



LineM: assessing metamorphopsia symptom using line manipulation task

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Abstract

Metamorphopsia patients experience distortions in their views. The number of metamorphopsia patients is arising with the increase in the elderly population. For early detection of metamorphopsia, examination approaches have been proposed. However, none of the existing methods can be employed to precisely assess the perceptions of patients. We propose LineM as a novel method to precisely measure the distorted views of metamorphopsia patients based on interactive line manipulation task involving the patients. To explore the potential of LineM, a case study which uses the measured results from LineM to visualize the distorted views of metamorphopsia patients is presented. Furthermore, a novel technique for compensating the distorted views of individual metamorphopsia patients using the results from LineM is also presented. Considering that elderly individuals account for the majority of metamorphopsia patients, an intuitive and user-friendly prototype system has been implemented. The effectiveness and usability of LineM and the compensation method were demonstrated via a qualitative and subjective experiment that involved metamorphopsia patients and elderly participants.

Keywords Metamorphopsia · Computer-based assessment · Line manipulation · Distortion compensation

1 Introduction

Metamorphopsia is a visual defect, and people with metamorphopsia exhibit distorted perceptions of objects. This defect is one of the symptoms caused by various eye diseases or injuries, such as age-related macular degeneration (AMD), central serous chorioretinopathy (CSC), but a major cause is the AMD, which is a disorder that occurs in the macula, the central area of the retina that enables us to view things with clear detail. With an increase in the elderly population, the incidence of AMD ascends year by year. It was reported that the number of affected individuals in the USA reached 1.75 million in 2004 [1] and the number of affected individuals worldwide will rise to 288 million by 2040 [2]. It is reported in [3] that metamorphopsia can largely affect a person's quality of life. Their study revealed that among 102 participants with AMD, 45.1% experienced distorted views of lines of words in books, newspapers, or computer displays; 22.6% experienced distorted views of the frames of windows or bookshelves, 21.6% experienced distorted views of the lines of tiles on a bathroom wall, and 18.6% experienced distorted views of people's faces. AMD is a progressive disease with no known cure. Although some

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types of AMD can be treated by operation, the symptoms of AMD usually cannot be completely resolved.

In a clinical setting, the Amsler Grid [4] and M-CHARTS [5] are two most commonly employed methods for the diagnosis of metamorphopsia. With the Amsler Grid [4], a patient is asked to report the distorted area. M-CHARTS [5] utilize the fact that a human eye requires a continuous retinal stimulus to perceive distortion. By showing a patient dotted line at different dot intervals, the degree of distortion can be assessed. Both methods, however, cannot quantitatively access how a patient's view is distorted. Optical coherence tomography (OCT) images taken off a patient is adopted as a part of the examination for metamorphopsia before treatment. However, it is difficult to directly link the pathological lesion observed on an OCT image to the distorted view perceived by the patient. A lack of the assessment of a patient's view has prevented smooth communication between doctors and patients and affected the treatment planning and evaluation of treatment results. Recently, computer-based metamorphopsia diagnosis systems [6–10] were proposed. All these methods, however, are for the early detection or monitoring of metamorphopsia and cannot provide highly accurate and quantized measurement result of the symptoms. On the other hand, if a metamorphopsia patient's view can be quantitatively measured, then an ophthalmologist and the patient can simultaneously share the view, which may lead to a better-informed consensus at clinic sites.

In this paper, we propose a novel technique, LineM, for assessing the perceptions of metamorphopsia patients. Patients are asked to perform a simple task: to deform several straight lines until they perceive the lines to be straight. The distortions in their perceptions can be measured from their manipulations. A manipulation map that corresponds to the distorted views of individual metamorphopsia patients can be obtained. Considering the majority of the metamorphopsia population, we developed an input device that is user-friendly to the elderly. We presented the basic idea of line manipulation to assess metamorphopsia symptoms and the design of the input device in [11]. In this study, we present LineM as the prototype system and conduct a subjective experiment to validate its effectiveness and usability. Our subjective experiment has two parts. The first part, which involved two metamorphopsia participants, shows the effectiveness of line manipulation for assessing metamorphopsia symptoms. The second part is a usability test that involves eight elderly individuals who have normal vision. The results of the test demonstrate the feasibility of LineM. To further demonstrate the potential of LineM, we conducted a case study that applies the results from LineM for visualizing the view of a metamorphopsia patient. The results qualitatively show that LineM can be used to improve the communication between metamorphopsia patients and doctors or people with normal vision. Furthermore, we

present a novel technology for compensating the distorted views of metamorphopsia patients using the results from LineM. By pre-deforming an image in directions opposite to the directions of the distortion caused by the disease, each metamorphopsia patient can achieve a corrected view of the image that is adapted to his/her symptoms. The developed compensation application reveals the potential of LineM for improving the quality of life of metamorphopsia patients using digital technology.

