ache, pain, or discomfort, did this interfere with your ability to work?"

course of the work day, for example, by incorporating furniture that is height adjustable.

A high prevalence of discomfort in the neck, back, and wrists has been shown in nonradiologist office workers, as well as in radiologists [3,4]. In their survey of breast imagers, Thompson et al showed that repetitive strain injury was most commonly reported in the neck and wrists [8]. In our study, 33% of radiologists reported right wrist pain and 66% of respondents reported neck pain at least one or two times in the previous work week. More than half of those reporting neck symptoms stated that the discomfort at least slightly interfered with their ability to work. Neck pain was more likely to interfere with work in radiologists that are older or have been practicing longer. Because we included trainees in our survey, our data may underestimate the prevalence and impact of neck pain, because it might be slightly skewed toward a younger demographic.

Table 3. Associations of individual and work-related risk factors with high pain score

Risk Factors	High Pain (%)	χ^2	*P* Value
Age		0.7025	.402
Under 40	46.8		
Over 40	55.6		
Gender		0.1719	.678
Male	48.3		
Female	52.6		
Years board certified		0.0414	.839
<10	49.1		
10+	51.2		
Rank		2.743	.098
Attending	44.6		
Resident	62.5		
Shift length (hours)		4.021	.045
<7	30.0		
7+	55.1		

Further investigation into the etiology of radiologists' neck pain is required, but it could be due to improper monitor positioning, insufficient neck support from the chair, or even eye strain. This finding should be taken into consideration when choosing reading room furniture and equipment. Radiologists may benefit from education about reading room ergonomics and proper adjustment of furniture and equipment before each reading session.

Although our study did not demonstrate significant gender differences with respect to overall pain, we found statistically significant gender differences in location and severity of discomfort. Female radiologists were more likely than male radiologists to report right shoulder, left shoulder, and left forearm symptoms. They were more likely than male radiologists to report moderately or very uncomfortable neck, low back, and hip or buttock pain. They were also more likely to report that right thigh pain slightly or substantially interfered with their ability to work. Interestingly, gender differences have also been observed in other industries. Erdinc found that female gender was significantly associated with musculoskeletal discomfort in the neck and upper extremity in occupational notebook personal computer users [4]. These differences may be due to furniture design that favors a male body habitus or differences in position and posture between genders. More investigation is needed to better understand how to optimize workstation ergonomics for the female radiologist.

This study has some limitations. There was potential for self-selection bias such that those with musculoskeletal symptoms may have been more likely to respond than those without. Because trainees were included, the average age of participants was 36.94, which is likely younger than the average age of practicing radiologists. In addition, it was a single-institution study that may not reflect the ergonomics or demographics of other practices.

In summary, musculoskeletal strain symptoms were prevalent among radiologists. Greater than 7 hours per day at a PACS workstation was significantly associated with a higher overall pain score. Symptoms differ in location and severity among male and female radiologists. Symptoms may be more likely to interfere with work with increasing age and increasing years in practice. Further investigation is required to determine if ergonomic education and changes in furniture and equipment design would ameliorate pain and discomfort in radiologists.

TAKE-HOME POINTS

- The majority (80%, n = 78) of participants reported working 7 hours per day or more at a computer workstation, and more than half (52%, n = 51) spent 100% of their time in a seated position.
- Radiologists most frequently reported symptoms in the neck, back, and right upper extremity.
- Musculoskeletal symptoms varied in location and severity between male and female radiologists.
- Musculoskeletal symptoms were more likely to interfere with work with increasing age and increasing years in practice.
- Greater than 7 hours per day at a PACS workstation was significantly associated with a higher total pain score.

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Tired in the Reading Room: The Influence of Fatigue in Radiology

EC: Editor's Choice
SA-CME

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Abstract

Commonly conflated with sleepiness, fatigue is a distinct multidimensional condition with physical and mental effects. Fatigue in health care providers and any secondary effects on patient care are an important societal concern. As medical image interpretation is highly dependent on visual input, visual fatigue is of particular interest to radiologists. Humans analyze their surroundings with rapid eye movements called saccades, and fatigue decreases saccadic velocity. Oculomotor parameters may, therefore, be an objective and reproducible metric of fatigue and eye movement analysis can provide valuable insight into the etiology of fatigue-related error.

Key Words: Fatigue, saccades, fixations, eye tracking, error

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INTRODUCTION

Contemporary radiologists practice in an environment of increasing workloads, reduced reimbursement, and shorter turnaround times to interpret increasingly complex examinations [1]. Because financial compensation in many practices is dependent on productivity, radiologists may interpret studies faster than their "natural" reporting speed, take fewer breaks, and work longer hours to optimize compensation [2]. Pressure to increase productivity has evolved with little understanding of the perceptual, cognitive, and physical limitations of interpreting radiologists, despite evidence that increased workload and fatigue is associated with visual tiredness, cognitive overload, and decision fatigue [1,3]. As radiologists strive to maximize productivity, it is important to consider the potential implications of fatigue to ensure that higher volume and reporting speeds do not compromise patient outcomes.

FATIGUE VERSUS SLEEPINESS

The terms "sleepiness" and "fatigue" are commonly conflated in both clinical research and practice [4]. Sleepiness is defined as drowsiness, sleep propensity, and decreased alertness [5]. Fatigue is typically described as weariness, weakness, and depleted energy [5]. Although the two conditions often coexist, fatigue can occur without sleepiness. Insomniacs, for example, may feel fatigued without being sleepy [5]. Both fatigue and sleepiness can have adverse effects on daily functions, but their etiology and preventative interventions may differ [4].

FATIGUE—TYPES AND MEASUREMENT

A term with multiple meanings, "fatigue" has both physical and mental components [6]. Exertion and discomfort are physical manifestations of fatigue and lack of motivation and "sleepiness" are considered mental components [6]. Lack of energy reflects both physical and mental aspects of fatigue [6]. Several subjective scales are used to measure fatigue (eg, Brief Fatigue Scale), but there is no

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gold standard and data interpretation may depend on the particular scale employed [4,5].

Fatigue-Critical Flicker Fusion Test

One controversial measurement of fatigue is the Critical Flicker Fusion test (CFF). During this test, the subject indicates the minimum frequency at which a flickering light is perceived as flickering and not continuous, the "fusion-frequency threshold" [7]. Because the threshold provides a measure of the observer's ability to distinguish discrete sensory events, it is thought to provide a measure of central nervous system (CNS) activity or "cortical arousal" [8]. A lower CFF value is, therefore, believed to be associated with CNS fatigue [9]. As CFF is sensitive to both intrinsic and extrinsic factors, the impact of either factor can be confounded by the other factor's influence [8]. Despite its potential limitations, CFF has been used to assess fatigue in radiologists.

Two studies showed a decline in the CFF frequency (the rate at which the stimulus appears as continuous, indicative of CNS fatigue) of radiologists after a 4-hour work shift and one shift of undefined duration [9,10].

FATIGUE IN GENERAL MEDICINE

Fatigue in health care professionals can potentially contribute to medical errors [11]. Recent analysis estimates a mean rate of death from medical error of over 251,000 per year, suggesting it is the third most common cause of death in the United States [12]. To reduce errors potentially caused by fatigue, in 2003 the ACGME implemented resident work-hour restrictions with the expectation that this would have a positive effect on patient care outcomes and resident quality-of-life measures [13,14].

Subsequent studies demonstrate that residents with shorter work hours report improved quality of life, better sleep, and less fatigue, but work-hour restrictions have not translated into definitive improvements in patient outcomes [13,14].

VISUAL FATIGUE

As interpretation of medical images relies highly on visual input, in addition to "general" fatigue, visual fatigue is of particular concern in radiology. The first step in the interpretation of medical imaging is detection, noting a finding of potential medical concern. This initial task is of prime importance, because without detection subsequent steps leading to diagnosis cannot be executed [15].

Most investigations regarding the quantification of visual fatigue are focused on its oculomotor-related symptoms. These symptoms reflect changes in the accommodation and vergence responses of the eye as well as changes in pupil and eye-blink responses. Accommodation refers to the action of the ciliary muscles contracting or relaxing, altering the curvature of the lens of the eye to optimize the focus of images on the retina [16]. Vergence is the simultaneous movement of both eyes in opposite directions to obtain or maintain single binocular vision on an object as a function of its distance (focal point). Accommodation and vergence decline with fatigue, resulting in decreased ability to maintain focus on a set point in space (eg, a solitary pulmonary nodule in a chest x-ray) [16] (Fig. 1). An extended period of image interpretation at close viewing distances requires active and sustained convergence and accommodation, which tire ciliary and extraocular muscles [6,16,17].

