Eye-Tracking Device Comparisons of Three Methods of Magnetic Resonance Image Series Displays

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This study evaluated the effectiveness of three kinds of display methods for magnetic resonance (MR) image interpretation using an eye-tracking device. Seven radiologists interpreted head MR studies by using a single monitor (17-inch, 1,024 × 1,280 bit) in the 4 images/screen display format. Three paging modes were compared: (A) rapid paging only, (B) multiple image series display at the same slice position with consecutive rapid paging, and (C) simultaneous display of multiple series with each image series being browsed independently. Using an eye-mark camera, the radiologist's point of fixation and the duration of fixation were recorded during actual image interpretation. In mode A, the duration of fixation was short, and the points of fixation were distributed randomly over the visual field. In mode B, the points of fixation were clustered chiefly on a specific image series. In mode C, the points of fixation were not clustered on a specified series, but the duration of viewing the T2 series was relatively long. The total tracing area in mode B and C was smaller than that in mode A. Multiple series display, in which selected key series of slices could be viewed effectively, was found to be suitable for MR image interpretation.

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KEY WORDS: picture archiving and communications system (PACS), image interpretation, magnetic resonance imaging (MRI), cathode ray tube (CRT) display.

THE DISPLAY METHOD is a key issue in the use of a cathode ray tube (CRT) viewing station in daily clinical practice.¹⁻² For primary computed tomography (CT) interpretation, we have previously reported on a conventional browsing mode providing rapid paging in combination with the "cut-and-save" of key images.³⁻⁴ Using this display mode, serial CT images can be viewed like a roll of film. It was found to be very useful for viewing CT images, but not acceptable for magnetic resonance (MR) image interpretation because MR studies contain more complex image series than CT examination.³ For MR image interpretation, comparison among several image series (different pulse sequences, different slice planes, with or without contrast enhancement) is frequently required.

Recently, another display method that permits the simultaneous display of several related image series on a single CRT monitor has been developed in our system.⁴ The study discussed in this article

evaluated the effectiveness of then conventional single series browsing mode and two multiple series display modes using an eye-tracking device.

MATERIALS AND METHODS

A commercially available CRT viewing station, TWS-860 (Toshiba Corp, Tokyo, Japan) was used in this study. The viewing station had six monitors (17-inch, 1,024 × 1,280 × 8 bits). By using an eye-tracking device, three kinds of display methods were compared: (1) mode A (conventional browsing mode), which provides rapid serial paging of a single image set and in which all images are consecutively displayed like a roll of film (Fig 1); (2) mode B (synchronized), which permits simultaneous display and paging of multiple image series locked at the same slice position; and (3) mode C (asynchronized), in which multiple image series were displayed simultaneously but with independent paging of each image series. In both mode B and mode C, T1-, T2-, and proton density-weighted images can be displayed at the same time on a single monitor (Fig 2). Multiple series display mode has been developed as a special testing mode for our system but is not commercially available.

Seven radiologists interpreted head MR studies with 4 image series in modes A, B, and C by using a single CRT monitor. Their clinical experience ranged from 2 to 13 years, and 5 radiologists were board-certified. MR images studied were three cases of brain tumor and three cases of cerebral infarction. All cases had typical findings, and the radiologists were able to identify the abnormalities easily. Each study included axial T1-weighted images, T2-weighted images, and proton density images. The number of images per case ranged from 48 to 64. The room illumination was variable, but kept at 170 lux on the console desk. The distance from the eye to the CRT monitor was between 45 and 75 cm. To record the movement of the eye-spot position, the eye-mark system EMR-7 (Nac Co, Tokyo, Japan) was used. The observer wore the device on the head, and an infrared light-emitting diode light source (950 nm wavelength) projected a spot of light onto the cornea. The reflected spot was detected by a metal-oxide semiconductor (MOS) image device, and the eye-spot position, ie, the radiologist's actual point of fixation, was identified. The observer's visual field was moni-

