European Journal of Radiology 59 (2006) 257–264

EJR
EUROPEAN JOURNAL OF RADIOLOGY

www.elsevier.com/locate/ejrad

Thin-section CT of the lungs: Eye-tracking analysis of the visual approach to reading tiled and stacked display formats

S.M. Ellis [a,d,*], X. Hu [b,d], L Dempere-Marco [b,d], G.Z. Yang [b,d], A.U. Wells [c,d], D.M. Hansell [c,d]

[a] *Department of Radiology, London Chest Hospital, Bonner Road, London E2 9JX, United Kingdom*
[b] *Department of Computing, 180 Queen's Gate, South Kensington Campus Imperial College, London SW7 2AZ, United Kingdom*
[c] *Department of Respiratory Medicine, Royal Brompton Hospital Sydney Street, London SW3 6NP, United Kingdom*
[d] *Department of Radiology, Royal Brompton Hospital, Sydney Street, London SW3 6NP, United Kingdom*

Received 10 August 2005; received in revised form 10 May 2006; accepted 17 May 2006

Abstract

Objective: To use eye-tracking analysis to identify the differences in approach to and efficiency of reading thin-section CT of the lungs presented tiled and stacked soft-copy displays.
Materials and methods: Four chest radiologists read 16 thin-section CT examinations displayed in either a tiled (four images at once) or stacked (full screen cine) format. Eye-movements were recorded and analysed in terms of movement type; saccade distance (classified by the calculated range of useful peripheral vision), number of fixations, duration and direction of gaze—comparison of the areas of the images viewed.
Results: Cases presented in stacked format were read quicker than when presented in tiled format with a greater fixation frequency (5 fixations versus 4.5 fixations points per 100 data points; $p < 0.001$) and a greater proportion of short saccades (97% versus 94%; $p < 0.005$). The consistency with which the observers viewed equivalent areas of the scan images in different cases was greater when viewing in stacked format (mean kappa 0.45 versus 0.36; $p < 0.05$) suggesting a more systematic approach to reading.
Conclusion: Eye-tracking data demonstrates why thin-section CT examinations of the lungs are read more efficiently when displayed in a stack as opposed to a tiled format.

Keywords: HRCT; Eye-tracking; PACS

1. Introduction

The proportion of radiologic image reading that is performed directly from a computer screen ('soft copy' reporting) as opposed to that performed from film ('hard copy' reporting) has dramatically increased [1]. Computing power and monitor quality have developed to the extent that the comparison of reporting efficacy of CT images between viewing hard and soft copy images [2] is no longer an issue, and attention has now turned towards the optimal way of viewing images in terms of workstation design [3], including the size and number of images that should be displayed at any one time [4]. An inherent advantage of a stacked, as opposed to a tiled, display format for reading contiguous images of a 3-D volume, has been demonstrated in terms of reporting accuracy and viewing speed [5]. However, the relevance of this observation to non-contiguous thin-section CT imaging is uncertain as features that traverse multiple images may present on adjacent images in distinctly different positions.

Modern eye-trackers enable the non-obtrusive assessment of workstation presentation ergonomics to be analysed in terms of eye-movements [6]. The characterisation of eye-movements involves assumptions as to the cognitive and subliminal processes underlying them including the influence of peripheral vision. In order to identify eye-movements that may be guided by peripheral vision, the range of peripheral vision for a given task needs to be assessed.

It is assumed that a more ordered and therefore efficient approach to reading an image will be reflected by a greater proportion of short saccadic eye movements either directed by a system of search or by useful peripheral vision. A more chaotic approach to reading would result in a greater number of large saccadic movements between fixations.

* Corresponding author at: Department of Radiology, London Chest Hospital, Bonner Road, London E2 9JX, United Kingdom. Tel.: +44 2089832473; fax: +44 2089832231.
E-mail address: Stephen.ellis@bartsandthelondon.nhs.uk (S.M. Ellis).

0720-048X/$ – see front matter
doi:10.1016/j.ejrad.2006.05.006

A structured approach to reading CT images will be reflected in the consistency with which the most important areas of the image are viewed. Such areas may relate to specific abnormalities found in that case but others will relate to the anatomical structures that tend to be affected by the disease process being hypothesised by the reader. This may alter according to the characteristics of a given disease. The direct comparison of spatial data between different cases is impossible due to varying anatomy. The mapping of spatial data onto a calculated 'normal' template, retaining the anatomical features present, allowed a more accurate comparison of spatial data between cases from different patients. No attempt was made to identify the areas the reader considered most important as the experiment was designed around comparing reader approach rather than identifying the features each reader found significant.