In research studies, accommodation and vergence measures are considered objective indicators of visual

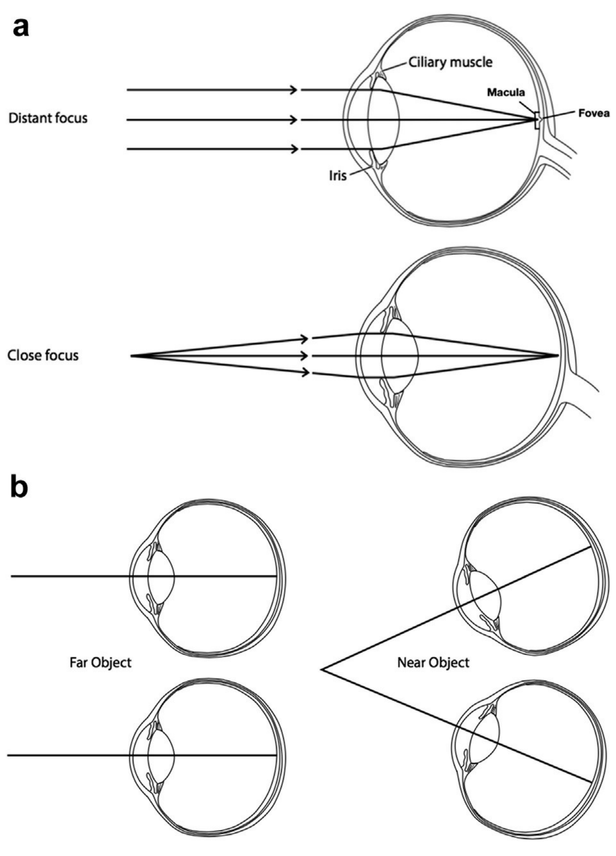

Fig 1. (a) Accommodation. Accommodation is the process where the eye changes optical power to maintain focus on objects. Accommodation increases as objects get nearer. To focus on near objects, the ciliary muscle contracts and the lens assumes a more spherical shape. (b) Convergence. When viewing far objects, the eyes are parallel. To look at a near object, the eyes converge—rotate toward each other—to maintain binocular vision.

fatigue [6,16]. Krupinski and Berbaum [16] found that radiologists had worse accommodation after a day of reading than at the start of the workday. Affected at all distances, participants were least able to accommodate to near targets (critical for radiologic interpretation, a near-work task). This difficulty to focus can make it harder to detect abnormalities, by either reducing accuracy or necessitating additional reading time if accuracy is preserved [16]. Ikushima et al [9] also found that radiologists' visual strain, measured on a subjective scale, increases after a day of reading.

EFFECTS OF FATIGUE ON INTERPRETIVE ERROR

Increased eye strain after a shift does not necessarily predict interpretative error. Early studies found no difference in the error rates of residents before and after a 15-hour shift, or of attending radiologists from the beginning to the end of the workday in pulmonary nodule detection tasks [18,19]. However, neither study measured physical or visual fatigue. In 2010, Krupinski et al [20] investigated the effect of fatigue in the detection of "easy"- and "hard"-to-detect bone fractures, finding that readers were more myopic (nearsighted), were more subjectively fatigued, and experienced increased visual strain after a day of diagnostic interpretation, compared with the morning before diagnostic reading. Detection accuracy was lower for late versus early readings [20].

CT scans are viewed dynamically, with successive images presented one after another under the radiologists' control. Because the internal processing of dynamic and static images differs, the impact of fatigue could vary [21]. Krupinski et al [21] studied this possibility by investigating the effect of fatigue and error in CT scan interpretation in a nodule detection task. After a day of reading, radiologists had high levels of visual strain and statistically significantly decreased accuracy for nodule detection [21].

Ruutiainen et al [22] found an increased number of clinically significant interpretation disparities between preliminary resident reports in the last 2 hours of a 12-hour overnight shift, compared with the final readings by attending physicians rendered the following day. Although the residents' level of fatigue was not directly ascertained, the authors surmised that fatigue was the most plausible explanation for this deterioration in performance [22].

In clinical practice, attending radiologists operate without defined work hours and can choose shifts and work hours that do not optimize their performance. Furthermore, residents routinely work 16- to 24-hour shifts, often overnight and without adequate sleep. It is therefore likely that fatigue-related effects are more significant in clinical practice than has been demonstrated experimentally.

OCULOMOTOR DYNAMICS AND SCENE ANALYSIS

When scanning the immediate surroundings, the eyes make jerky saccadic movements, interleaved with fixation periods [23]. These saccades are rapid movements of the eyes that capture detailed snapshots with the fovea—the central part of the retina, with sufficient photoreceptor density to provide high-resolution vision [23]. The fovea is only about 0.4 mm in diameter, corresponding to about 2 degrees of visual angle, but plays a critical role in resolving detail [24] (Figs. 2 and 3). Under normal viewing conditions, observers generate several saccades per second, unconsciously selecting their goals. The visual system does not obtain useful information while a saccade is in motion; thus, vision is dependent upon the information gathered during the fixation pauses between saccades [25].

One of the major components of interpretation is how images are searched. Radiologists obtain a significant amount of information before a focused visual search. In 1975, Kundel and Nodine found that radiologists

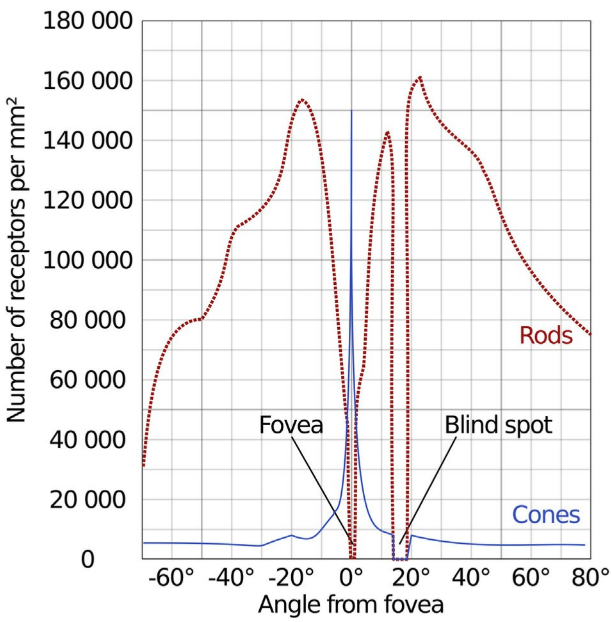

Fig 2. Relationship of rod and cone density to the distance from the fovea. The retina contains 2 different types of photoreceptors, rods and cones, and the region of the retina with the highest visual acuity is the area of highest cone density, the fovea centralis.

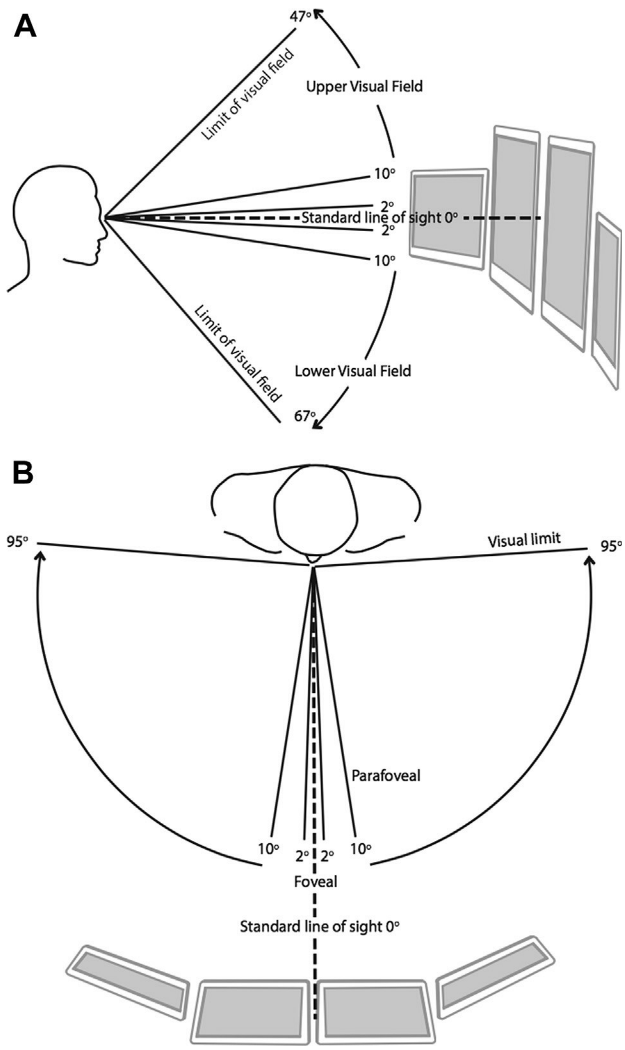

Fig 3. Vertical (A) and horizontal (B) field of view of the human eye. The fovea is the portion of the retina with the highest spatial resolution constituting the central 2 to 4 degrees of the visual field.

detected abnormalities on chest radiographs presented for 200 msec (enough time for just a single fixation) with 70% accuracy, indicating that valuable information can be extracted from an image without performing a detailed examination [26]. Subsequent studies confirm this finding demonstrating that radiologists can detect abnormalities in sub-second viewing times with high accuracy [27-30].

