Eye-tracking Aided Digital Training System for Strabismus Therapy

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Abstract—Strabismus is one of the common vision disorders. For people with mild strabismus, many evidences showed that doing eye muscle exercise would be very helpful to straighten the weak eyes and improve eye performance eventually. In this paper, we propose an eye-tracking aided training system for strabismus therapy. We aim at helping strabismus people train eye muscle movements with a real-time training system. The disparities of the two eye gazes of strabismus sufferers are displayed on the screen immediately, providing real time and interactive feedback. Four subjects with strabismus and three subjects with normal eyes were invited to participate in the training with the proposed system. In this study, we achieved very promising results that demonstrated the effectiveness of the proposed training system and the possibilities of using this system in the real life applications.

Index Terms—strabismus, training system, eye tracking, eye muscle exercise

I. INTRODUCTION

Strabismus, is a common ophthalmic disorder in the popularity [1]. For people with manifest strabismus, the eyes are in a misaligned condition and fail to focus simultaneously on a same point in space. Strabismus may be caused by various reasons like eye injuries or disease, cranial nerve palsies, myasthenia gravis and brain or birth problems, and could be classified into different types according to the signs and symptoms. For example, according to the occurrence frequency, strabismus can be categorized into constant and intermittent. If concerning the misalignment directions, there are Exotropia and Esotropia (horizontal strabismus) [2] and Hypertropia and Hypotropia (vertical strabismus) [3]. Usually, strabismus happens to one eye (named as “weak eye” below). In Exotropia and Esotropia cases, the “weak eye” rotates inward or outward, and in Hypertropia and Hypotropia cases the “weak eye” rotates upward or downward. The other eye is totally healthy and well functional (named as “healthy eye” below). For people with strabismus, “weak eye” and “healthy eye” do not line up in the direction and focus on different objects. Then two different images would be received and sent to the brain. To avoid confusion from the double vision, the brain would be trained to tend to ignore the blurred or wrong image transferred from the “weak eye” and only acknowledge the information from the “healthy eye”. As time goes on, without proper treatment, the “weak eye” would come to be totally ignored from the brain and become vision loss. It is called “amblyopia” [4].

In order to examine strabismus, an ophthalmologist performs a thorough evaluation using traditional strabismus diagnosis and measurement methods such as cover test, Maddox rod, Hirschberg test and so on, and comes to a diagnosis based on the examination performance and visual inspection based on his/her experience. Strabismus cases would be quite different from people, requiring different medical treatments depending on the underlying reasons. If strabismus is severe, eye muscle surgery may be needed. But for people with mild strabismus, keeping on doing eye muscle exercise would be very helpful to straighten the eyes [5]-[7]. It is well known that there are six different muscles that move the eyes. They include the superior rectus, inferior rectus, lateral rectus and medial rectus for horizontal movements, and the superior oblique and inferior oblique for vertical ones. As eye muscle exercise for curing strabismus takes a rather long time, it would become a high cost for people with strabismus problem who would like to have regular vision training under a guidance of ophthalmologist. On the other hand, along with the development in the eye tracking technology, more and more researches show that current eye tracking techniques are capable of providing a conformable, easy-to-use and light weight non-invasive way to accurately and robustly measure human beings’ eye movements (the error is less than 1 degree) in the applications of laboratorial uses and real-world life [8] and [9]. Besides involving eye-tracking techniques to improve the performance of various tasks like visual attention [10]-[12] and human behavior study [13]-[15], people also tried to use eye tracker to diagnose strabismus [16] and
In Chen’s study [17], the feasibility of using eye tracking aided digital system for strabismus diagnosis has been verified. It showed the potential in applying such eye tracking technique to other aided applications for strabismus.

In this paper, we propose an eye-tracking aided training system for strabismus therapy. A study has been carried out and the effectiveness and practical applications for strabismus training have been demonstrated. The rest of this paper is organized as below. Section II introduces the proposed eye-tracking aided training system. Section III reports our testing results. A conclusion is drawn in Section IV.

II. EYE-TRACKING AIDED TRAINING SYSTEM

A. System Setup

The eye-tracking aided training system includes three components: the training software, a portable eye tracker and a laptop. Fig. 1 (a) shows a real environment when subject is using the proposed system, where subject sits in front of the monitor with a fixed distance (around 50-60 cm) under a guidance of our instructor. A close-up view of the device set-up is shown in Fig. 1 (b). The eye tracker is adhered below the laptop’s monitor with a tracking target showing. Tobii X2-60 is used in this training system. Benefiting from the high sampling rate (60Hz) and tracking accuracy (0.4°) of Tobii X2-60, the training system is capable of precisely tracking people’s eye movement in a real-time training environment.