The major contribution of this paper is summarized as follows:

1. A novel technique LineM for precisely assessing the views of metamorphopsia patients using an interactive line manipulation task;
2. Subject experiments for validating the effectiveness and usability of LineM;
3. A visualization case study for qualitatively evaluating the effectiveness of LineM;
4. A novel technique for compensating the distorted views of metamorphopsia patients using the results from LineM;
5. A subjective experiment involving two metamorphopsia patients to validate the effectiveness of the proposed compensation technique.

The remainder of the paper is organized as follows: Sect. 2 reviews the related work; Sect. 3 presents the basic idea of using a line manipulation task for assessing metamorphopsia symptoms; Sect. 4 presents the details of LineM; Sect. 5 introduces subjective experiments for validating the effectiveness and usability of LineM; Sect. 6 introduces two applications of Line M; Sect. 6.1 presents a visualization case study; and Sect. 6.2 presents the proposed compensation technique and the evaluation experiments.

2 Related work

2.1 Clinical diagnosis

In clinical tests, the Amsler Grid [4] and M-CHARTS [5] shown in Fig. 1 are two common approaches for metamorphopsia diagnosis. For tests with the Amsler Grid [4] (Fig. 1a), an examinee can be diagnosed with metamorphopsia if he/she reports any distortion in the grid. The interval between neighboring lines of [4] corresponds to 1° of the viewing angle. For the M-CHARTS (Fig. 1b), a continuous straight line and a sequence of dotted lines (intervals of 0.1° , 0.2° , 0.3° , 0.4° , etc.) will be shown to examinees. One crucial observation is that people with metamorphopsia can perceive misalignments from one continuous straight line; in other words, the symptoms may not be reflected via dotted

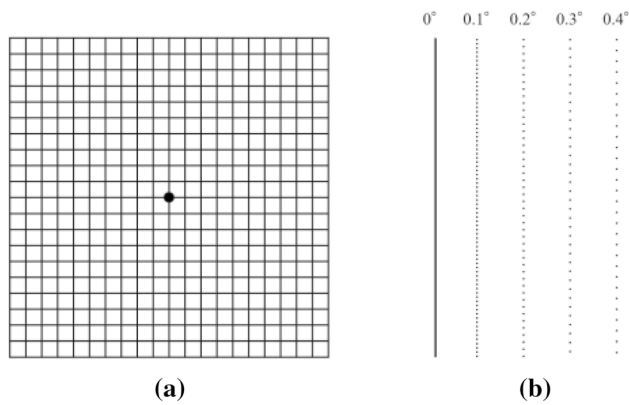


Fig. 1 Two clinical test methods for metamorphopsia. **a** Amsler grid. **b** M-CHARTS

lines if the interval is sufficiently large. In the M-CHARTS, the line that is shown can be continuously replaced by that of a larger interval until the distortion is not perceived by the examinee. With the M-CHARTS, the distortion degree is supposed to be obtained. However, neither of these two methods can precisely locate the position of distortion or quantitatively measure the amount of distortion in the view of a patient.

2.2 Computer-based diagnosis

Adopting a computer screen as the source of stimuli, computer-based metamorphopsia examination methods [6–10] have been proposed.

Based on the hyperacuity of the human visual system, that is, people have a higher ability to sense a misalignment at borders than to distinguish two points with an extremely small distance, Loewenstein et al. [6, 7] proposed a Preferential Hyperacuity Perimeter (PHP) test. In the test, dotted lines with slight misalignments were shown to examinees, who were asked to point out the position of distortion. However, individuals with metamorphopsia may indicate that a straight area is distorted because of the symptoms. In [8, 9], three circles that are aligned horizontally are shown to examinees, one of which is mixed with a radial frequency pattern, and examinees need to point out the distorted circle. Similar to Amsler Grid [4] and M-CHARTS [5], these approaches can only diagnose whether examinees have metamorphopsia rather than provide a quantitative assessment of the distortion symptom.

Wiecek et al. [10] proposed showing users a few points, which can form some shapes, such as rectangle. Users are required to regulate these shapes by a mouse, because these shapes are initially misaligned. However, this task is not easy for users, especially for the elderly, to use a mouse to

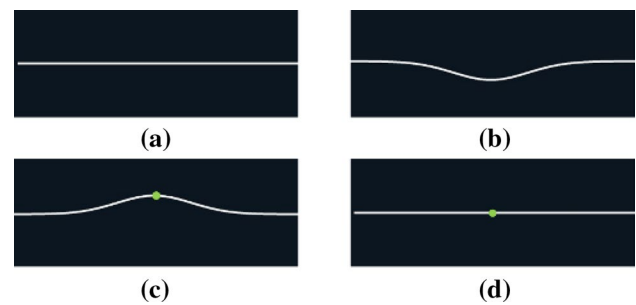


Fig. 2 Basic idea of line manipulation-based assessment. **a** Original line stimulus. **b** Simulated perception of a metamorphopsia patient to stimulus (a). **c** Line stimulus operated by the patient. **d** Simulated perception of a metamorphopsia patient to stimulus (c)

adjust the points, and this task cannot provide an accurate assessment to the views of metamorphopsia patients.

