

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

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].

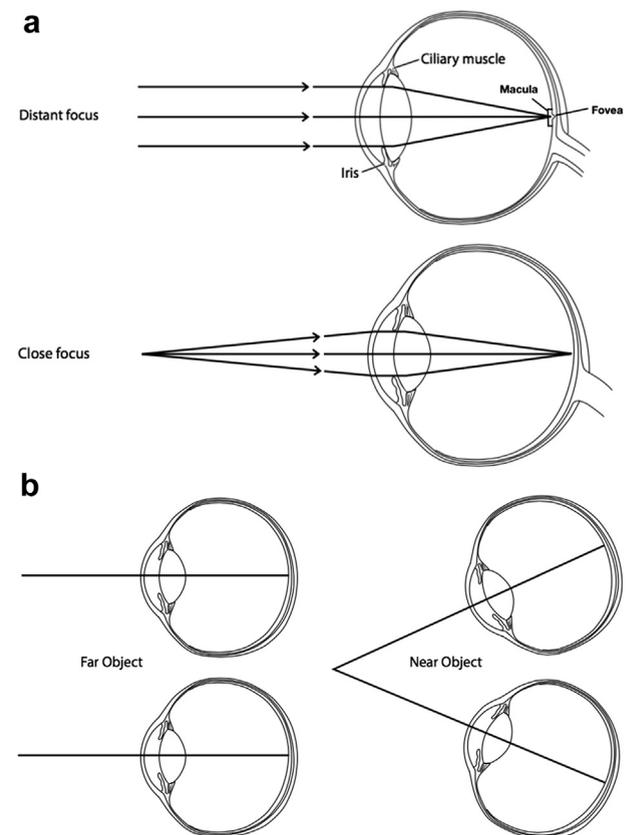
### VISUAL FATIGUE

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].

Ruutinen 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].

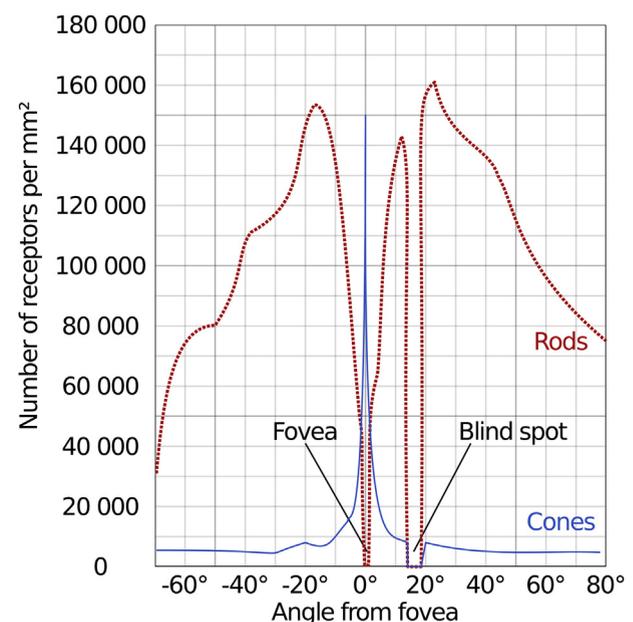
In clinical practice, attending radiologists operate without defined work hours and can choose shifts and work hours that do not optimize their performance. Furthermore,

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.