Visual search of complex images, such as radiographic studies, is thought to occur in two steps. The first step consists of a rapid primary global or "gist" response, which takes place during the first 40 to 200 msec of looking at an image [23,29]. The radiologist may rapidly identify abnormal areas in the image with peripheral vision and select them for subsequent foveal scrutiny [27,31]. A second "systemic scan" then occurs, which allows for accurate object recognition using foveal vision [27]. Features are examined carefully and tested against the readers' cognitive schema to determine whether a finding is suspicious. Once concordance is achieved between image elements and the viewer's cognitive scheme, a decision is made [31]. This step, termed the "bottleneck of attention," lasts seconds to minutes and is capacity limited [27,28].

ELUCIDATION OF ERRORS IN RADIOLOGY WITH EYE-TRACKING TECHNOLOGY

Errors in image interpretation have been recognized since the seminal works of Garland in 1949 [32]. Inadequate and erroneous perception are the primary etiologies for these mistakes [33]. The estimated interpretive error rate in a mix of normal and abnormal cases averages 3.5% to 4%. However, when the case mix consists exclusively of studies with abnormalities the error rate increases to approximately 30% [34]. This rate of error has remained virtually unchanged for over 50 years [34,35].

Modern research conducted with eye-tracking technology has demonstrated a link between oculomotor dynamics and cognitive processes [36]. This understanding has been instrumental in elucidating the nature of radiologic error. Three types of false-negative or omission errors have been defined: (1) search errors—failure of the observer to fixate the fovea on the lesion; (2) recognition errors—the observer fixates on the lesion for a short time but fails to discern it from the background; (3) decision-making or cognitive errors—the observer fixates on the lesion for a sufficient amount of time, but either does not recognize concerning features of the lesion or actively dismisses them [31,35,37]. Search and recognition errors are considered to be "perceptual" in nature [35].

THE INFLUENCE OF FATIGUE ON EYE MOVEMENTS

Mental fatigue has major effects on eye movement dynamics and increased time on task is linked to decreased saccadic velocity [38]. Saccadic velocity (the speed of the saccade measured in degrees/second), therefore, has the potential to serve as an objective and noninvasive biomarker of fatigue [39].

Di Stasi et al [40] measured subjective fatigue and eye-movement dynamics of surgical residents before and after a 24-hour shift and found that residents felt more fatigued with increased time on duty and had decreased saccadic velocity (Fig. 4). Other studies have reported similar oculomotor findings as a function of fatigue/time on task in both laboratory and natural scenarios [38,41,42].

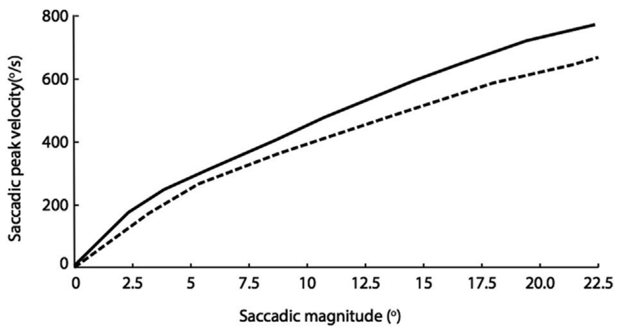

Fig 4. Effect of time on duty and the saccadic peak velocity–magnitude relationship. There is a consistent relationship between saccadic velocity and amplitude (saccadic magnitude in degrees of visual angle), termed the "main sequence." The slope of the main sequence decreases with increased time on duty in postcall (dashed line) versus precall (solid line) surgical residents. This finding is attributable to decreased saccadic velocity with increased fatigue. (Based on Di Stasi LL, McCamy MB, Macknik SL, Mankin JA, Hooft N, Catena A, Martinez-Conde S. Saccadic eye movement metrics reflect surgical residents' fatigue. Ann Surg 2014;259:824-9).

UTILITY OF OCULOMOTOR MEASURES OF FATIGUE IN THE STUDY OF MEDICAL INTERPRETATION ERRORS

Eye-movement analysis can provide valuable insights into the nature of fatigue-related error, such as whether fatigue changes the nature of visual search, whether fatigued radiologists have typical viewing patterns, and whether fatigue-related error is cognitive or perceptual in etiology.

Fatigue and Search Pattern Analysis

The analysis of search patterns (scanpaths) has provided insight into the nature of expertise (Fig. 5) and, similarly, can determine how fatigue affects specific elements of search [27,43-45].

Scanpath alteration as a consequence of fatigue has been noted in nonmedical tasks. During a 30-minute sustained attention task in which subjects had to detect digits in a rectangular array, subjective fatigue increased, the number of fixations decreased, the distance between fixation location and target digits increased, and the subjects' gaze drifted toward the center of the screen over time [46]. Another study found increased mean fixation duration as a function of subjective fatigue during free visual exploration of a landscape [47].

The Influence of Fatigue on Gaze Volume and Coverage

Recent studies have quantified radiologists' gaze volume (as a percentage of the image viewed) during CT chest interpretation, demonstrating that radiologists look at an average of 27%-69% of the parenchyma [43,48,49].

Radiologists often report that they "barely look at" and "gloss over" studies at the end of a long, demanding shift. These subjective feelings may be reflected in changes in their interpretation time and/or the percentage of the image viewed. Burling et al [50] found that radiologists spend less time interpreting CT colonography examinations as they near the end of a day of work: they interpreted the

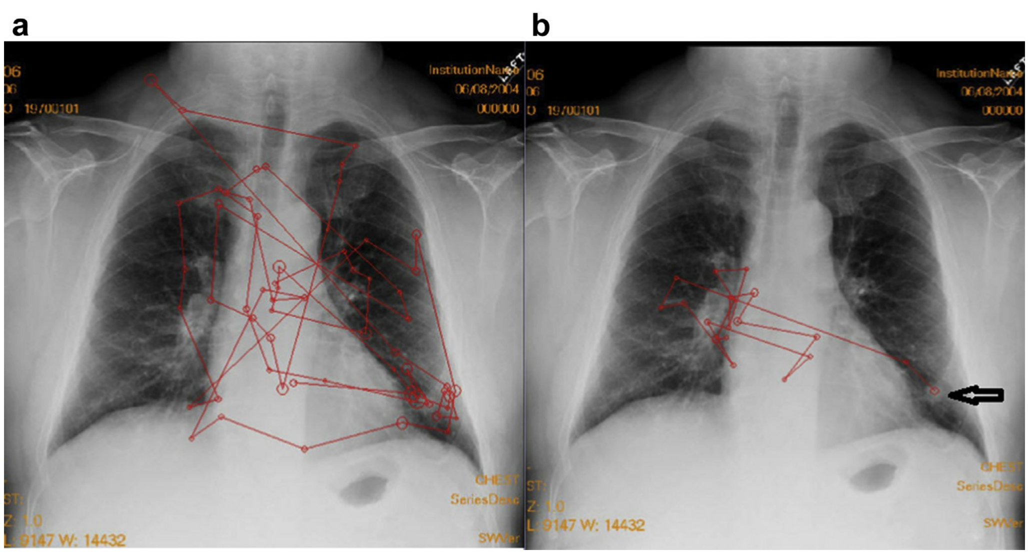

Fig 5. Typical scanpath in a first-year (novice) radiologist (a) and an expert radiologist (b) while searching a chest radiograph (CXR) for lung nodules. This CXR has a pulmonary nodule at the left base (arrow). Expert radiologists demonstrate more efficient scanpaths (red lines) compared with novices with fewer fixations (circles), less coverage of the image, fewer saccades, and faster arrival at the abnormality.

last five cases 29% faster than the first five cases of the shift. This increase in interpretive speed at the end of a shift suggests that radiologists may be less thorough toward the end of a long reading period, possibly secondary to decreased image coverage/gaze volume. Both scan coverage and interpretation times can be assessed utilizing eye-tracking technology to elucidate the effects of fatigue on interpretation mechanics.

Eye-tracking technology can also provide insight into whether fatigued radiologists neglect any specific portion of the visual field. Roge et al [51] studied ocular dynamics in subjects while they drove a simulator for 1 hour. Monotonous driving resulted in decreased vigilance and deterioration of the useful visual field for both sleep-deprived and non-sleep-deprived participants. The authors suggest that deterioration of the useful visual field may be progressive, taking the form of tunnel vision when sleep debt is not significant and affecting the whole visual field in the presence of significant sleep deprivation [51]. Similarly, fatigued interpreters may neglect a portion of the image, with resultant search errors.