In our study, we propose the use of line manipulation as the metric to quantitatively measure the spatial distortions of metamorphopsia patients and present the novel idea of using measured data to provide compensated views for individual patients.

3 Basic idea

In our study, we propose quantizing the distortion in a user's perception as a two-dimensional manipulation map. Each point in the map can be regarded as a vector, which indicates a deviation from its original position.

To obtain the manipulation map of metamorphopsia, first, we decompose the measurement into horizontal and vertical directions. Correspondingly, vertical and horizontal lines are presented to users. The users can deform the vertical and horizontal lines in the left–right direction and up–down direction, respectively, to make the lines appear straight to them. Second, manipulation maps can be obtained by recording the user's manipulations on the lines. Figure 2 illustrates the basic idea of the proposed method. Given a straight line (Fig. 2a), a metamorphopsia patient may perceive the line to be a curvy line (Fig. 2b). With manipulation by the patient (Fig. 2c), the line appears straight to him/her (Fig. 2d). Last, the amount of displacement from the original line can be used to define the distortion of the patient view.

For an inspection of the entire field of view, multiple lines should be presented to cover the whole area of the retina. As shown in Fig. 3, to establish the spatial correspondence between the screen and the retina, it is necessary to keep the patient looking at a particular fixation point during the line manipulation. Therefore, a dot stimulus is given at the center of the computer screen to guide the gaze of the patient. Similar to [10], for a reliability check, we adopt an eye tracker to

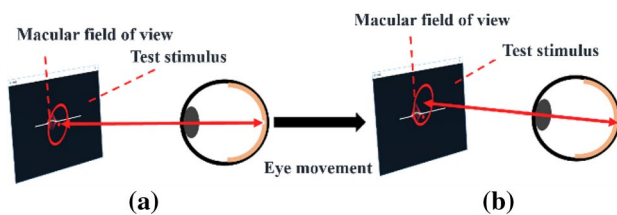


Fig. 3 Correspondence between the screen and the retina. **a** Mapping of retina to the center of screen. **b** Mapping of retina to the area deviated from the center of the screen

track the gaze of the user and disable the manipulation if the gaze deviates from the fixation point.

4 LineM

The overall construction of LineM is shown in Fig. 4. LineM consists of a personal computer (PC), a liquid-crystal display (LCD) screen, an input device, and an eye tracker. A user operates the input device to manipulate the lines that are presented on the screen. With the proposed measurement program installed, the PC receives manipulation information from the input device and updates the stimulus on the screen. The eye tracker monitors the eye movement and feeds back gaze data to the PC.

4.1 Line manipulation

To measure the amount of distortions in the vertical direction, horizontal test lines are presented, while vertical lines are used to measure the distortion in the horizontal direction. Figure 5 shows one example of horizontal test line that is presented on the screen. A red dot stimulus in Fig. 5 guides the user gaze to the center of the screen. The green dot can be moved by the user along the test line to indicate an operating point, at which the user can lift or drop the point.

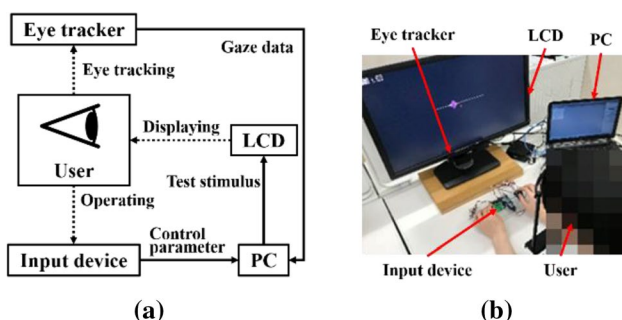


Fig. 4 Overview of LineM system. **a** Construction. **b** Snapshot of manipulating task

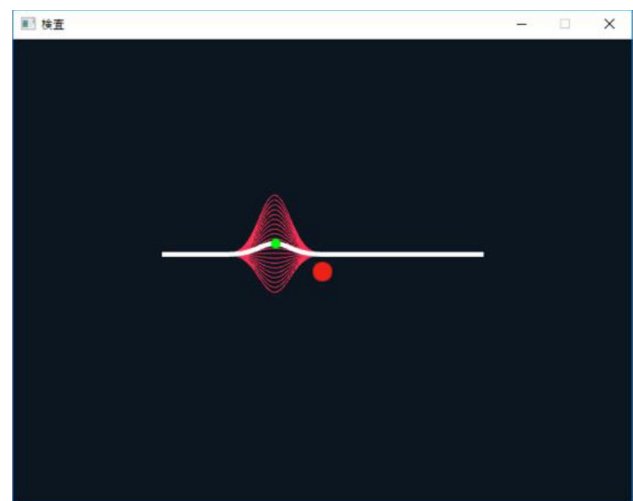


Fig. 5 Instance of a test line

Since it is almost impossible for users to adjust each point on the test line, we extract 50 control points from the test line at regular intervals. Users can directly manipulate the test line by these points. The deformation at the control points is propagated to the whole line using radial basis functions (RBFs). In our current implementation, we constrain deformation of the line in the form of the Catmull–Rom spline, which forms smooth wavy or curvy lines that simulate a certain percentage of metamorphopsia symptoms. A Gaussian function is chosen for the RBF. In particular, with one control point, which is denoted as i^{op} and operated by the user, other control points i will be moved following a Gaussian function. Here, p_i^{next} represents the new position of point i , which is computed as

