

Development of a contactless operation system for radiographic consoles using an eye tracker for severe acute respiratory syndrome coronavirus 2 infection control: a feasibility study

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ABSTRACT

Sterilization of medical equipment in isolation wards is essential to prevent the transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. Particularly, the radiographic console of portable X-ray machines requires frequent disinfection because it is regularly moved; this requires considerable infection control effort as the number of patients with coronavirus disease 2019 (COVID-19) increases. To evaluate the application of a system facilitating noncontact operation of radiographic consoles for patients with COVID-19 to reduce the need for frequent disinfection. We developed a noncontact operation system for radiographic consoles that used a common eye tracker. We compared calibration errors between with and without face shield conditions. Moreover, the use of console operation among 41 participants was investigated. The calibration error of the eye tracker between with and without face shield conditions did not significantly differ. All ($n = 41$) observers completed the console operation. Pearson's correlation coefficient analysis showed a strong correlation ($r = 0.92$, $P < 0.001$) between the average operation time and the average number of misoperations. Our system that used an eye tracker can be applied even if the operator uses a face shield. Thus, its application is important in preventing the transmission of infection.

Section: RESEARCH PAPER

Keywords: Infection control; SARS-CoV-2; eye-tracking manipulation; contactless device; radiographic console

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1. INTRODUCTION

An outbreak of severe acute respiratory syndrome coronavirus (SARS-CoV-2) infection occurred in Wuhan, China, in December 2019 [1]–[5]. Since then, the virus has been transmitted worldwide, and consequently, the World Health Organization declared it a pandemic on March 11, 2020. This infection can be primarily transmitted via droplets and contact routes [6]–[8]. Currently, infection control measures, including social distancing, using masks or face shields, and frequent handwashing and disinfection, are important [9], [10], particularly in the medical field. Hospitals with isolation wards for patients with coronavirus disease 2019 (COVID-19) are taking various

measures to prevent infection transmission. The environment where patients with COVID-19 are treated is zoned as clean (cold zone), intermediate (warm zone), and unclean (hot zone) areas [11]–[13] to prevent hospital-wide infection. However, it is difficult to completely control infection despite such isolation measures [14].

Chest radiography is important for the management of COVID-19, and portable X-ray machines are used in isolation wards. In most hospitals, after imaging patients in the isolation ward is completed, all areas that may have come in contact with the patient or been exposed to droplets, including the device, the flat panel detector, and imaging console attached to the flat panel detector system, should be disinfected [13]. However, medical staff can be mentally and physically exhausted during a

pandemic, making it difficult to perform appropriate disinfection. Moreover, disinfection may not have been strictly practiced prior to the pandemic [15]-[17]. When several patients with COVID-19 undergo imaging, the console should be disinfected to prevent secondary infections, such as due to methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci infections, even if imaging was conducted in the same ward. Nevertheless, it is difficult to disinfect a plastic bag covering a complex-structures medical device while wearing personal protective equipment. Therefore, the radiographic console, which is touched frequently, can be a source of infection [18].

Reducing the frequency of touching the imaging equipment, which can be achieved using contactless input devices, is important in addressing these issues. Currently, several contactless devices are available. However, their use for protection against SARS-CoV-2 infection has not been reported. Previous studies have assessed the use of contactless input devices to operate medical devices without touching them in the clinical setting [19]-[24]. Such devices are effective in maintaining sterile rooms [19]. Therefore, this study aimed to assess the use of an eye tracker, which does not require body movement, as a contactless input device.

Image display systems have been successfully manipulated via eye tracking during interventional radiology, thereby allowing images to be paged and magnified using the observer's eye movements alone [25]. In this study, we applied such technology to develop a radiographic console operation system for infection control during portable X-ray imaging of patients with COVID-19. Face shields are used as personal protective equipment in the management of patients with COVID-19, and they create an obstruction between the eye tracker and the eyes. Therefore, we evaluated our operating system by assessing calibration errors between with and without face shield conditions, average time required for console operation, and average number of misoperations.