Fatigue and its Influence on Omission Errors

Lastly, eye tracking technology can elucidate the nature of omission errors made by fatigued radiologists by analyzing the length of time spent fixating on abnormalities that were seen but not interpreted as abnormal (ie, consistent with a cognitive error) [37]. Cognitive versus perceptual errors likely require different approaches for amelioration via training and system support [35].

CONCLUSION

Although technological solutions, such as computer-aided detection, have been advanced as a solution to interpretive error (including those errors engendered from fatigue), clinical results thus far have been mixed, at best [52]. Other technological techniques such as osseous subtraction in chest imaging have also been advanced, with promising results; however, for the foreseeable future, imaging interpretation remains a human endeavor and is thereby subject to human emotional, physical, and mental states—including fatigue [53,54]. As such, it is critically important for radiologists and practice leaders to leverage neuroscience tools to understand and mitigate effects of fatigue on interpretation. Targeted interventions may then be proposed, studied, and implemented to ameliorate any negative effects on patient safety.

TAKE-HOME POINTS

- The implications of fatigue on interpretive error are important to study, given its potential to compromise patient safety.
- In addition to "generalized" physical and mental fatigue, radiologists have to consider the effects on visual oculomotor fatigue, given the primacy of lesion detection in diagnostic interpretation.
- Radiologists demonstrate decreased ability to focus and decreased accuracy with fatigue.
- Fatigue decreases the velocity of rapid eye movements, termed "saccades," which occur between fixation periods, potentially an objective metric of fatigue.
- Although technological solutions have been advanced as a solution to reduce errors in interpretation, for the foreseeable future radiology is a human endeavor. As such, factors such as fatigue, which potentially decreases performance, are important to comprehensively understand.

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Factors Associated with Repetitive Strain, and Strategies to Reduce Injury Among Breast-Imaging Radiologists

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Purpose: To investigate the prevalence of repetitive strain injury (RSI) among breast-imaging radiologists, the factors associated with such symptoms, and strategies to reduce injury.

Methods: In 2012, an anonymous survey regarding RSI and work habits was administered to 2,618 physician members of the Society of Breast Imaging via e-mail. Analysis of 727 (27.8%) de-identified responses was completed using STATA 12.1. Pain levels before and after implementation of digital imaging were compared with the Wilcoxon signed-rank test. The associations between RSI symptoms and work habits were assessed with logistic regression and test for trend.

Results: In the survey 438 of 727 (60.2%) respondents reported RSI symptoms, and 242 of 727 (33.3%) reported prior diagnosis/treatment. Results showed a statistically significant trend for the odds of RSI symptoms to increase with decreasing age ($P = .0004$) or increasing number of daily hours spent working ($P = .0006$), especially in an awkward position ($P < .0001$). Respondents recalled a significant increase in pain level after implementation of PACS, and a decrease in pain after ergonomic training or initiating use of an ergonomic mouse, adjustable chair, or adjustable table ($P < .001$, all comparisons). Only 17.7% (129 of 727) used an ergonomic mouse and 13.3% (97 of 727) had attended ergonomic training. Those with RSI symptoms or prior diagnosis of a Repetitive Strain Syndrome (RSS) were more likely to desire future ergonomic training compared with those without symptoms or injury (odds ratio 5.36, $P < .001$; odds ratio 2.63, $P = .001$, respectively).

Conclusions: RSI is highly prevalent among breast-imaging radiologists nationwide and may worsen after implementation of PACS or with longer work hours. Ergonomic training and ergonomic devices may diminish or prevent painful RSI among radiologists.

Key Words: Repetitive strain injury, breast-imaging radiology, ergonomics

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INTRODUCTION

PACS and digital imaging improve radiologist efficiency and turnaround times [1-3] and save costs [4,5]. But repetitive work at computer workstations can produce repetitive strain injuries (RSIs) [6-12], which have the potential to decrease productivity. As case volumes increase in radiology practices [13,14], it is especially important for radiologists to know how to protect against RSI. The American National Standards Institute (ANSI) has been publishing guidelines for human interactions with computers since 1988 [6], and several recent publications have endorsed both ergonomic work environments and ergonomic training for RSI prevention [2,4,5,7-9,12,15-19].

Despite widespread availability of computer ergonomic guidelines, a single-center survey of departmental

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radiologists after PACS installation found that RSI symptoms were prevalent in more than 58% of respondents; 38% had a prior diagnosis of a repetitive strain syndrome (RSS) [20]. In the breast-imaging field, most radiologists read film mammograms on alternators before the 2000 FDA digital mammography approval [21]. After FDA approval, radiologists began to read digital mammograms, ultrasounds, and MRIs on mammography-specific or PACS workstations. These computerized workstations changed the way breast imagers interacted with their environment, raising a new risk for RSI. The goal of our national study was to estimate the prevalence of RSI among breast imagers, to identify factors associated with RSI symptoms, and to assess the prevalence and impact of ergonomic workplace strategies to reduce injury in the breast-imaging reading environment.

METHODS

We developed an anonymous survey instrument for the Society of Breast Imaging as part of a quality assurance project on the prevalence of RSI in breast imagers, incorporating questions based on existing literature about computer workstation ergonomics. In 2013, our institutional review board approved the retrospective analysis of the anonymous cross-sectional survey data.

The survey incorporated questions from a previously published "Ergonomic Survey" instrument, including those regarding: departmental position; current use of digital or analog mammography at work; hours per day spent at a personal computer or PACS workstation; hours per day spent in an awkward position (eg, with wrist bent, bent at the waist leaning forward, kneeling, stooping, squatting, reaching overhead); current RSI (eg, pain, stiffness, soreness, or cramping in any extremity, or the back or neck area related to work tasks); and prior diagnosis of an RSS or overuse syndrome [20]. Age information was grouped into 5-year intervals from $\leq$34 to >65 years. Additional information collected included sites of pain or discomfort related to work tasks, and use of an ergonomic mouse or peripheral input device, adjustable chair, or adjustable table at work. A previously validated visual analog scale consisting of a 10-cm horizontal line that ranged from 0 to 10 was used to assess self-reported pain before and after implementation of a computer PACS workstation and various ergonomic devices or training in the workplace [22].

Our online Qualtrics (www.survey.qualtrics.com) survey instrument was administered by e-mail to the 2,618 physician members of the Society of Breast Imaging in November 2012 and was resent in December 2012 to increase the response rate. A total of 727 (27.8% response rate) anonymous responses were received. Statistical analysis was performed using STATA 12.1 (College Station, TX). The difference in self-reported median pain levels before and after implementation of PACS workstations or various ergonomic devices or training was calculated using the nonparametric Wilcoxon signed-rank test.

In the literature evaluating socioeconomic data, principal component analysis is a statistical technique commonly used to reduce several correlated variables (ie, income, education, health insurance) into a single socioeconomic score index [23]. Because the use of various ergonomic devices was correlated with each other in our study, we applied this analysis to generate an ergonomic score index that accounted for the use of an ergonomic mouse or peripheral input device, adjustable chair, and adjustable table. Univariate and multivariate logistic regression was performed to assess the association between RSI symptoms and the following variables: ergonomic score index, desire for ergonomic training, age, and number of hours spent working in an awkward position or number of hours spent at a computer or PACS workstation. A test for a trend in the odds of RSI symptoms with increasing age or number of hours spent working at a computer or in an awkward position was also calculated. P values and 95% confidence intervals (CIs) were generated using logistic regression or Wilcoxon signed-rank test where applicable. A P value of <.05 was considered statistically significant.

RESULTS

Table 1 lists information on the respondents' demographics and work environment. Although 80.3% (n = 584 of 727) reported that a breast-imaging workstation or PACS had been installed, only 17.7% (n = 129 of 727) were using an ergonomic mouse or peripheral input device; only 56.4% (n = 410 of 727) had adjustable tables at work, but adjustable chairs were highly prevalent (n = 667 of 727, 91.7%). A majority of respondents (n = 630 of 727, 86.6%) had not participated in ergonomic training sessions at work but expressed interest in participating (n = 534 of 630, 84.8%).

Table 2 reports the prevalence of RSI symptoms (n = 438 of 727, 60.2%) and diagnoses/treatment (n = 242 of 727, 33.3%), with the most common sites being in the neck and wrists, respectively. In a free-response textbox, respondents were allowed to report additional sites of RSI or prior treatment for a RSS; the elbow was the most common reported site.

A statistically significant trend was found for the odds of current RSI symptoms to increase with decreasing age (P = .0004), greater number of hours spent working each day (P = .0006), and greater number of hours spent in an awkward position (eg, with wrist bent, stooping; P < .0001). A significant trend was found for the association of decreasing age with working $\geq$6 hours (P < .001). Inclusion of all 3 variables in a multivariate model mildly attenuated the association between RSI symptoms and number of hours worked; the association between RSI and either age or hours spent in an awkward position remained statistically significant (Table 3).