$$p_i^{next} = p_i^{pre} + \Delta p \exp\left(\frac{(i - i^{op})^2}{\sigma^2}\right) \quad (1)$$

where p_i^{pre} denotes the position of point i before the operation; Δp is the movement of the operating point, which is calculated as $\Delta p = p_{op}^{next} - p_{op}^{pre}$, and p_{op}^{pre} and p_{op}^{next} indicate the position of i^{op} before the operation and the position of i^{op} after the operation, respectively. The parameter σ determines the influence range of the operation; a large σ corresponds to a low-frequency distortion, while a small σ reveals a high-frequency sharp distortion. Because the nature of distortions in the field of view varies among persons, it is better to allow users to adjust σ . However, since the elderly account for a substantial number of AMD patients, it is not desirable to have the patient aware of the parameter σ . To provide the user intuitive control over σ , we display curves that correspond to the specified σ (red lines in Fig. 5) to assist the user to choose an appropriate value for σ .

For a summary of user manipulations on the test line, three types of operations are required by the measurement system, that is, specification of the position and degree of the distortion, which refer to i^{op} , σ , and Δp in (1).

4.2 Input device

Given the requirement of user operations, a preliminary experiment is conducted by adopting the gamepad shown in Fig. 6 as an input device. We set the two joysticks of the gamepad as input units. The left joystick is used to select and move an operating point, while the right joystick is used to adjust the parameter σ . To evaluate the proposed measurement system with the gamepad, elderly participants were invited to participate in the experiment. However, the participants commented that it was challenging for them to complete the test using the joystick-only device. It was especially confusing that multiple types of operations are assigned to one-input channel. Moreover, since the users must keep their eyes on the fixation point, it is extremely difficult to manipulate the positions that are apart from the center area.

To solve the problem, we propose a prototype of an input device to accommodate elderly users. As shown in Fig. 7, our input device consists of two slide-volume controllers and one joystick, that is, the three simple control units are utilized to respond to three types of user operations, as we previously mentioned. For both horizontal test lines and vertical test lines, the joystick is used to determine the new position of the operating point. When a horizontal test line is presented, a left slide-volume controller is employed to select the operating point, while the right slide-volume controller is employed to adjust σ . For the vertical test line, the roles of the two slide-volume controllers are switched.



Fig. 6 Gamepad controller adopted in the preliminary experiment. Left joystick, up–down: move operating point (horizontal line), or select operating point (vertical line); left–right: select operating point (horizontal line), or move operating point (vertical line). Right joystick, up–down: increase/decrease σ (horizontal line); left–right: increase/decrease σ (vertical line)

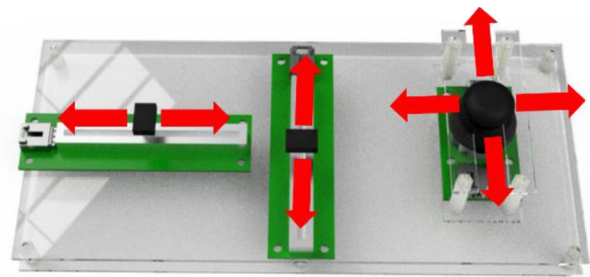


Fig. 7 Prototype for the proposed input device. Left slide-volume controller: select operating point (horizontal line), or adjust σ (vertical line). Right slide-volume controller: adjust σ (horizontal line), or select operating point (vertical line). Joystick: move the operating point vertically or horizontally. The joystick unit can be rotated by 90° depending on whether the stimulus is horizontal line or vertical line

5 Evaluation experiment

To validate the effectiveness of LineM, two patients with metamorphopsia were invited to participate in our subjective experiment. Moreover, a usability test of the prototype system, which involves eight elderly participants (three males and five females aged 50 to 90 years old with normal vision), was performed.