2. MATERIAL AND METHODS

2.1. Development of a contactless operation system using an eye tracker

In this study, we used Tobii PCEye Mini (Tobii, Stockholm, Sweden) as the eye tracker for our contactless operation system (Figure 1). This small and light weight devices has the following measurements: width, 169.5 mm; height, 17.8 mm; thickness, 12.4 mm; and weight, 59 g. It can be easily installed on the radiographic console used in portable X-ray systems. The usable distance from the eye detector ranges from 45 to 85 cm, the sampling rate of the eye tracker is 60 Hz, and the recommended screen size is up to 19 in. We used a computer with the following specifications: Windows 10 Home 64 bit, Intel Core i7-6700HQ central processing unit, and NVIDIA GeForce GTX 960M; its screen size was 17 in (Monitor size: width, 38.4 cm; height, 21.6 cm). The eye tracker could be easily used with a universal serial bus connection; however, it requires prior calibration. The system provided with the Tobii PCEye Mini was used for calibration. There was a function in this system to inform the observer whether the position of the observer is appropriate in order to properly calibrate the system. In addition, instructions are displayed on the screen regarding the location to be gazed for calibration so that it can be facilitated. Specifically, we entered the gaze detection range and gazed at seven points on the screen, i.e., centre, upper right, upper centre, upper left, lower right,

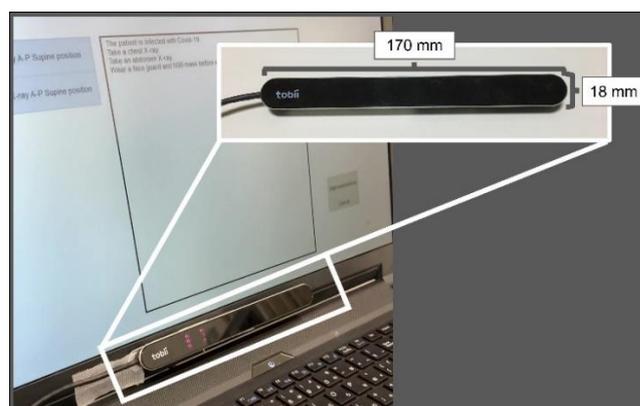


Figure 1. Overview of Tobii PCEye Mini (Tobii, Stockholm, Sweden).

lower centre, and lower left. We used the pupil centre corneal reflection method to calibrate the operator's gaze point by measuring the corneal reflection point of the irradiated infrared light and the position of the pupil when gazing at each point, which improved with the eye tracker [26].

We developed a contactless operation system for radiographic consoles that used an eye tracker to prevent the transmission of SARS-CoV-2 infection. We used Microsoft Visual Studio (Microsoft, Redmond, WA, USA) as an integrated development environment, C# (Microsoft), and the Nuget package of Tobii.Interaction v.0.7.3 (Tobii Core SDK, Tobii). The principle of the operation was based on the characteristics of eye movement. The two types of fixations are saccade, which is a quick movement of the gaze, and fixation, which requires the maintenance of gaze on the same spot [27], [28]. The vector was calculated as the amount of gaze point movement on the screen for 0.02 s to detect the fixation state.

In this study, we considered the saccade state if the amount of movement exceeded 200 pixels (0.02 cm per pixel, which is approximately 4 cm). An amount of movement of 200 pixels in 0.02 s could be considered a saccade [25]. If the amount of movement was below this threshold, the system was considered in fixation state. The only commands required to operate the radiographic console were moving the cursor and clicking. Therefore, we developed a method to move the cursor in accordance with the movement of the gaze point and to click when the fixation state is reached. Figure 2 shows the use of the console operation system for imaging.

In total, 41 students from radiological technology participated, and they were briefed in advance about the operation system. Table 1 shows the characteristics of the observers.

2.2. Considerations of the system

Because eye tracking may not be possible when a face shield is worn, the developed system was used with and without face shield. We used a face shield (Logi Meister, Osaka, Japan) made of polyethylene terephthalate with following measurements: height, 22 cm; width, 33 cm; and thickness, 0.25 mm. The distance from the eyeball to the face shield is approximately 4 cm (Figure 3). We performed (1) a comparison of calibration errors between the two face shield conditions and (2) an analysis of console operation.