As shown in Fig. 2, the training software is composed of four main modules: personal information, eye location, eye distance and task selection. Each module’s function is illustrated as below:

- **Personal Information**: fill in subject’s basic information, such as name, age, gender, and eye status (strabismus or normal);
- **Eye Location**: enable or disable real-time display of left and right eye locations while training;
- **Eye Distance**: enable or disable real-time display of gaze distance while training;
- **Task Selection**: select training task. Currently, there are total 4 training tasks included. More interesting tasks would be explored and added to Task 5 and 6 later.

![Figure 1. System introduction. (a) real training environment; (b) a close-up view of the device set-up in this system.](image)

B. Calibration

Before starting a training task, a 9-point calibration is firstly conducted to tune the eye tracker by recording subject’s fixation on the known locations. As shown in Fig. 3(a), the calibration dots will be shown in sequence from the top to down and from the left to right on the screen. There is only one dot displayed at a time and the displayed locations cover the range of the entire screen. Subject is required to fixate on the moving red dot as possible as they can. According to the calibration landmarks, the system will automatically determine where subject is looking at the screen during training. A good calibration is of vital importance to the following training performance. Thus, we use 9-point calibration in the system. After calibration, the calibration results will be presented to subject to evaluate if the calibration accuracy is acceptable (refer to Fig. 3 (b)). If not, another re-calibration starts; if yes, the training task starts.

![Figure 2. The training software in the proposed system.](image)

![Figure 3. Calibration process. (a) 9-point calibration.](image)
C. Tracking Task Design

In the training software, we designed four tasks with a consideration of training time, fixation location, and what kind of muscle movement we want to train. In task 1 and task 2, to train subject’s eye fixation ability, a fixed target located in the center of the screen was used and subject is required to consistently focus on the target within a limited time period. To further train subject’s eye controlling ability like moving two eyes in one direction, targets showing at different locations were designed in task 3 and task 4, and subject is encouraged to follow and fixate to the target as possible as he/she can. A comparison of the training tasks is elaborated in Table I.

An illustration map of task 3 is shown in Fig. 4. The target is highlighted in blue and initialized at location 1. After 10s the target moves to location 2 and then move to location 3 after another 10s. The total training time is 30s.

### Table I. A Comparison of the Designed Training Tasks

| Task | Instruction                          | Location       | Duration               |
|------|--------------------------------------|----------------|------------------------|
| 1    | staring at the picture               | center         | end once two eyes are both locating at the picture |
| 2    | staring at the highlighted region    | center         | 10s                    |
| 3    | staring at the highlighted regions   | three locations| 30s (10s for each location) |
| 4    | moving eyes from left to right in the highlighted tunnel | a tunnel from left to right | 30s |

D. Real-Time Feedback Mechanism

A real-time feedback mechanism is designed in the training system to guide subjects during training process. Besides of the real-time eye gaze locations and distance display, we also design a color scheme in the feedback mechanism. Except task 1 (we used an image as a target in task 1), the designated targets in the other tasks are all originally highlighted in blue color. As shown in Fig. 5, if both or any of the left and/or right eye gaze(s) are/is not within the designated target (target without hitting), the target is blue color; when both left and right eye gazes are within the target (target with a hitting), the target will immediately change to pink. However, once both or any of the left and/or right eye gaze(s) are/is not within the designated target, it will change back to blue again.

E. Training Performance Evaluation

In order to evaluate how many percent of the time subject is capable of fixating/hitting on the target, a hit rate is defined as

$$\text{HitRate} = N_h / N_T, 0 \leq \text{HitRate} \leq 1 \quad (1)$$

where $N_h$ is the number of eye gaze points that hit on the target, and $N_T$ is the number of the total collected eye gaze points during the training. Hit rate can be used as evaluation of subject’s eye controlling ability. A larger hit rate indicates subject is more capable of locating both left and right eye gazes on the target.

We also measure the sensitivity of eye performance to different locations. Take task 3 as an example. We compute the portion of hit rate in each location as

$$\text{HitRate}_{i} = N_{hi} / N_h \quad (2)$$

where $N_{hi}$ is the number of eye gaze points that hit on the target in $i$th location.

For normal people, the hit rate in different locations should be always evenly distributed. But for people with strabismus, eye performance would be biased by the location according to the past researches.