5.1 Qualitative evaluation of manipulation map

Figure 8 shows the results of the line manipulation performed by one of the participants, whose right eye has

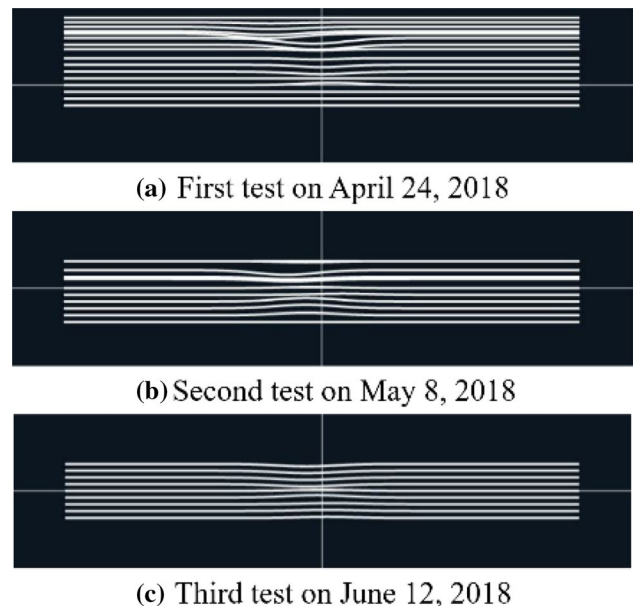


Fig. 8 Measuring result of one metamorphopsia participant test on three days



Fig. 9 Optical Coherence Tomography image of one metamorphopsia patient

metamorphopsia, on three different days. An OCT image, which was taken before the experiment performed on the last day, is shown in Fig. 9. The nub marked red reveals edema under the macula. To precisely assess the distortions in the views, the participant was required to manipulate the test lines in small intervals at the area of distortion. The participant was asked to move the line to a location where distortion was perceived, which explains why the intervals between the lines in Fig. 8 are not consistent. The participant claimed that the symptoms would be different from day to day, while the results shown in Fig. 8 do reflect this situation. Note that there is no result for the vertical test line in our evaluation experiment. We presented vertical lines to the participant; however, he indicated that the luminance of some segments on the line appeared to be different, while no distortion existed, even though he moved the line in the pixel unit.

5.2 Usability test

Because the elderly account for the majority of the metamorphopsia population, elderly participants with normal vision were invited to evaluate the usability of the prototype system. Because the participants are not metamorphopsia patients, we distorted the straight lines, as shown in Fig. 10. The participants were assigned with the task of manipulating the distorted lines until they appeared to be straight. Before the experiment, participants could practice the operations for 5 to 10 min. The average time for eight participants to straighten a distorted test line is shown in Table 1. After the line manipulation experiment, we asked the participants rate the user-friendliness of the three control units of the proposed input device on a five-point Likert scale, where “5” denotes very easy to use; “4” indicates easy to use; “3” represents neither easy to use nor difficult to use; “2” denotes difficult to use; and “1” indicates very difficult to use. The average score of each unit’s friendliness is shown in Table 2. Table 1 shows that the system enabled measurement within

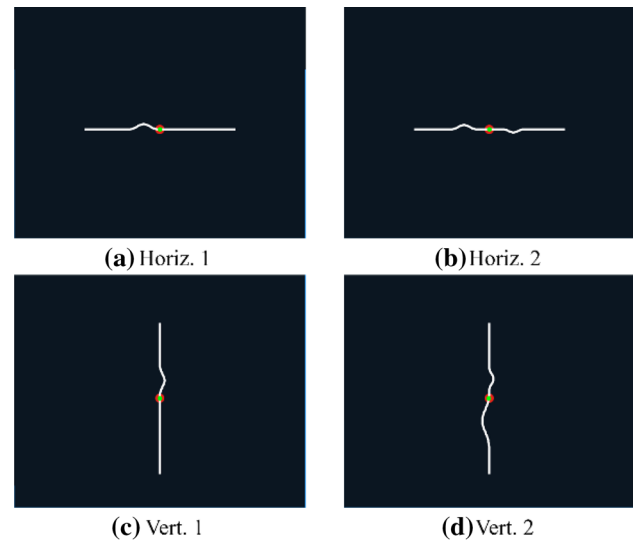


Fig. 10 Example of test lines utilized in the usability test with elderly participants

Table 1 Average time cost of one test line to be straightened by eight elderly participants with normal vision

	Average (s)	Standard deviation (s)
Horiz. 1	36.25	9.54
Horiz. 2	78.38	36.86
Vert. 1	51.75	28.95
Vert. 2	66.13	20.27

Table 2 Average friendliness score of each control unit in the proposed input device, as evaluated by eight elderly participants with normal vision

	Average	Standard deviation
Left slide volume	4.63	0.52
Right slide volume	4.00	0.53
Joystick	3.88	0.83

a reasonable time, and Table 2 shows that elderly users considered the three control units easy to operate.