In experiment 1, calibration of the eye detector was performed with and without a face shield. Subsequently, the error between the actual gaze point coordinates on the screen and the detected gaze point coordinates on the screen was

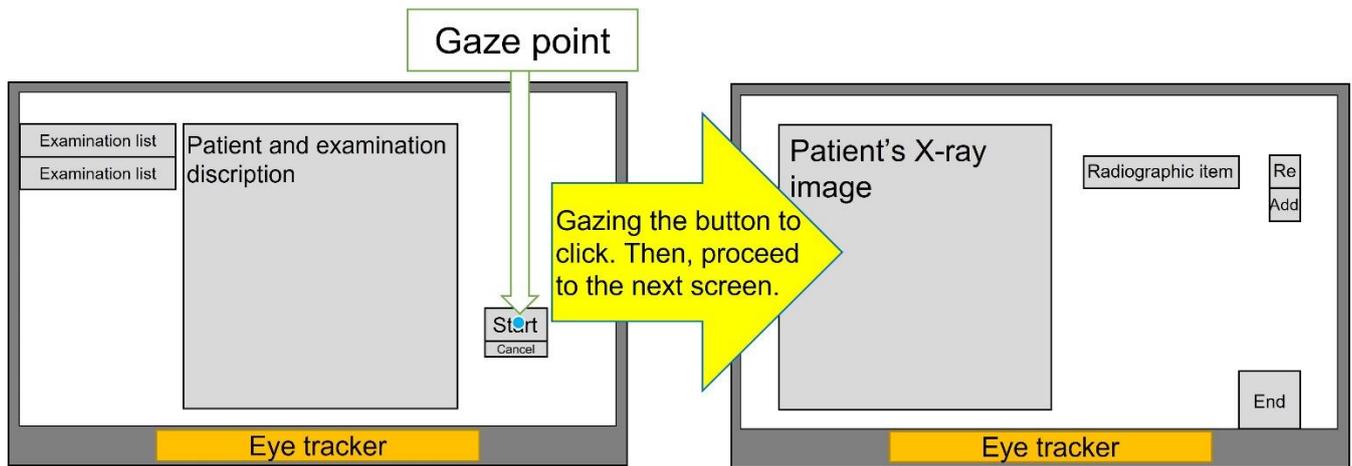


Figure 2. Operation of the radiographic console used in isolation wards. Real-time gaze analysis allows operations required in conducting examinations, such as clicking buttons based on gaze duration.

Table 1. Characteristics of the participants

Observer	Eye condition
1	Bare
2	With glasses
3	With soft contact lenses
4	With soft contact lenses
5	With soft contact lenses
6	With soft contact lenses
7	With soft contact lenses
8	With soft contact lenses
9	With soft contact lenses
10	With soft contact lenses
11	With soft contact lenses
12	With glasses
13	With soft contact lenses
14	With soft contact lenses
15	With soft contact lenses
16	Bare
17	With soft contact lenses
18	Bare
19	With soft contact lenses
20	With glasses
21	With soft contact lenses
22	With soft contact lenses
23	With soft contact lenses
24	With soft contact lenses
25	Bare
26	Bare
27	Bare
28	With soft contact lenses
29	With soft contact lenses
30	With soft contact lenses
31	With soft contact lenses
32	With soft contact lenses
33	With soft contact lenses
34	With soft contact lenses
35	With soft contact lenses
36	With soft contact lenses
37	With soft contact lenses
38	With glasses
39	With soft contact lenses
40	With soft contact lenses
41	With soft contact lenses

measured at the following nine points on the monitor: top left, top, top right, left, centre, right, bottom left, bottom, and bottom right. A gazing point was displayed on the screen to measure the error (Figure 4). The points on the four corners of the screen were displayed at a distance of 150 pixels each in the x and y coordinates from the screen edge (resolution: 1920 pixels × 1080 pixels) to assess the calibration error in the periphery as much as possible. The other five points were placed at the centre of the x and y coordinates. The coordinates of the mouse cursor while the operator was gazing at each point were measured five times. The measurement results were averaged to reduce measurement error due to nystagmus. Nystagmus is a cyclic and involuntary oscillatory movement of the eyeball. The effect of physiological nystagmus was reduced. The distance was calculated from the obtained coordinates. The calibration error was defined as the distance between actual gaze point which is the location coordinates of gazed by observer and the detection point coordinates for each of the nine points.