To measure how far away between left and right eye gazes, eye disparity is also computed as
where \( L_x \) and \( L_y \) are the x and y coordinates of the left eye, and \( R_x \) and \( R_y \) are the x and y coordinates of the right eye.

When two eyes are not moving to the same direction, the eye disparity would become large. In the following experimental results, normal people’s eye disparity is always within a reasonable range, which is much smaller than strabismus people’s eye disparity.

**F. Training Pipeline**

The training pipeline used in the below experiments is shown in Fig. 6. Before the first training session, our instructor briefly introduces the training pipeline and invites subjects to do some pre-testings (task 1 or 2). The pre-testings help subjects to get familiar with the system and better understand how to follow the guidance according to the real-time feedback mechanism. Then, calibration is conducted using 9-point, and subjects start to do training task. At the end of the experiment, subject’s feedback about the usability and effectiveness of the training system is collected.

![Fig. 6. Training pipeline.](Image)

**III. EXPERIMENTAL RESULTS**

In this study, we invited four subjects with mild strabismus problem (two males and two female, age ranging from 25 to 60 years old) to participate in the training therapy by our eye-tracking aided training system. Task 3 was selected as the training task and each subject was invited to train three times in separated days with an interval of seven days. During the training, subjects were encouraged to remain seated in a comfortable chair without any unnecessary head/body movement. They were instructed to try their best to make sure both their left and right eye gazes locating on the target and keep the target staying at pink color.

Table II shows the experimental results in terms of \( N_h \), \( N_r \) and HitRate. It is observed that subjects’ hit rate all increased after three times of trainings. All the subjects became more skillful in the eye muscle controlling that longer hitting time achieved. For subject 4, the hit rate in 3rd training was a bit poorer than 2nd time. It is because the total collected eye gaze points (\( N_r \)) was larger in 3rd time. Only 249 eye gaze points were collected in 2nd training, while total 405 points were collected in 3rd. It was also found that the training effect on different subjects was different. For subject 1 and 2, the training effect was significant and much higher hit rate achieved in the last training. While, for subject 3 and 4, the training effect was minor. But we still can see the improvement in the eye performance.

On the other hand, as subject 2 was wearing a glass with correction function during training, so her performance was much better than the other three subjects in terms of \( N_h \), \( N_r \) and HitRate. After the three training sessions, we also invited subject 2 to participate another testing without glass wearing. Her hit rate sharply dropped to 0.3565.

| Subject | \( N_r \) | \( N_h \) | HitRate (\%) | \( N_r \) | \( N_h \) | HitRate (\%) | \( N_r \) | \( N_h \) | HitRate (\%) |
|---------|---------|---------|--------------|---------|---------|--------------|---------|---------|--------------|
| 1       | 1       | 0       | 0            | 3       | 0       | 0            | 626     | 246     | 39.30        |
| 2*      | 706     | 311     | 44.05        | 567     | 341     | 60.14        | 627     | 424     | 67.62        |
| 3       | 264     | 0       | 283          | 0       | 0       | 611          | 64      | 10.47   |              |
| 4       | 316     | 0       | 249          | 2       | 0.80    | 405          | 3       | 0.74    |              |

\* wearing functional eye glasses

Table III shows the number of eye gaze points that hit on the target in every location (\( N_h \)) and corresponding HitRate. It is found, comparing to the other two locations, bottom right is usually the weak one for people with mild strabismus to fixate to.

Fig. 7 shows the statistical distribution of subjects’ eye disparity distribution in each training session of each subject. It is observed that eye disparity has been shortened in 3rd training session, comparing to the distribution in 1st training session. The average of subjects’ eye disparity in every training session was presented in Table IV. Also, the significance of the difference between the eye disparity distribution in 1st training and 3rd training has been verified by using t-test. The corresponding p-values were presented in Table IV as well.

In order to compare the results collected from people with strabismus, we also invited three subjects with normal eyes to participate the eye-tracking aided training. Table V shows the corresponding results. Comparing to the results presented in Table II and IV, the obtained hit rate of people with normal eyes (> 80%) was much higher and the eye disparity is much smaller. In other words, the proposed eye-tracking aided training system is capable of providing an objective evaluation of eye performance.
In this paper, we propose an eye-tracking aided training system to help train eye muscle movements for people with mild strabismus. The aim of this system is to provide a real-time training to guide people to well control their eye movements and return an objective evaluation of the eye performance. To verify the effectiveness of the training system, we invited four subjects with mild strabismus to participate in this study. Promising experimental results were obtained and the feasibility of the proposed training system was demonstrated. Also, the training feedbacks from subjects were all positive. In the future, we will further test our eye-tracking aided training system on more people with strabismus problem and design more good training tasks. To avoid over-time training that would induce eye fatigue and other eye problems, a timer would be also added into the system.