6 Applications

6.1 Distortion visualization

Using the data obtained from LineM, a simulated view of metamorphopsia patients can be generated. Figure 11a shows a snapshot of Alexander Platz, which is excerpted

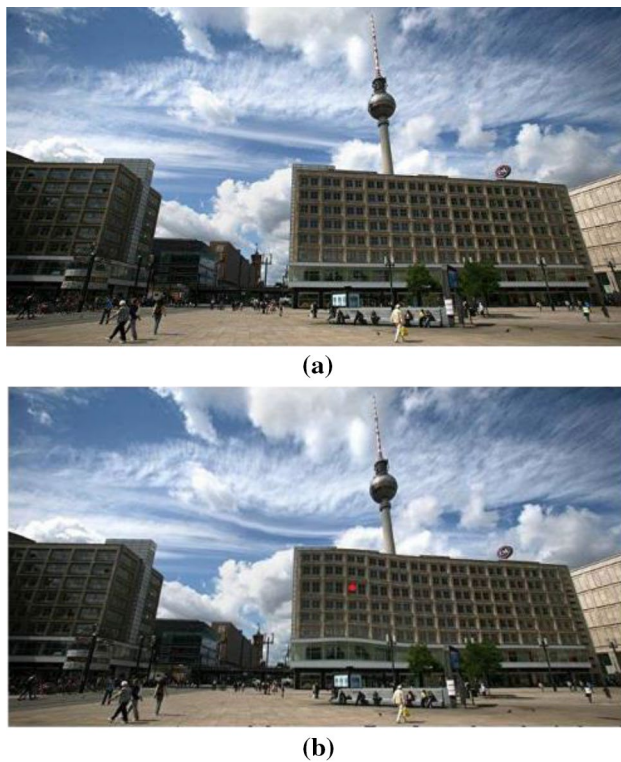


Fig. 11 Simulated view of metamorphopsia with the data obtained from LineM. **a** Original image. **b** Simulated view

from <https://www.berlin.de/en/>. The simulated view of the third test of the participant, which we introduced in Sect. 5.1, is shown in Fig. 11b, in which the red dot indicates the gaze point. We discover that a part of the building in Fig. 11a is distorted in Fig. 11b. From the manipulation of the user, the distortion can be estimated as a visual angle of approximately 6° in the horizontal direction and a visual angle of approximately 3° in the vertical direction, respectively.

Furthermore, we adopted three kinds of traditional two-dimensional (2D) vector and scalar field visualization schemes to visualize the measuring results. Using the results in Fig. 8c, we calculated the displacement vectors for the vertical direction. As shown in Fig. 12, the sampled displacements are depicted with colored vector glyphs (Fig. 12a) and their continuous versions are visualized with the pseudo color-coding and height field in Fig. 12b, c, respectively. A contrast feature distribution of displacements, i.e., downward displacement in the upper portion and upward displacement in the lower portion, can be clarified.

6.2 Distortion compensation

Given the manipulation map M obtained from LineM, the image I' for compensating the distortion can be generated.

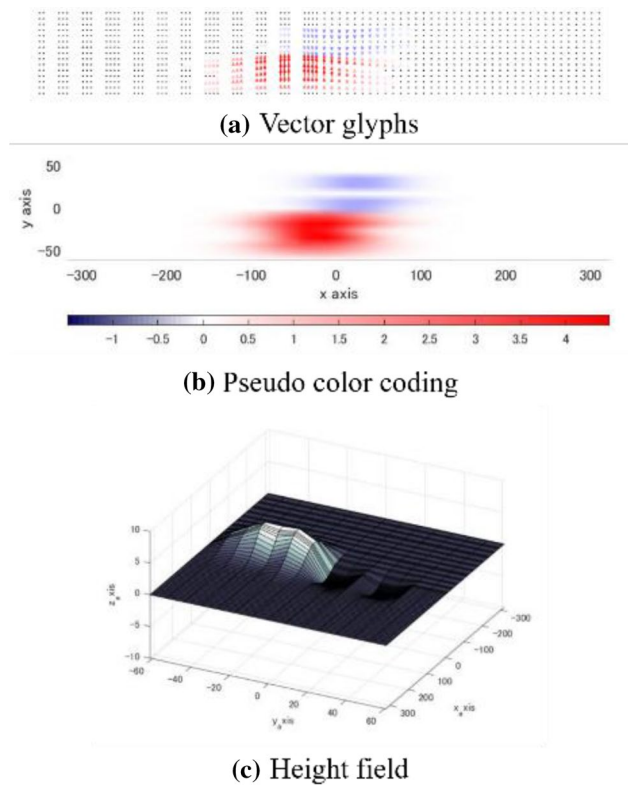


Fig. 12 Visualization for the results of third test on the participant with metamorphopsia

Distortions can be corrected if we apply the deformation, that the user operated on the test lines, to an input image.

Because the manipulation map obtained from LineM only contains the sparse data on test lines, it is necessary to estimate a full-resolution manipulation map M' from M via interpolation methods, such as linear interpolation, Akima spline interpolation, and cubic interpolation. The value of a pixel x in the compensating image can be calculated as

$$I'(x) = I(x + M'(x)), \quad (2)$$

where $M' = (d_x, d_y)$ indicates a movement vector at x . To evaluate the effectiveness of the compensating images, we conducted a subjective study which involved metamorphopsia participants. The experiment consists of two aspects: fixed viewpoint compensation and dynamic viewpoint compensation.