Table 1. Demographics and characteristics of the work environment of 727 respondents

Characteristic	Number	%
Departmental position		
Resident	16 of 727	2.2
Fellow	34 of 727	4.7
Attending	677 of 727	93.1
Age (years)		
≤34	82 of 727	11.3
35-39	104 of 727	14.3
40-44	83 of 727	11.4
45-49	88 of 727	12.1
50-54	96 of 727	13.2
55-59	131 of 727	18.0
60-64	74 of 727	10.2
≥65	69 of 727	9.5
Mammography		
All digital	661 of 727	90.9
All analog	5 of 727	0.7
Both digital and analog	61 of 727	8.4
Number of hours per day spent working at a personal computer, breast-imaging workstation, or PACS		
0-4	11 of 727	1.5
>4-6	49 of 727	6.7
>6-8	253 of 727	34.8
>8	414 of 727	56.9
Number of hours per day spent in an awkward posture (eg, with wrist bent, bent at the waist leaning forward, kneeling, stooping, squatting, reaching overhead)		
0-2	302 of 727	41.5
>2-4	149 of 727	20.5
>4-6	115 of 727	15.8
>6	161 of 727	22.1
Breast-imaging workstation or PACS has been installed		
Yes	584 of 727	80.3
Own a personalized ergonomic mouse or other ergonomic input peripheral devices at work		
Yes	129 of 727	17.7
Work area has adjustable chairs		
Yes	667 of 727	91.7
Work area has adjustable tables		
Yes	410 of 727	56.4
Prior participation in an ergonomic training session at work		
Yes	97 of 727	13.3
Would be interested in participating in an ergonomic training session at work if it were available*		
Yes	534 of 630	84.8

*Number out of 630 respondents who had not previously participated in an ergonomic training session at work.

Respondents recalled a statistically significant increase in their pain level after implementation of a PACS workstation ($P < .001$). However, those who underwent ergonomic training and/or initiated use of an ergonomic mouse or peripheral input device, adjustable chair, and adjustable table reported a significant decrease in pain after these ergonomic workplace changes ($P < .001$, all comparisons), although pain was not eliminated (Table 4). Among 438 radiologists who reported RSI symptoms, 392 were currently using ≥1 ergonomic intervention (n = 392 for adjustable chair; n = 237 for adjustable table; n = 78 for ergonomic mouse; n = 64 for ergonomic training). For a unit increase in ergonomic score, respondents were 38% less likely to report RSI symptoms, even after adjusting for age and number of hours worked (odds ratio [OR] 0.62, 95% CI 0.43-0.89, $P = .009$).

Table 2. Prevalence and location of RSI symptoms and RSS diagnosis among 727 respondents

	Number	%
Frequently experience pain, stiffness, soreness, or cramping in any extremity, or the back or neck area that you feel may be related to your work tasks		
Yes	438 of 727	60.2
No	289 of 727	39.8
Select all sites of pain or discomfort related to your work tasks*		
Hands	133 of 438	30.4
Wrists	199 of 438	45.4
Neck	312 of 438	71.2
Shoulder	257 of 438	58.7
Upper back	205 of 438	46.8
Lower back	158 of 438	36.1
Lower extremities/sciatica	71 of 438	16.2
Other (please state location)	54 of 438	12.3
Elbow	29 of 438	6.6
Past diagnosis or treated for a repetitive strain or overuse syndrome, or believe they may have suffered from such a condition†		
Yes	242 of 727	33.3
No	485 of 727	66.7
Select all sites of previously diagnosed or treated repetitive strain or overuse syndrome		
Hands	48 of 242	19.8
Wrists	101 of 242	41.7
Neck	89 of 242	36.8
Shoulder	71 of 242	29.3
Upper back	49 of 242	20.2
Lower back	38 of 242	15.7
Lower extremities/sciatica	20 of 242	8.3
Other (please state location)	35 of 242	14.5
Elbow	22 of 242	9.1

RSI = repetitive strain injury; RSS = repetitive strain syndrome.
*Number out of 438 respondents who reported frequently experiencing pain, stiffness, etc. related to work tasks.
†Number out of 242 respondents who reported a past diagnosis or treatment for a repetitive strain or overuse syndrome.

Among the 630 radiologists who previously had not attended ergonomic training, those with current symptoms (OR 5.36, 95% CI 3.28-8.74, $P < .001$) or prior diagnosis/treatment for an RSS or overuse syndrome (OR 2.63, 95% CI 1.47-4.70, $P = .001$) were significantly more likely to want to participate in ergonomic training compared with those without symptoms or prior injury. These associations remained significant after adjusting for age (OR 5.01, 95% CI 3.0-8.3, $P < .0001$) and number of hours worked (OR 2.47, 95% CI 1.37-4.45, $P = .003$).

DISCUSSION

Digital imaging saves time and costs and improves efficiency [1-5], but with increasing case volumes [13,14] and longer workstation hours, radiologists may develop painful RSI symptoms that limit productivity

Table 3. Characteristics and trends associated with current RSI symptoms

Characteristic	Current RSI symptoms, n Yes	No	Unadjusted OR (95% CI)	Unadjusted *P* value	Adjusted* OR (95% CI)	Adjusted* *P* value
Age (years)						
≥60	66	77	Reference	N.A.	Reference	N.A.
50-59	138	89	1.81 (1.18-2.78)	.006	1.53 (0.95-2.46)	.08
40-49	111	60	2.16 (1.36-3.43)	.0009	1.84 (1.10-3.07)	.02
≤39	123	63	2.28 (1.44-3.60)	.0003	1.96 (1.183.25)	.009
Test of trend of odds				.0004		
Number of hours per day spent working at a personal computer, breast-imaging workstation, or PACS						
0-4	2	9	Reference	N.A.	Reference	N.A.
>4-6	24	25	4.32 (0.79-23.5)	.06	3.29 (0.57-19)	.18
>6-8	146	107	6.14 (1.27-29.7)	.01	4.12 (0.77-21.9)	.097
>8	266	148	8.09 (1.69-38.7)	.002	4.23 (0.80-22.4)	.090
Test of trend of odds				.0006		
Number of hours per day spent in an awkward posture (eg, with wrist bent, bent at the waist leaning forward, kneeling, stooping, squatting, reaching overhead)						
0-2	107	195	Reference	N.A.	Reference	N.A.
>2-4	106	43	4.49 (2.86-7.06)	.0001	4.53 (2.93-7.00)	.0001
>4-6	95	20	8.66 (4.79-15.7)	.0001	8.34 (4.86-14.3)	.0001
>6	130	31	7.64 (4.60-12.7)	.0001	7.20 (4.50-11.5)	.0001
Test for trend of odds				.0001		

CI = confidence interval; N.A. = not applicable; OR = odds ratio; RSI = repetitive strain injury.

*Multivariable logistic regression model includes the following independent variables: age, hours per day spent working, and hours per day spent in an awkward position.

[8-10,19,20,24]. RSI has been widely documented in repetitive, low-force work roles, including typist/administrative assistant, nurse, housewife, and assembly line worker [25-27], although little work has been done among radiologists [10,20]. A recent case report documented carpal tunnel and cubital tunnel syndrome among 4 radiologists [10], and a single-center study by Boiselle et al [20] showed that most of their radiologists exceeded 8 workstation hours, with >58% of respondents having RSI symptoms and 38% reporting a prior RSS diagnosis.

Our study found a similar prevalence of RSI symptoms and RSS diagnoses among breast imagers (60% and 33.3%, respectively), most commonly in the neck, wrists, and elbow, with a similar period effect as in the Boiselle et al article [20], as respondents recalled a significant increase in their pain level after PACS implementation (P = .001). However, unlike other repetitive-work field surveys that showed a higher RSI prevalence in older subjects [27], our study reports a higher RSI prevalence among younger breast imagers, possibly as a result of their longer work hours. Together, such findings underscore that long hours on PACS may be predisposing radiologists to significant RSI injuries. Furthermore, if younger radiologists continue to accumulate injury over years of PACS use, the epidemiologic age distribution of RSI may shift to older ages unless there is an intervention.

Table 4. Difference in median pain level with changes in work environment

	Median Pain (IQR) Before	After	*P* value
PACS	2.9 (1.7, 5.1)	4.05 (2, 6.2)	<.001
Ergonomic input device or mouse	6.1 (3.2, 7.7)	2 (1, 3)	<.001
Adjustable chair	5 (3, 6.8)	2.9 (1.8, 4.4)	<.001
Adjustable table	5 (3, 7)	2.1 (1, 3.55)	<.001
Ergonomic training	5.7 (3, 7.15)	3.05 (1.85, 5.1)	<.001

P value was calculated using the Wilcoxon signed-rank test. IQR = interquartile range.