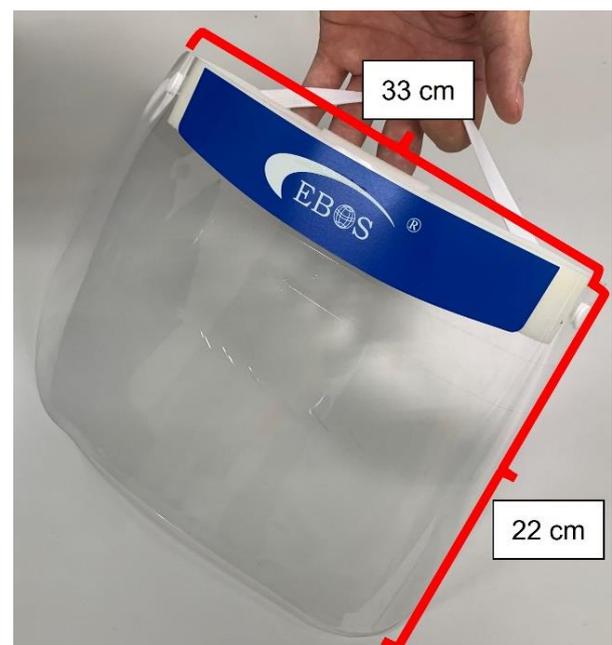


Figure 3. Image of the face shield made of polyethylene terephthalate (Logi Meister, Osaka, Japan) used in this study.

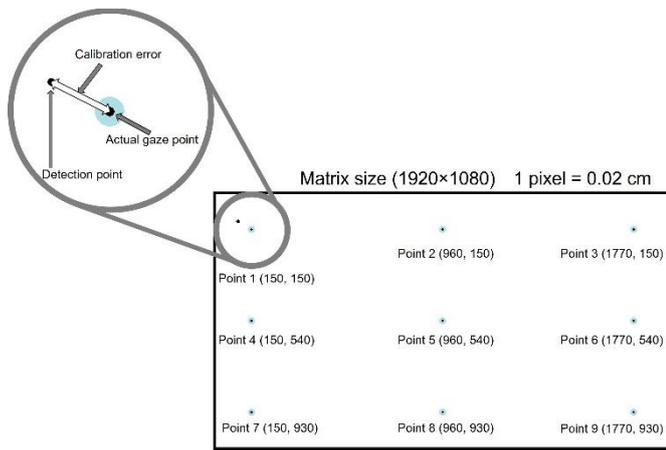


Figure 4. Illustration of the nine measurement points evaluated in this study. The calibration error was measured by calculating the difference in the coordinates between the detection and actual gaze points.

In experiment 2, the developed system was used to evaluate the operability of the console simulating the radiographic console attached to the flat panel detector system while the operator is wearing a face shield. This radiographic console simulated that used in the clinical setting (Console Advance DR-ID300CL; Fujifilm, Tokyo, Japan) and was divided into the patient selection (Figure 5 a), radiographic item confirmation (Figure 5 b), and (3) radiographic screens (Figure 5 c). The clicked locations are listed below.

- (1) Patient selection screen: Select a patient from the list (Figure 5 a-1)
- Select button (Figure 5 a-2)
- (2) Radiographic item confirmation screen: Start examination button (Figure 5 b-3)
- (3) Radiographic screen: Select the radiographic item (Figure 5 c-4)
- Re-imaging process (Figure 5 c-5)
- Add the same type of imaging (Figure 5 c-6)
- Click the End button (Figure 5 c-7)

These buttons measured 26 cm × 1 cm, 3 cm × 1 cm, 4 cm × 2 cm, 10 cm × 2 cm, 2 cm × 2 cm, 2 cm × 2 cm, and 4 cm × 4 cm, respectively. The experimental procedure was based on the actual examination procedure, and the console was operated in the order of patient selection, confirmation of radiographic items, and operation of the radiographic screen (Figure 6). The time between the start of the operation and the completion of clicking the end button was measured. The number of clicks on the screen was recorded, as was the number of clicks caused by accidental eye pauses. The procedure mentioned above was performed five times with each observer.

2.3. Statistical analysis

The data obtained were the calibration errors at each of the nine positions under the two face shield conditions in experiment 1. We used the paired t test to investigate whether significant differences existed in the average calibration error of all observers. We also investigated whether significant differences existed in the average calibration error at each point for all observers. A value of $P < 0.05$ was considered statistically significant.