1.1. Experiments and aims

1. An initial experiment to determine to what extent the readers used in this study could discern contrast and fine detail entirely from their peripheral vision.
2. Recording of the eye-movements of the readers whilst reading thin-section CT scans in one of two different display formats to explain differences in reader approach due to display format
3. Comparison of where on the CT images the readers looked by mapping the eye tracking data onto a standardized stack of CT images generated by combining 24 normal thin-section CT scans. To determine whether the areas viewed are consistent and whether display format has an impact on this consistency.

2. Materials and methods

Four experienced chest radiologists with experience ranging from 10 to 27 years read a selection of 16 thin-section CT examinations of the chest on a 22 in. diagonal high contrast 100 Hz multisync computer monitor. The analysis of the observers' eye-movements required that the examinations be read in an environment designed around an eye-tracking camera that kept natural light to a minimum. A chin rest 70 cm from the computer monitor was used to stabilize the head position to aid the eye-tracking process.

2.1. Eye-tracking

The eye-movements of the observers were recorded using an ASL500 remote eye-tracking system (Applied Science Laboratories, MA). The system used infrared light to illuminate the eye and identified reflections from the cornea, called the 'glint', and the retina through the pupil. The relative position of the 'glint' to the centre of the pupil gave a measure of the direction of gaze of the eye and was calculated in real time during the experiment (resolution 0.25° visual angle, accuracy 0.5° visual angle). Calibration was performed by recording the calculated direction of gaze as the observer fixated each of nine specified points on the computer monitor. Proprietary software was used to synchronise the eye-tracking data with the CT image being displayed and this superimposition was displayed and updated in real time to ensure there was not drift in the calibration.

2.2. Calculating useful peripheral vision

Five images were created in a painting program (Paint Shop Pro 5.12, Jasc, MN) which displayed a uniform background of typical lung parenchyma taken from thin section CT images; on these were superimposed bronchiectatic airways or mosaic attenuation using a Clone Brush facility (a function that enables the copying of a section of one picture to another). The absence of a normal parenchymal background could have artificially enhanced the observer's peripheral vision-based detection [7]. Five images were created in this fashion, three containing bronchiectatic airways and two containing mosaic attenuation (Fig. 1). Each image was divided by a horizontal and a vertical line into four quadrants and the distance from the centre of the image to the cloned abnormality differed between quadrants. The images were designed to test the extent of useful peripheral vision in identifying fine detail (mildly bronchiectatic airways)

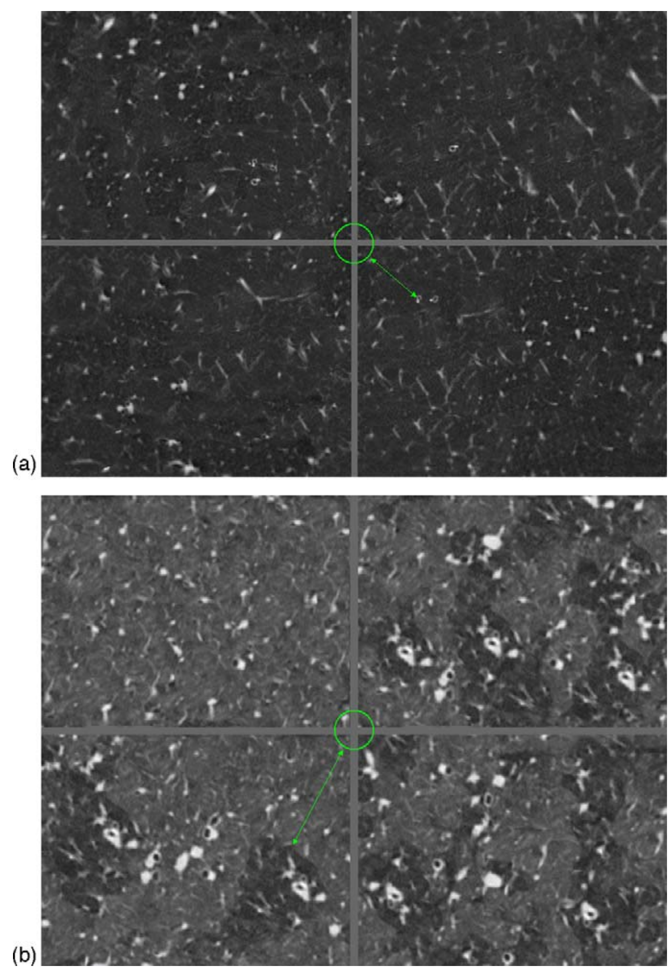

Fig. 1. Images generated in a graphics program using a clone brush function. (a) Bronchiectasis; (b) mosaic attenuation at varying distances from a central point. The central circle defines the area in the centre of the image into which the eye must be tracked for the image to be visible. The distance to the abnormality in each quadrant is calculated from the edge of the central circle as indicated (double headed arrow).