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Fig 1. Conventional browsing mode. Note that all the images are consecutively displayed like a roll of film by dragging the mouse. (A) Four images per screen and (B) one image per screen.

tored by means of a charge-coupled device (CCD) camera fixed to the forehead, and the eye-spot position was displayed on the TV monitor as a bright box-cursor superimposed on the image of the visual field. The unit's field of view was 60° in the horizontal direction and 45° in the vertical direction. While allowing free head movement, the EMR-7 provided tracking accuracy of within 1° in the horizontal direction and about 3° in the vertical direction.⁵

To maintain tracking accuracy, observers tried to minimize head movement during interpretation, and periodic calibration checks were performed. The eye-mark was recorded on videotape from the beginning to the end of reading (reporting process not included). For calibration of the eye tracker, the center of the visual field was adjusted to correspond to the center of the monitor. Eye movement was analyzed by using a data processing unit, V-714 (Nac Co, Tokyo, Japan), and a personal computer, PC9800 (NEC Co, Tokyo, Japan). Tracings of the eye-spot at 30 frames per second and the duration of fixation were obtained. The definition of "fixation" was when the eye-spot position was concentrated within $2^\circ/100$ ms. Reading times for one case and for each pulse-sequence were obtained by reviewing the videotape.

RESULTS

Table 1 summarizes time measurements in each display method. The average reading time required

to interpret one case in mode B and C was relatively shorter than that in mode A. Table 2 shows the average reading time ratio for each pulse-sequence.

Figures 3, 4, and 5 show examples of the distribution of the points of fixation for one observer in each display mode. The size of the circle (Figs 3A, 4A, and 5A) indicates the duration of fixation. The larger the circle, the longer the duration. Three-dimensional graphs (Figs 3B, 4B, and 5B) show the density of points of fixation corresponding to Figs 3A, 4A, and 5A. Here, the visual field was divided into a 60×60 grid; the higher the column, the higher the fixation frequency. Each column indicates the number of the points of fixation within a 3×3 degree of the visual field.

In mode A, the duration of fixation was short, and the points of fixation were distributed randomly over the visual field (Fig 3). On the other hand, in mode B the points of fixation were clustered chiefly on a certain series (usually, on

Fig 2. Multiseries display mode for MR image interpretation. Multiple image series can be viewed at one time on a single CRT monitor. Each series can be browsed synchronously (mode B) or asynchronously (mode C).

Table 1. Average Reading Time for 1 Case

Display Mode	Average Reading Time in Seconds	Range in Seconds
A: Conventional browsing	80	30-132
B: Synchronized	58	32-99
C: Asynchronized	61	29-144

T2-weighted images). The frequency of viewing the other image series was low (Fig 4). In mode C, the points of fixation were not clustered on a certain series. The duration of viewing the T2 series was relatively long (Fig 5). The total tracing area in mode B and mode C was smaller than that in mode A.

With regard to visual search patterns, three major types were noted as follows:

- (1) Radiologists viewed all images in a sequential manner as they were displayed on the monitor. This “over viewing” pattern was usually noted in mode A.
- (2) Radiologists started MR image interpretation by scanning a certain image series (proton density-weighted images for 3 observers, T2-weighted images for 3, and T1-weighted images for 1) and fixated on several images that were attractive. Subsequently, other image series were viewed for analyzing abnormalities detected on the initially interpreted series. This pattern was noted in 5 of 7 radiologists in mode B and in all radiologists in mode C. This type could be regarded as the typical scan pattern in the multiple series display mode.
- (3) Radiologists compared images acquired using different pulse sequences at the same slice position from the first to the last image. Then, they concentrated on several slices showing abnormal findings. Two radiologists showed this type of reading process in mode B. All observers found multiple series display mode (especially, mode B) more comfortable than mode A because the differ-

Table 2. Average Reading Time Ratio for Each Pulse-Sequence

Pulse-sequence	Mode A	Mode B	Mode C
	Conventional Browsing	Synchronized	Asynchronized
T1-weighted	26.6%	15.7%	33.7%
T2-weighted	38.5%	60.8%	32.8%
Proton density-weighted	32.9%	23.5%	33.5%

Fig 3. Conventional browsing mode. The duration of fixation was short (A), and the points of fixation were distributed randomly over the visual field (B).