The average operation time and the average misoperation time for the radiographic console were obtained in experiment 2. Moreover, we investigated whether the calibration errors obtained from experiment 1 was correlated with the average

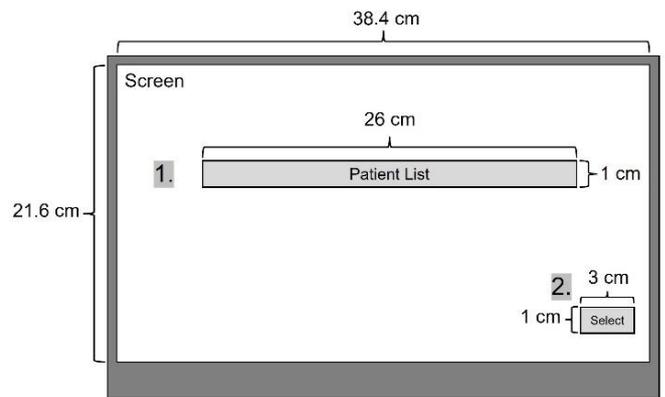


Figure 5 a. Components of the radiographic console used in this study (Patient selection). The numerals in boldface indicate the button click steps.

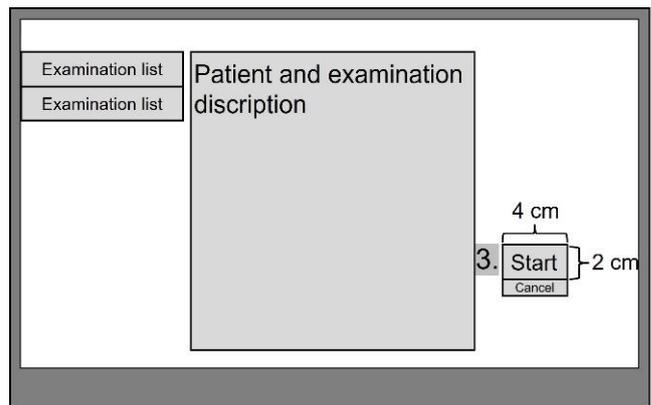


Figure 5 b. Components of the radiographic console used in this study (Radiographic item confirmation). The numerals in boldface indicate the button click steps.

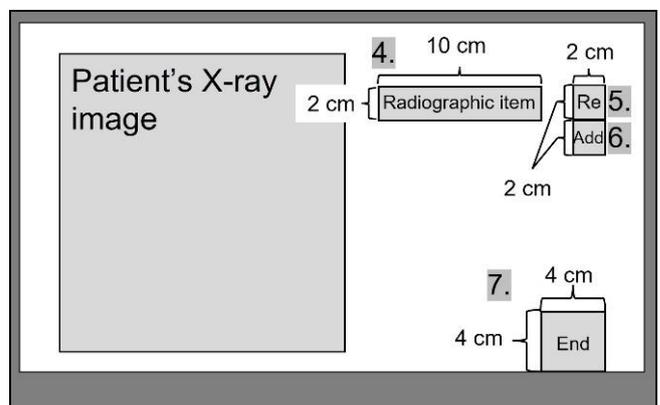


Figure 5 c. Components of the radiographic console used in this study (Radiographic screens). The numerals in boldface indicate the button click steps.

operation time and the average number of misoperations. Furthermore, the correlation between the average operation time and the average number of misoperations was evaluated via Pearson's product-moment correlation coefficient analysis. The results ranged from -1.0 to 1.0, with -1.0 and 1.0 representing a negative and positive correlation, respectively. An absolute value of < 0.2 was defined as almost no correlation; 0.2 – 0.4, weak correlation; 0.4 – 0.7, medium correlation; and ≥ 0.7 , strong correlation. A P value of < 0.05 indicated a correlation between the two face shield conditions.

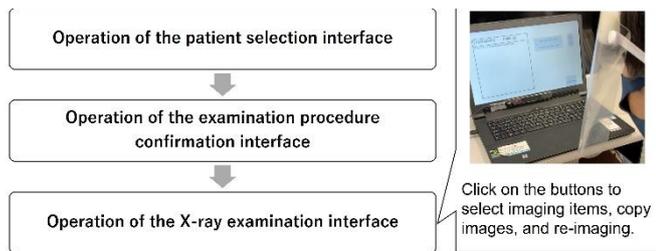


Figure 6. Overall scheme of the experimental procedure.