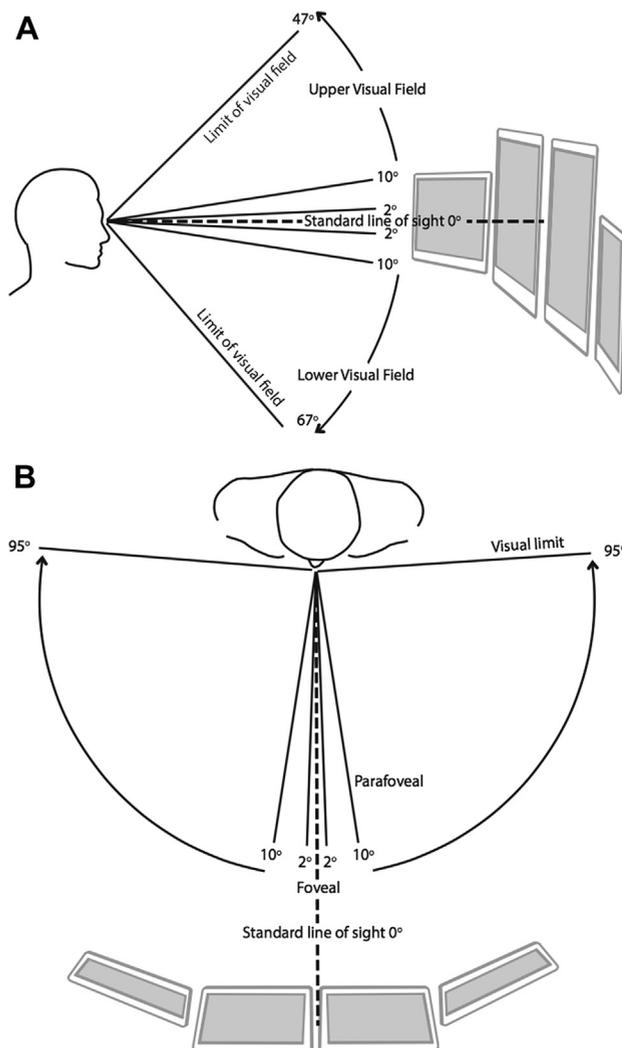
## OCULOMOTOR DYNAMICS AND SCENE ANALYSIS

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

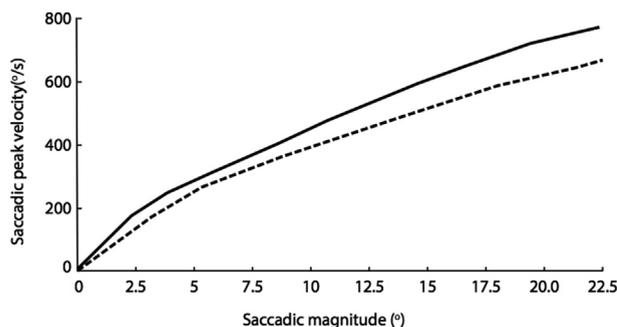
Errors in image interpretation have been recognized since the seminal works of Garland in 1949 [32]. Inadequate and erroneous perception are the primary etiologies for these mistakes [33]. The estimated interpretive error rate in a mix of normal and abnormal cases averages 3.5% to 4%. However, when the 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

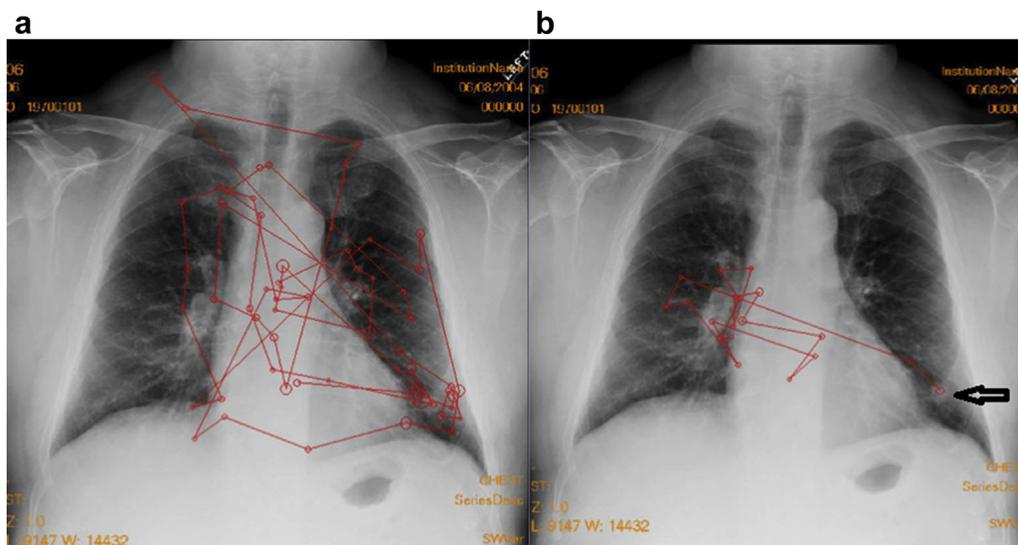
The analysis of search patterns (scanpaths) has provided insight into the nature of expertise (Fig. 5) and, similarly, can determine how fatigue affects specific elements of search [27,43-45].

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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