The relationship between computer work and RSI has been long established [28]. A recent study reported a 43% increase in the use of radiology services after PACS implementation, which could further potentiate the risk for RSI [14]. Our study found that most recommendations on ergonomic practices and workstations [5,8,9,16,18,19], including formal guidelines from the Occupational Safety and Health Administration [29] and ANSI [6], were not being widely incorporated. Almost half of our respondents did not have adjustable tables to allow seated or standing image interpretation, even though adjustable tables have been shown to improve RSI symptoms [20]. In addition, respondents to our survey study reported a substantial pain-level decrease after table installation ($P < .001$). The prevalence and impact of use of personalized peripheral input devices or a computer mouse among radiologists had not been previously investigated, and their use was uncommon (17.7%) among our respondents, although they were reported as effective in improving pain ($P < .001$).

Such simple, inexpensive ergonomic interventions may help prevent continued or future RSI among radiologists by helping them assume neutral postures that reduce neck, shoulder, back, and wrist strain [6,8,11,29].

Proper ergonomic positioning and posture training has been endorsed repeatedly to prevent injury among radiologists working at the computer [8,20], and 80% of radiologists in Boiselle et al's study [20] reported improvement in RSS after such training. In our study, those participating in ergonomic training reported a subsequent decrease in their pain level ($P < .001$). However, most respondents had *not* participated in any ergonomic training through their job, despite a strong desire to have access to such training. The overall lack of attention to the importance of ergonomics in the workplace is concerning and may explain the high prevalence of RSI in our study. We recommend that radiologists utilize the Rapid Office Strain Assessment Checklist (Sonne et al [12]) to evaluate the ergonomics of their work environment, and follow the ANSI guidelines on interventions to prevent injury [6].

Limitations

Our study has several important limitations. This is a cross-sectional survey, so causality cannot be directly assessed. Because the data were originally collected anonymously for quality assurance purposes for the Society of Breast Imaging, we do not have any demographic data or RSI information on nonrespondents, and the demographic data on respondents are limited. Thus, it was not possible to conduct a sensitivity analysis to estimate the impact of nonrespondent bias on our results or adjust for potential demographic confounders.

The modest response rate raises concern for selection bias if respondents were more likely to participate because they had RSI. On the other hand, for nonrespondents, there is potential for worker bias because those who are no longer working or utilizing e-mail, owing to significant RSI, may have been unable to respond to this survey. Although our response rate of 28% is relatively low, it is an acceptable response rate for an e-mail-based survey, especially considering that there were no financial or other incentives for completing the survey [30-33]. In addition, the proportion of respondents exceeds that of recent e-mail-based surveys of national radiology groups, such as an 11% response rate for an e-mail-based survey of the members of the Association of University Radiologists and Society of Chairs of Academic Radiology Departments recently published in the *JACR* [33]. Moreover, the proportions of patients reporting RSI symptoms and a prior RSS diagnosis were comparable to those in a previous study [20] that gave paper surveys to a single department of radiology (achieving a higher response rate of 68%). Finally, we sampled breast-imaging radiologists, who may not be representative of practices in other fields of radiology. Future studies should assess responses across disciplines of radiology to confirm the generalizability of these results.

TAKE-HOME POINTS

- Among breast-imaging radiologists responding to this national survey, the prevalence of current RSI symptoms is 438 of 727 (60.2%), and the prevalence of prior diagnosis or treatment for a specific RSS or overuse syndrome is 242 of 727 (33.3%).
- Although 80.3% (n = 584 of 727) reported that a breast-imaging workstation or PACS had been installed, only 17.7% (n = 129 of 727) were using an ergonomic mouse or peripheral input device, and only 56.4% (n = 410 of 727) had adjustable tables at work, whereas adjustable chairs were highly prevalent (n = 667 of 727, 91.7%).
- A minority of respondents (n = 97 of 727, 13.3%) had participated in an ergonomic training session at work, but among those who had not previously participated, 84.8% (n = 534 of 630) expressed interest in participating in ergonomic training if it were available.
- There was a statistically significant trend for the odds of current RSI symptoms to increase with decreasing age ($P = .0005$), greater number of hours spent working each day ($P = .0006$), and greater number of hours spent in an awkward position (eg, with wrist bent, stooping; $P < .0001$).
- Respondents recalled a statistically significant increase in their pain level after implementation of a PACS workstation, but a significant decrease in their pain level after ergonomic training, or after use of an ergonomic mouse or peripheral input device, adjustable chair, or adjustable table ($P < .001$, all comparisons).
- Improvement in the ergonomics of the workplace of breast-imaging radiologists may help prevent RSIs among radiologists and ensure that they can provide timely and efficient patient care. Thus, we strongly recommend that radiology departments take aggressive action to prevent radiologist injury through work-based ergonomic training and ergonomic changes in the reading room.

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Musculoskeletal Symptoms Amongst Clinical Radiologists and the Implications of Reporting Environment Ergonomics—A Multicentre Questionnaire Study

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Abstract This multicentre study aimed to assess compliance of the reporting environment with best ergonomic practice and to determine the prevalence of musculoskeletal symptoms related to working as a radiologist. All 148 radiology trainees and consultants in 10 hospitals across the region were invited to complete a musculoskeletal symptoms and reporting ergonomics questionnaire. Best ergonomic reporting practice was defined, following literature review, as being able to alter the following: monitor, desk, chair and armrest height, chair back support, ambient light, and temperature. The frequency that these facilities were available and how often they were used was determined. One hundred and twenty-three out of 148 (83 %) radiologists responded, and 38 % reported radiology-associated occupational injury. Lower back discomfort was the commonest radiology associated musculoskeletal symptom (41 %). Only 13 % of those with occupational injury sought the advice of occupational health. No reporting environments conformed completely to best ergonomic practice. Where certain facilities were available, less than a third of radiologists made personal ergonomic adjustments prior to starting a reporting session. Radiologists who had good self-assessed knowledge of best ergonomic practice had significantly less back discomfort than those with poor self-assessed knowledge ($P<0.005$). We demonstrated high prevalence of musculoskeletal symptoms amongst radiologists. Poor compliance of the reporting environment with best ergonomic practice, in combination with our other findings of a low level of ergonomic awareness, low rates of making ergonomic adjustments and seeking appropriate help, may be implicated. We hope this study raises awareness of this issue and helps prevent long-term occupational injury amongst radiologists from poor ergonomic practice.

Keywords Ergonomics · Musculoskeletal pain · Occupational health · Occupational injury · Radiology

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Introduction

Clinical radiologists encounter ergonomic challenges daily; be it whilst reporting at workstations or when performing diagnostic or interventional procedures. In the era of picture archiving and communications systems (PACS), the computer workstation is a crucial component of diagnostic radiology. The Health and Safety (Display Screen Equipment) Regulations 1992 define display screen equipment as "any alphanumeric or graphic display screen" and a user as "an employee who habitually uses display screen equipment as a significant part of his normal work" [1]. The definition of a workstation also incorporates "the immediate work environment around the display screen equipment" [1]. Visual display unit (VDU) users who do not adhere to good ergonomic practice may decrease their efficiency and productivity, as well as increasing their risk of repetitive stress injury, eye strain, backache, shoulder and neck pain [2]. Such symptoms can potentially progress to long-term morbidity. For example, the inappropriate use of a computer mouse and keyboard has been linked with the development of carpal and cubital tunnel syndrome symptoms [3]. Poor ergonomic practice may also have repercussions for patients. Workstations that are not optimised for personal use result in eyestrain and fatigue. Prabhu et al. speculate that tired eyes and brains commit more errors and that by implementing certain ergonomic measures, eye fatigue can be reduced, efficiency increased and error rates in reporting minimised [4].

Regular and prolonged computer use subjects the human body to unique strains [5, 6]. Review of the literature regarding ergonomic practice reveals several facilities that should be at the disposal of the reporting radiologist in order to reduce the impact of these stresses. Eye fatigue and strain on neck muscles amongst computer users can be reduced by gazing downwards at an angle of 14° or more [4]. Consequently, the top of the visual display unit should not be above the level of the user's eyes. To achieve this, monitors and desk height should be adjustable to the user's height [7]. Computer-friendly chairs are important to maximise comfort and efficiency. Specifically, the chair and armrest heights should be adjustable to reduce upper limb symptoms, as fixed armrests are generally too low [4]. Where adjustable chair height is not available, a foot rest can facilitate good posture and reduce back pain [3]. Adjustable lumbar support on a reporting chair can also reduce the incidence of lower back pain [7].

The most comfortable temperature for sedentary work is between 20 and 24 °C (68–75 °F), with a relative humidity between 40 and 60 % [4]. However, the comfort range of temperature varies with the season. Computer workstations and monitors generate heat and raise the ambient temperature within a reporting room. The radiologist should be able to control ambient temperature and humidity with air conditioning. The relative balance between monitor light output and background reporting room lighting is an important factor in determining the degree of radiologist fatigue, as well as efficiency and accuracy [8]. Reiner et al. assessed the impact of luminance in interpreting radiographs and found a subjective increase in the observed level of confidence of interpretation as monitor brightness increased [9]. Furthermore, monitor brightness was inversely proportional to reporter fatigue [9]. On-off light switches should be located near each workstation, ideally with individual dimmers to enable users to adjust the lighting depending on the task being performed [3]. Consideration should also be given to screen shields that reduce screen glare, especially on older monitors [2].