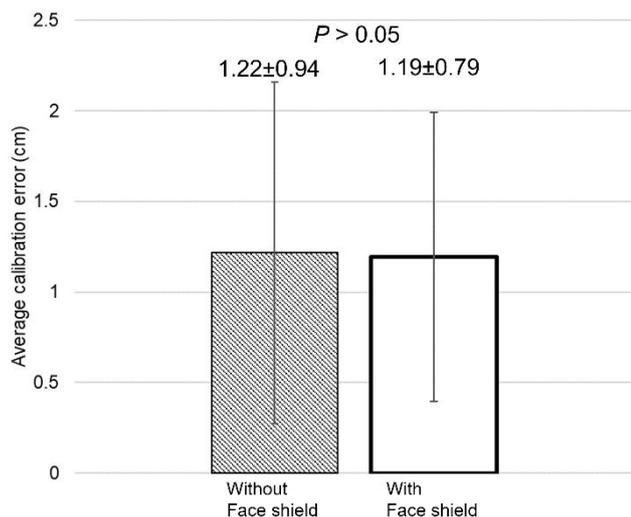


Figure 7. Comparison of calibration errors between the use and nonuse of a face shield at all measurement points for all observers.

3. RESULTS

3.1. Experiment 1

The average \pm standard deviation (SD) calibration errors at all points for all observers with a face shield and those without a face shield were 1.22 ± 0.94 cm and 1.19 ± 0.79 cm, respectively (Figure 7). No significant difference between the two face shield conditions was observed. Data about the average calibration error at each point for all observers are shown in Figure 8. The nine measurement points corresponded to top left, top, top right, left, centre, right, bottom left, bottom, and bottom right. Only measurement point 7, which represented the bottom left, had a

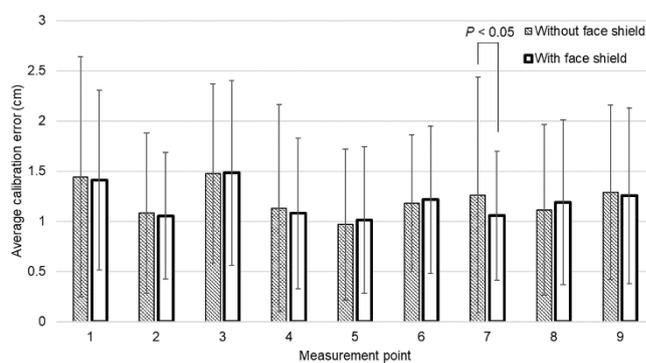


Figure 8. Calibration errors according to measurement point.

significantly larger calibration error in the no face shield condition. Data about the average calibration error for all points for each observer are shown in Figure 9. There was no tendency for operation either with a face shield or that without a face shield to be consistently larger, although significant differences were observed for 16 of the 41 observers.

3.2. Experiment 2

Although students and not radiologists participated in this study, they were able to operate the console easily. There was no significant difference between the calibration error of the eye tracker with and without the face shield. The results of the experiment revealed that all observers ($n = 41$) were able to operate the console. The average operation time was 37.89 ± 24.22 s, and the average number of misoperations was 5.4 ± 4.1 . Pearson's product-moment correlation coefficient analysis found a very strong positive correlation ($r = 0.92$, $P < 0.001$) between the average time required to complete the operation and the average number of misoperations (Figure 10 a). It found no correlation ($r = 0.24$, $P = 0.13$) between the average operation time and the calibration error (Figure 10 b) also between the average number of misoperations and the calibration error ($r = 0.28$, $P = 0.08$) (Figure 10 c).

4. DISCUSSION

There have been no studies to utilize eye tracker for infection control of SARS-CoV-2. In previous study, there are methods to manipulate image display systems using motion sensors [19]-[24]. however, there are very few cases in which manipulation was achieved using an eye tracker. Therefore, the study by use of an