Fig 4. Multiseries display mode, synchronized (mode B). (A) The points of fixation were clustered chiefly on a certain series (usually, on T2 weighted images). (B) The frequency of viewing the other image series was low.

Fig 5. Multiseries display mode, asynchronous (mode C). (B) The points of fixation were not clustered on a certain series, but the duration of viewing the T2 series (A) was relatively long.

ent image series could be viewed at one time.

DISCUSSION

In modern Radiology departments, the number of image interpretations in a picture archiving and communication system (PACS) environment has grown. Reducing stress and increasing work efficiency at the CRT viewing station is highly desirable, and progress has been made toward establishing the optimal display format from the viewpoint of ergonomics. Recently, a sufficient degree of efficiency has been achieved to permit the use of CRTs in daily clinical practice.¹⁻⁴ However, there are several problems to be overcome in interpreting studies with multiple sets of images.

Operating the system can itself disturb the concentration of the reader during interpretation. Many radiologists still prefer film reading to CRT reading. For this reason, the workstation display method should be designed on the basis of the reading process and should be as simple as possible.⁴ Total

eye movement during interpretation and room illumination should be related to the subjective degree of eye fatigue.⁵⁻⁶ Eye fatigue is essentially a subjective phenomenon, and is difficult to evaluate quantitatively. However, eye movement can be analyzed with an eye-tracking device, and detailed analysis of the radiologist's visual search patterns is an essential requirement in establishing the optimal display format.⁶

In mode A, repeated paging among several clusters of different image series was required. On the other hand, in modes B and C, selected key series of slices could be viewed effectively, and total eye movement was reduced compared with mode A.

Eye fatigue should be more serious when the points of fixation are spread over the visual field,⁶ and, therefore, all radiologists in our study believed that the multiple series display mode was more comfortable than mode A. Mode B should be best because it provides simultaneous display of several image series at the same slice position.

The design of our study was quite simple (head MR studies with typical findings, axial images only, single monitor). Tasks may be relatively simple, and eye fatigue would not be so severe. Although our preliminary evaluation suggested that multiple series display mode should be superior to the conventional browsing mode for MR image interpretation, more detailed studies (multiple monitors, multiple examinations) are required. However, a single monitor is preferable to maintain a high tracking accuracy. Also, for the development of small effective viewing stations with acceptable levels of performance, our results with a single monitor are noteworthy.

CONCLUSION

In summary, a comparison between the conventional browsing mode and the multiple series display mode was carried out by using an eye-tracking device. All observers found multiple series display more comfortable than the conventional browsing mode. From the viewpoint of the radiologist's reading process, multiple series display should prove to be a more suitable design for MR image interpretation than the conventional browsing mode.

REFERENCES

1. Ishigaki T, Ikeda M, Shimamoto K, et al: Digital radiology and PACS. *Nagoya J Med Sci* 56:53-67, 1993
2. Hirota H, Shimamoto K, Yamakawa K, et al: Clinical

evaluation of newly developed CRT viewing station: CT reading and observer's performance. *Comput Med Imaging Graph* 19:281-285, 1995

3. Shimamoto K, Yamakawa K, Ishigaki T, et al: Clinical evaluation of newly developed PACS at Nagoya University Hospital (abstract). *Radiology* 193(P):175, 1994

4. Shimamoto K: Recent advances and clinical evaluation of PACS at Nagoya University Hospital. *Medical Imaging Technology* 13:809-815, 1995

5. Beard DV, Johnston RE, Toki O, et al: A study of radiologists viewing multiple computed tomography examinations using an eyetracking device. *J Digit Imaging* 3:230-237, 1990

6. Saito T, Aoki S, Matsuno A, et al: Quantitative analysis of eye movement during VDT work. *Nippon Ganka Gakkai Zasshi* 96:1047-1054, 1992