Prabhakar et al. surveyed the prevalence of musculoskeletal symptoms and working practices amongst 28 radiologists at a single American institution [10]. Siegel et al. conducted a multicentre study of seven sites from around the world regarding radiologists' opinions on factors that promote radiology productivity in the soft-copy reporting environment [11]. Boiselle et al. looked at repetitive stress symptoms amongst radiologists in a single American institution [12]. However, to date, no study has quantified the adherence of the reporting environment in routine clinical practice with best ergonomic practice or explored the types of advice radiologists sought for the treatment of occupational-related musculoskeletal symptoms. We aim to address these issues in our multicentre cross-sectional study.

Methods

Participants

Ethical approval was not necessary for this questionnaire-based survey [13]. The paper-based questionnaire was distributed to all clinical radiologists; both consultants (faculty and senior radiologists) as well as registrars and fellows, working in the following ten teaching and district general hospitals in the Severn Deanery: Bristol Children's Hospital, Bristol Royal Infirmary, Cheltenham General Hospital, Frenchay Hospital (Bristol), Gloucester Royal Hospital, Great Western Hospital (Swindon), Musgrove Park Hospital (Taunton), Royal United Hospital (Bath), Southmead Hospital (Bristol) and Weston General Hospital. Eligible participants were all radiologists (consultants and trainees) working at the time of the survey.

Questionnaire

A paper-based questionnaire was devised following review of the literature and scrutiny of established and validated questionnaires for the analysis of musculoskeletal symptoms, including The Nordic pain questionnaire [14] and the Saskatchewan Health and Back Pain Survey [15]. The questionnaire was piloted amongst radiologists at Southmead Hospital. The questionnaire was amended and then distributed to all radiologists working in the institutions within the Severn Deanery. The questionnaire was broadly divided into three components as follows: (a) background demographic information, (b) personal musculoskeletal symptoms/occupational injury resulting from working as a radiologist and the type of treatment sought for these ailments, and finally (c) compliance of reporting environments with best ergonomic practice. The survey was conducted over a 2-month period between June and July 2011. A covering letter attached to the questionnaire instructed respondents to only report musculoskeletal symptoms that they felt were directly attributable to working as a radiologist (e.g. to exclude symptoms relating to previous injuries sustained outside of the radiology workplace and include symptoms that occur or worsen during the working week and symptoms that resolve during holidays).

Statistical Analysis

Data from the survey were entered into Microsoft Excel (Microsoft Corp., Seattle, WA, USA). Statistical analysis by unpaired two-tailed chi-squared test was performed using GraphPad Prism (GraphPad Software, San Diego, CA, USA). Significant levels were set at $P<0.05$.

Results

Of the 148 subjects who were invited to participate, 123 (83 %) responses were received. The majority of respondents were male (68 %), consultants, aged between 36 and 45 years and worked full time (Table 1).

Prevalence of Musculoskeletal Symptoms

Forty-six out of 120 (38 %) respondents considered themselves to suffer or have suffered from an occupational injury that they attributed to working as a radiologist, and 8/46 (17 %) of those respondents who had suffered an occupational injury required time off work due to the injury. The length of time off work ranged from 1 day to 6 months. Three respondents required surgical invention for their injury (two microdiscectomies and one subacromial shoulder decompression). The most common occupational injury symptom caused by working as a radiologist was lower back pain, present in 51/123 (41 %) respondents (Table 2).

Significantly fewer respondents aged <55 years suffer/have suffered with neck pain from working as a radiologist, compared with those aged >56 years (24/106 (23 %) vs. 5/12 (42 %), $P<0.001$).

Table 1 Descriptive statistics for survey group

Characteristic	Value n (%)	Characteristic	Value n (%)
Gender		Work pattern	
Male	84 (68 %)	Full time	104 (86 %)
Female	37 (30 %)	Part time	19 (14 %)
No response	2 (2 %)	No response	0 (0 %)
Age		Experience	
24–35	30 (24 %)	1st year trainee	10 (8 %)
36–45	40 (33 %)	2nd year trainee	6 (5 %)
46–55	36 (29 %)	3rd year trainee	4 (3 %)
56–65	12 (10 %)	4th year trainee	6 (5 %)
>65	0 (0 %)	5th year trainee	4 (3 %)
No response	5 (4 %)	Fellow	0 (0 %)
		Consultant	93 (76 %)

Table 2 Prevalence of occupational injury symptoms ($n=123$)

Symptom(s) induced by working as a radiologist	%
Eye sensitivity to glare	14
Eye discomfort	17
Neck discomfort	25
Lower back discomfort	41
Shoulder discomfort	27
Elbow discomfort	7
Wrist discomfort	20
Hand discomfort	12

Sources of Advice/Treatment for Work-Related Musculoskeletal Symptoms

Of those who had suffered an injury, 6/46 (13 %) consulted occupational health and 11/46 (24 %) sought no help or advice. The sources of help and the frequencies at which they were consulted are detailed in Table 3.

Of the 74/120 (62 %) who did not classify themselves as having suffered with an occupational injury, 41/74 (55 %) suffer or had suffered with at least one symptom which they attributed to working as a radiologist and 6/74 (8 %) had sought advice from a healthcare professional regarding their occupation-induced symptoms.

Compliance with Best Ergonomic Practice

Seventeen out of 122 (14 %) felt they have received formal training on making ergonomic adjustments to their working

Table 3 Frequency of consultation of sources of help for those respondents with occupational injury. Some individuals sought the advice of multiple 'other' sources ($n=46$)

Source of help	%
Occupational health doctor	13
No help	24
Other	
General practitioner	20
Orthopaedic surgeon	9
National Health Service physiotherapist	20
Private sector physiotherapist	13
Private sector chiropractor	11
Radiology colleague	24
Self-help (e.g. internet research)	22
Miscellaneous	11

environment. When asked to score their level of agreement with the statement "I understand what best ergonomic practice is" on a seven-point Likert scale (where 1=strongly disagree and 7=strongly agree), the mean response was 3.9 (mode=5, median=4; n=118).

Subgroup analysis of respondents who had not suffered an occupation injury was conducted to assess the impact of ergonomic knowledge on musculoskeletal symptoms. Respondents with prior occupational injury were excluded as their ergonomic knowledge may have been affected by subsequent occupational health input. Those respondents who scored 6 or 7 where defined as having good ergonomic knowledge. Those who responded who gave a score of 0 or 1 were defined as having poor ergonomic knowledge. Comparison of the prevalence of musculoskeletal symptoms amongst these cohorts is described in Table 4.

Fifty-seven out of 123 (46 %) of respondents work on average 1–2 h at a PACS workstation without a break, and 65/122 (53 %) had worked in excess of 3 h at a workstation without a break within the last month (Table 5).

The compliance of the working environment with best ergonomic practice is detailed in Table 6. The ability to alter chair height (98 %) and ambient light (83 %) were the most common ergonomic facilities at the radiologist's disposal. The other facilities were not as widely available. No workstation complied completely with best ergonomic practice. Where certain ergonomic facilities were available, adjustments were only routinely made to ambient light (73 %), ambient temperature (79 %) and chair height to a lesser degree (58 %). Ninety-two out of 119 (77 %) felt that an annual ergonomic review with occupational health should be available for radiologists.

Discussion

In this multicentre study, we have quantified the prevalence of musculoskeletal injury amongst consultant and trainee radiologists, explored the types of help sought for such symptoms and determined the adherence of reporting environments to best ergonomic practice. We found that occupational injury was self-reported in 38 % of respondents. Boiselle et al. noted a prevalence of 58 % of repetitive stress symptoms amongst faculty members, fellows and residents in a single American radiology department [12]. Their response rate was 68 % (73/107) compared to our 83 % (123/148).