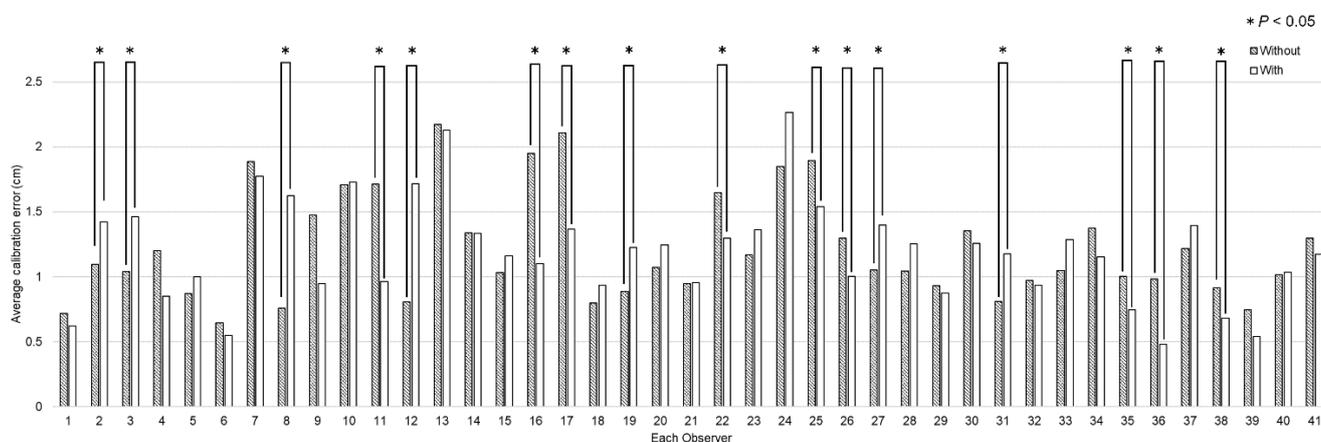


Figure 9. Calibration errors of all measurement points according to observer. Significant differences were detected between some observers.

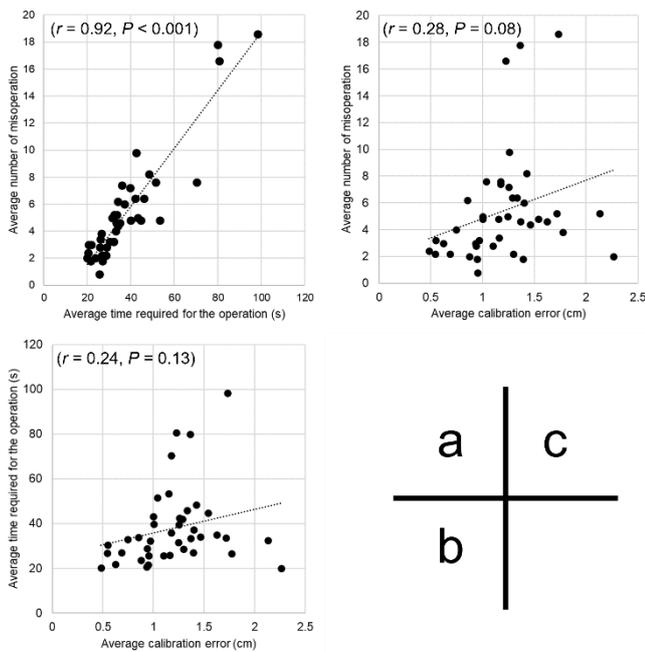


Figure 10. a) – c) Results of Pearson's product–moment correlation coefficient analysis of the manipulation experiment data obtained for each observer.

eye tracker was state-of-the-art. Furthermore, it is versatile and useful because it can be used not only for SARS-CoV-2, but also for infection control against other viruses and pathogenic bacteria.

The method proposed in this study can not only prevent the risk of contact infection but also save supplies and improve the time efficiency of disinfection. The mean calibration errors at all points for all observers did not significantly differ with and without the use of face shield. Forty-one observers participated in this study, representing a relatively large number of people.

One of the primary characteristics of eye detectors is that the four corners of the screen are prone to errors during calibration. In this study, we followed the guidance of the calibration system attached to the eye tracker, made the distance between the computer screen and the observer constant, and calibrated the system to have the same geometric arrangement. However, because the pupil centre corneal reflection method was used to detect the shape of the eyeball and the position of the reflection of infrared light on the eyeball, even a slight shift in position may have affected the calibration error. Nevertheless, poor operability on the four corners of the screen is not an uncommon outcome. In such a case, operability can be improved by placing the buttons closer to the centre and making them appear with gazing time or eye movement.