6.2.1 Fixed viewpoint compensation

In the experiment of the fixed viewpoint, the gaze of a participant was assumed to be fixed on the center of an image. As shown in Fig. 13, the original image (Fig. 13a) and compensating image (Fig. 13b) were simultaneously presented to the participant. The participant was required to gaze at

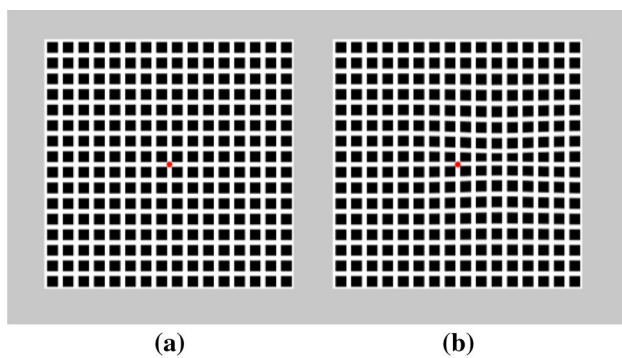


Fig. 13 Images utilized in the experiment of fixed viewpoint compensation. **a** Original image. **b** Compensation image

Table 3 Rate of the compensating image was selected as “straighter” among two trials, evaluated by three participants

	First trial	Second trial
Participant 1	8/10	8/10
Participant 2	7/10	7/10

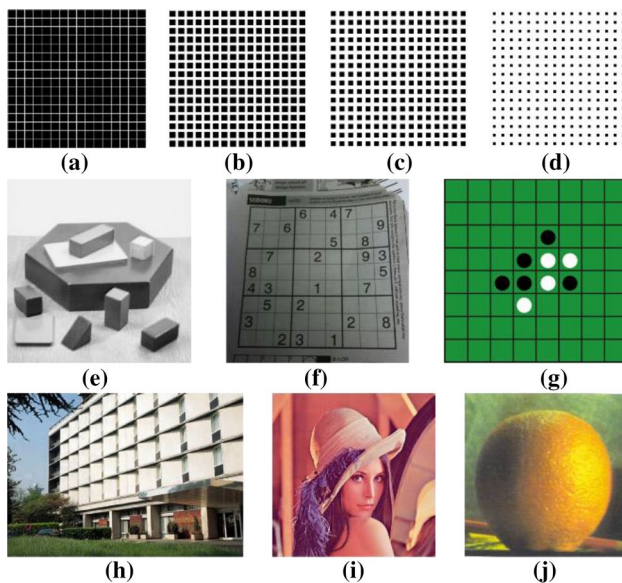


Fig. 14 Original images utilized in the compensation experiment

the red dot and indicate which image looked straighter. In the experiment, ten images were selected, and the rate of the compensating images that were chosen is shown in Table 3. To improve the reliability of the results, each participant conducted the experiment twice. For both participants, it can be confirmed that the symptoms of metamorphopsia had improved to some extent with the compensating images. The ten images are shown in Fig. 14. Figure 14i, j shows the two images, which were evaluated as “no difference before and

Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do: once or twice she had peeped into the book her sister was reading, but it had no pictures or conversations in it, “and what is the use of a book,” thought Alice, “without pictures or conversations?” So she was considering, in her own mind (as well as she could, for the hot day made her feel very sleepy and stupid), whether the pleasure of making a daisy-chain would be worth the trouble of getting up and picking the daisies, when suddenly a White Rabbit with pink eyes ran close by her.

Fig. 15 Instance of compensating for reading

after applying the compensation,” which indicates that the compensation effect became unclear whether there was no straight line in the original image.

6.2.2 Dynamic viewpoint compensation

For practical application, it is necessary to produce compensating images that are accompanied with the movement of a user’s gaze. The first idea that came to us is to obtain user’s gaze information via an eye tracker and update the compensating image. A preliminary experiment shows, however, that this eye tracker-based method demands high accuracy and time efficiency of an eye tracker; otherwise, a small deviation can invalidate the compensating image.

As an alternative to an eye tracker, a mouse cursor-based compensation application was developed in this study. The position of the mouse cursor is regarded as an indicator of a user’s gaze, and the compensating image is consequently generated. An instance related to reading is shown in Fig. 15. The green box represents the area where compensation is applied, and users can move the mouse to change the area. Because it was difficult for users to clearly describe the effect of compensation in the reading task, a much simpler experiment related to dynamic viewpoint was conducted in this study. As shown in Fig. 16, in the dynamic viewpoint experiment, 2×2 grid diagrams were presented. Participants were asked to choose the diagrams that appeared “straight.” To eliminate the influence from peripheral vision, a transformation of distortion was performed to these diagrams when they were inactivated. Only the diagram that was activated by a mouse cursor, i.e., diagram wrapped by a green box in Fig. 16, will be randomly applied with one of the three following transformations:

1. restoring the distorted diagram to straight, and then transforming it according to the manipulation map assessed by the proposed system

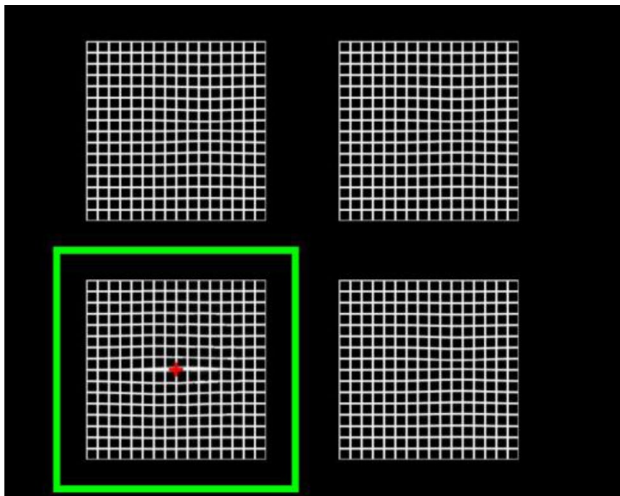


Fig. 16 Interface of the mouse cursor-based application for dynamic compensation

Table 4 Number of correct selection occurrences among 80 rounds of trials in dynamic viewpoint experiment, as evaluated by two participants

	Correct selection
Participant 1	71/80
Participant 2	69/80

- restoring the distorted diagram to straight, and then transforming it according to a randomized manipulation map.
- restoring the distorted diagram to straight.

The activated diagram became distorted again after the cursor was moved away from the diagram. The effect of compensation can be verified if the selected diagram processed by transformation 1 was selected by the user. In the experiment, each participant had been shown 4 sets of images which originated from Fig. 13a–d, respectively, and each set had been repeated 20 times. As a result, each participant had 80 rounds of trials. The number of the diagrams that were processed by transformation 1 is shown in Table 4. In each trial, the possibility that a correct diagram was selected was 1/2, and a binomial test was applied. The results of the test show that there was an effect of compensation with a significance of 99% for both participants.

7 Discussions

In our current implementation, we model the deformation of the line with Catmull–Rom spline and use Gaussian-based RBF for controlling the propagation of deformation, which forms smooth wavy or curvy lines. These types of

metamorphopsia are mainly found among the patients with CSC, the fourth most common retinopathy [12]. In our experiment, the effectiveness of LineM was validated by two CSC patients. However, metamorphopsia caused by other diseases may present some high-frequency or spike-like distortions. Therefore, extension of current system for dealing with high-frequency distortion can be an important future work.

Most elderly participants also had other vision problems. It is necessary to exclude other factors to obtain accurate assessment results with LineM. The symptom of metamorphopsia is usually different for two eyes or presented in only one eye. In the experiments, we assessed the symptom of each eye by blindfolding one eye. This step hindered the manipulation due to the lack of depth cue. Considering the compensation application, it is important to perform the assessment task and the compensation with both eyes. A potential solution is to use a stereo display which can display different images to the two eyes.

8 Conclusion

In our study, we proposed LineM as a novel computer-based technique to precisely assess the distorted views of metamorphopsia. Evaluation experiments that involved metamorphopsia patients and elderly individuals demonstrated the effectiveness and usability of LineM. A visualization case study and a novel technique for compensating metamorphopsia patients' distorted views have been developed to validate the usefulness of LineM. Experiments that involve two metamorphopsia participants demonstrated that LineM combined with the compensation technique can improve the views of metamorphopsia participants for objects with straight lines.

As mentioned at the beginning of this paper, metamorphopsia is a progressive incurable disease. Moreover, the symptoms of metamorphopsia can vary from day to day depending on the physical conditions of the patients. LineM enables patients to assess their symptoms easily but precisely in daily life. Combined with the proposed compensation technique, LineM enables the displays of digital devices to be adapted to the symptoms of individual patients, which can largely improve their quality of life.

Aged people may have some forms of dementia, which may affect the visual primary cortex, and it may cause a similar result like dyslexia. LineM can assess and compensate the distorted view, no matter it arises from retina or visual cortex. The vision problems arisen from the latter case (visual cortex) are usually influenced by patients' physical and mental conditions, which can make the symptom changes from day to day. It shows the potential of LineM which can be easily used in daily lives. However, some kinds of dyslexia symptoms are known to be related to the semantic of

the contents. Since LineM only assesses the visual information, it cannot deal with those dyslexia symptoms related to the semantic of contents.

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Data availability All data generated or analyzed during this study are included in this published article.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this published paper.

Ethics approval The experimental protocol was established, according to the ethical guidelines of the Helsinki Declaration and was approved by the Ethics Committee of University of Yamanashi.

Consent to participate Written informed consent was obtained from individual or guardian participants.

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