The prevalence of occupational injury in our cohort may be underestimated, as 55 % of those respondents who did not classify themselves as formally having or having had an occupational injury did describe musculoskeletal symptoms which

Table 4 The prevalence of musculoskeletal symptoms in respondents with good ergonomic knowledge (n=7) compared with those with poor ergonomic knowledge (n=7)

Musculoskeletal symptom	Ergonomic knowledge % Good	% Poor	P value
Neck discomfort	14	14	=1.0
Back discomfort	0	71	<0.005
Shoulder discomfort	0	14	=0.3370
Elbow discomfort	0	14	=0.3370
Wrist discomfort	0	14	=0.3370

Table 5 Average and maximum uninterrupted reporting time at a PACS workstation

Time spent reporting at PACS station without a break (hours)	%
Average time (n=123)	
<0.5 h	3
0.5–1 h	16
1–2 h	46
2–3 h	25
>3 h	10
Maximum time within last month (n=122)	
1–2 h	21
2–3 h	26
>3 h	53

Table 6 Compliance with best ergonomic practice

Best ergonomic practice	% Yes
At my workstation, there is the option to alter:	
Computer monitor height (n=121)	55
Desk height (n=121)	2
Chair height (n=121)	98
Chair back support (n=121)	61
Chair armrest height (n=121)	25
Ambient light (n=121)	83
Ambient temperature (n=121)	60
When available, I routinely alter:	
Computer monitor height (n=67)	19
Desk height (n=3)	67
Chair height (n=118)	58
Chair back support (n=74)	28
Chair armrest height (n=30)	13
Ambient light (n=101)	73
Ambient temperature (n=72)	79
The following are at my disposal:	
Computer screen shield (n=122)	4
Foot rest (n=122)	3
Wrist support mouse mat (n=122)	23
Hands-free dictation (n=122)	32

they attributed to working as a radiologist. This may be because of lack of insight into the fact that their symptoms constituted an occupational injury. Such lack of recognition has previously been described amongst visual display unit users by Robertson et al. [16]. Raising awareness of the issue, followed by ergonomic training, significantly reduced self-reported musculoskeletal pain in this study [16].

Lower back discomfort was the most common symptom amongst our cohort, occurring in 41 %. However, lower back discomfort is a very common musculoskeletal symptom. The lack of a suitable age- and sex-matched control group of individuals who are not in employment for comparison means that we cannot conclude that working as a radiologist has a direct causal effect on the prevalence of the musculoskeletal symptoms documented. Furthermore, direct comparison of our results with other general musculoskeletal symptom data in the published literature is difficult due to the lack of consistency in definitions of symptoms, as well as different prevalence endpoints for musculoskeletal symptoms, e.g. point, annual or life time prevalence, between studies. In addition, we assessed for musculoskeletal symptoms that respondents attributed directly to working as a radiologist which represents a discrete prevalence subset, separate to lifetime prevalence. Nevertheless, our results are in keeping with a study from Prabhakar et al. who found similar results, with lower back pain described in 39 % in a survey of American radiologists [10].

It is important to realise that whilst lower back discomfort was the most commonly reported symptom, several serious work-related injuries were also described by the cohort. Seventeen percent of respondents who had suffered an occupational injury required time off work as a consequence. The length of time off work ranged from 1 day to 6 months, with some serious injuries requiring surgical treatment. Such sick leave has cost implications to radiology departments and may impact on workflow. Any potential short-term costs incurred to improve reporting environments ergonomics must be weighed against the potential costs of long-term radiologist sick leave resulting from poor ergonomic reporting practice.

Those aged under 55 years were significantly less likely to suffer from neck pain compared to their colleagues older than 55 years. A potential explanation might be the previous practice of continually changing films during hard copy reporting sessions by the older generation of radiologists. However, the fact that the majority of those surveyed (57 %) were aged less than 45 years and several junior trainees had suffered occupational injury despite only working as radiologists for a short duration is important. If this issue is not dealt with, there is a strong possibility of recurring problems during their radiology careers.

Of those with radiology-induced occupational injury symptoms, only 13 % sought the advice of occupational health. Other sources of help such as radiology colleagues and the internet were consulted with greater frequency. This could lead to inappropriate management. Yet, the vast majority of respondents (77 %) agreed that an annual occupational health review should be at the disposal of all radiologists. This opportunity may abrogate both the issues of not recognising the symptoms as occupational-related injuries and ensuring appropriate individualised workplace modifications are made to reduce the burden of occupational injury.

The majority of radiologists worked for longer than 1 h at a PACS workstation without a break, and 53 % had worked continuously for longer than 3 h at a PACS workstation in the last month. This finding is important as it has been documented that the main factor determining visual fatigue in a PACS user is the amount of time spent viewing display units [4]. We found that nearly half (46 %) of respondents work without a break at a PACS workstation for 1–2 h, which is in keeping with work by Siegel et al. who found that the median time spent at a workstation without taking a break in an American study was 1.5 h [11]. Boiselle et al. report that 68 % of radiologists worked for more than 8 h per day at a personal computer or PACS monitor [12]. It is recommended that people working at computer monitors should get up and stretch at least every half an hour [4]. Alternatively, it has been suggested that PACS users should look 20 ft away from their computer screen for 20 s every 20 min [3]. However, this would equate to 8 min of lost reporting time per day per radiologist, assuming they report for 8 h a day, or the equivalent of 2 h and 40 min lost reporting time in a Department of 20 radiologists.

We found that no working environments conformed completely to best ergonomic practice, in terms of being able to alter the monitor, desk, chair and armrest height, chair back support and ambient light and temperature. These shortcomings may contribute to the high prevalence of musculoskeletal symptoms amongst radiologists in our study. However, even where certain ergonomic facilities were at the radiologist's disposal, adjustments prior to reporting were made infrequently, with the exception of adjusting ambient light and temperature. The ability to alter desk height was only at the disposal of three radiologists; one routinely reported standing up, one optimised desk height for reporting sitting down and the other did not routinely make use of this facility. The user interface of computer mouse and keyboard is a key element; only 3 % of respondents (4/123) had personalised equipment in this regard, e.g. tracker ball mouse or optimised smaller keyboard.

The low level of awareness of radiologists regarding best ergonomic practice and the apparent lack of training of how to make ergonomic adjustments in 86 % may be important in this regard. Robertson et al. demonstrated that self-reported musculoskeletal pain and discomfort can be significantly reduced with ergonomic training amongst VDU users [16]. Awareness is the important first step and appears to be lacking amongst our cohort, and we hope this study will raise the awareness of this issue amongst other radiologists. In our study, the fact that the respondents with good self-assessed ergonomic knowledge suffered with significantly less lower back discomfort than those with poor knowledge supports this notion.

There are some limitations of our observational study. This was a cross-sectional study and, as previously alluded to, we cannot definitively comment on causal relationships between the musculoskeletal symptoms and reporting environment ergonomic facilities, or lack thereof. A potentially confounding issue is whether respondents had any prior medical problems predisposing them to musculoskeletal symptoms. Detailed questions in this regard were considered for the questionnaire. However, the feedback received from our pilot study was that such questions were too intrusive and would dissuade people from participating in the survey. The decision was taken to remove these questions but reiterate, on both the questionnaire and an accompanying covering letter, we were looking for respondents to only disclose symptoms that they attributed to working as a radiologist. Furthermore, detailed studies of prevalence of musculoskeletal symptoms have previously been conducted and published. We wanted to ensure as good a response rate as possible to assess compliance of reporting environments with best ergonomic practice and the types of advice for occupational injury that are being sought, which have not been reported before to the best of our knowledge. We subsequently achieved an impressive response rate of 83 %. Ultimately, regardless of whether the musculoskeletal symptom(s) experienced are a de novo work-related phenomenon or an exacerbation of a pre-existing injury, they should be addressed in the same manner at work with appropriate ergonomic interventions. In fact, if a radiologist were to suffer from a potential pre-existing injury that could be aggravated by poor ergonomic practice, there would be even more reason to ensure their reporting environment complies with best ergonomic practice.

Finally, the study population was confined to a region of the UK. However, we believe the radiological practice sampled broadly reflects current modern radiology practice. Nevertheless, responder bias within our cohort is still possible. In particular, those who have suffered occupational injury may have felt more compelled to complete the questionnaire than the 17 % who did not. An argument could be made that our self-reported data are subject to perceptive error, and that different data may have been gathered from occupational health records. However, very few respondents actually sought occupational health advice; furthermore, previous questionnaire studies have demonstrated good agreement between self-reported and documented illness [17]. We have relied upon the respondents' reports of the ergonomic facilities at their disposal, which may also be subject to recall bias.

Conclusion

In this multicentre study, we found a high prevalence of self-reported musculoskeletal symptoms and occupational injury amongst radiologists and poor compliance of the reporting environment with best ergonomic practice. Whilst it is impossible to be categorical on the basis of a cross-sectional study, our results imply that the aetiology of occupational injury is likely to be multi-factorial including paucity of ergonomic facilities, not personalising those facilities available, lack of training, long reporting sessions and not recognising symptoms as occupational injuries. Poor ergonomic practice impacts directly on radiologists by causing injury. It may also have implications for patients, and it is postulated that reporting under poor ergonomic conditions increases radiologist fatigue and causes more reporting error. Although further work is still required in this area, we hope our study raises awareness of this important issue amongst radiologists in order to recognise musculoskeletal symptoms as potentially associated with their work and to seek advice through the appropriate occupational health channels to ensure that optimal ergonomic improvements are made to their reporting environment.

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