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REFERENCES

[1] D. K. Coats, D. R. Stager Sr, G. R. Beauchamp, D. R. Stager Jr, M. L. Mazow, E. A. Paysse, and J. Felius, “Reasons for delay of surgical intervention in adult strabismus,” Arch Ophthalmol, vol. 123, pp. 497-499, 2005.
[2] E. M. Helveston, F. D. Ellis, J. Schott, J. Mitchelson, J. C. Weber, S. Taube, and K. Miller, “Surgical treatment of congenital esotropia,” American Journal of Ophthalmology, vol. 96, no. 2, pp. 218-228, 1983.
[3] C. Berens, B. F. Payne, and D. Kern, “Orthoptic training and surgery in hyperphoria and hyptonopia combined with lateral Deviations,” American Journal of Ophthalmology, vol. 18, no. 6, pp. 508-524, 1915.
[4] H. D. Bedell and M. C. Flom, “Monocular spatial distortion in strabismic amblyopia,” Investigative Ophthalmology & Visual Science, vol. 20, no. 2, pp. 263-268, 1981.
[5] E. M. Helveston, “Visual training: Current status in ophthalmology,” American Journal of Ophthalmology, vol. 140, no. 5, pp. 903-910, 2005.
[6] K. Kawahira, M. Shimodozono, S. Etoh, and N. Tanaka, “New facilitation exercise using the vestibulo-ocular reflex for ophthalmoplegia: preliminary report,” Clinical Rehabilitation, vol. 19, pp. 627-634, 2005.
[7] S. P. Kraft, “The functional benefits of adult strabismus treatment,” American Orthoptic Journal, vol. 58, pp. 2-9, 2008.

[8] M. Wedel and R. Pieters, “A review of eye-tracking research in marketing,” in Review of Marketing Research, Naresh K. Malhotra (ed.) (Review of Marketing Research, Volume 4), Emerald Group Publishing Limited, 2008, pp.123-147.

[9] M. L. Lai, M. J. Tsai, Z. Y. C. Y. Hsu, T. C. Liu, S. W. Y. Lee, M. H. Lee, G. L. Chio, J. C. Liang, and C. C. Tsai, “A review of using eye-tracking technology in exploring learning from 2000 to 2012,” Educational Research Review, vol. 10, 2013, pp. 90-115.

[10] Z. Liang, H. Fu, Y. Zhang, Z. Chi, and D. Feng, “Content-based image retrieval using a combination of visual features and eye tracking data,” in Proc. Symposium on Eye Tracking Research and Applications (ETRA 2010), 2010, pp. 41-44.

[11] Z. Liang, H. Fu, Z. Chi, and D. Feng, “Refining a region based attention model using eye tracking data,” in Proc. the IEEE International Conference on Image Processing, 2010, pp. 1105-1108.

[12] T. Toyama, T. Kieninger, F. Shafait, and A. Dengel, “Gaze guided object recognition using a head-mounted eye tracker,” in Proc. the Symposium on Eye Tracking Research and Applications (ETRA 2012), 2012, pp. 91-98.

[13] M. L. Mele and S. Federici, “Gaze and eye-tracking solutions for psychological research,” Cognitive Processing, vol. 13, pp. 261-265, 2012.

[14] U. J. Pfeiffer, K. Vogeley, and L. Schilbach, “From gaze cueing to dual eye-tracking: Novel approaches to investigate the neural correlates of gaze in social interaction,” Neuroscience & Biobehavioral Reviews, vol. 37, no. 10(2), pp. 2516-2528, 2013.

[15] J. D. Velasquez, “Combining eye-tracking technologies with web usage mining for identifying website keyobjects,” Engineering Applications of Artificial Intelligence, vol. 26, no. 5-6, pp. 1469-1478, 2013.

[16] R. A. Pulido, “Ophthalmic diagnostics using eye tracking technology,” Master of Science Thesis, KTH Royal Institute of Technology, Sweden, 2012.

[17] Z. Chen, H. Fu, W. L. Lo, and Z. Chi, “Eye-tracking aided digital system for strabismus diagnosis,” in Proc. 2015 IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2015, pp. 2305-2309.

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