The larger the calibration error, the larger is the gap between the gazed position and the coordinates of the mouse cursor. Therefore, there was a possibility of accidental clicking on a position other than the button owing to calibration errors. Moreover, the larger the calibration error, the more difficult it was to adjust the click position with the gaze point, which could increase the average operation time. Pearson's product–moment correlation coefficient analysis showed that there was a very strong correlation between the average operation time and the average number of misoperations. However, there was no correlation between the average calibration error and the average operation time and average number of misoperations. Although it is natural for the operation time to increase with the number

of misoperations, because the average calibration error does not correlate with the average number of misoperations, it is possible that a small calibration error, such as that in this study, would not have a significant impact on usability. Nevertheless, when we obtained feedback on the system's operability from observers after the experiment, several stated that the buttons were difficult to operate because of their small size and that they were able to click on the button by moving their eyes according to the amount of the shift when they clicked on a position different from the one they were looking at. Therefore, it is possible to reduce the effect of calibration error via the operator's effort, although the operation time will tend to increase because of misoperation. Despite the system's potential, its user interface needs to be improved because it can be easily operated at the same level as the current touch pad or touch panel operation for clinical use.

However, the average operation time was longer (20–80 s) than that when the same operation was performed with a mouse (approximately 10 s). The eye tracker was affected by the calibration error, and the detection results showed coordinates that were slightly different from the actual gaze point. Therefore, even a calibration error of a level that would not be problematic in such studies as a gaze analysis would be problematic in such cases as this one that require detailed button operation of the imaging console. We considered that this was a result of the small size of the buttons. If the button size is smaller than the calibration error, then it could be difficult to operate (Figure 11).

This study showed that it is possible to operate imaging consoles while wearing a face shield. Although it is difficult to immediately introduce this technology to the clinical setting, it can be used in clinical practice in the near future because the usability of the radiographic console can be improved by simply increasing the size of the buttons. Furthermore, the observers in this study were students; the system we developed is useful as it can be operated by observers who are not familiar with radiographic consoles. Taken together, the proposed manipulation method that used an eye tracker for infection control is not ready for clinical use. However, because it can be used even when a face shield is worn, its clinical application is feasible with improvements in the radiographic console.

It is necessary to improve the eye tracker and the UI in order to use the method in actual clinical situation. The first priority should be improvement of the UI. As mentioned above, the influence of calibration error can be reduced by improving the button size. Although the observer determined the operating position according to the system's instructions during the experiment, operation was possible even if the observer's position was slightly moved. However, there were cases when the gazing position could not be detected correctly while the operating position differed significantly from the position at the calibration. As a mentioned above, the usable distance of the eye

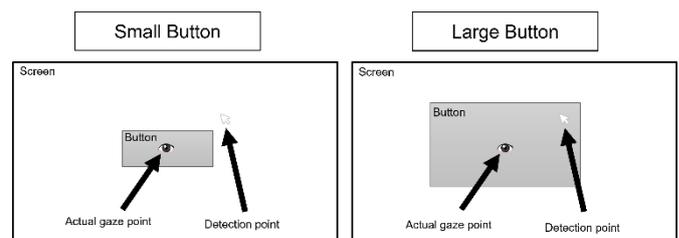


Figure 11. Effect of button size characteristics on difficulty in operating our contactless system that used an eye tracker. If the button size is larger than the calibration error, then the misoperation can be reduced if the button is pressed.

tracker ranges from 45 to 85 cm, which is approximately equal to the distance from which touch panel operation and/or mouse operation is performed. Therefore, it is usable within the range of normal use.

It was possible that the eye tracker would be unusable in the existence of natural light. However, experiments in this study were conducted in a laboratory where natural light existed and under fluorescent lighting. In other words, the experiments were conducted in an environment similar to a hospital room. In addition, there are cases in which eye tracker was used in hospital rooms in previous studies, although these studies were not directly operating computers [29], [30]. Therefore, we believe that the system in this study can be used without problems in the isolation ward where it is planned to be used.

5. CONCLUSIONS

Feasibility of a contactless operation system for radiographic consoles using an eye tracker for SARS-CoV-2 infection control has been demonstrated by this study.

The system developed in this study is extremely useful even when the operator uses a face shield. However, because of its long average operation time, a radiographic console designed with an eye tracker should be developed for daily clinical use. Thus, our proposed method can be useful for controlling not only SARS-CoV-2 infection but also other potential conditions in the future.

6. ACKNOWLEDGEMENT

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7. RESEARCH ETHICS AND PATIENT CONSENT

All procedures involving human participants were performed in accordance with the ethical standards of the relevant institutional and/or national research committee and the Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all participants. This research, which involves the development of a medical device operation system, specifically an image display system, using a contactless device, was approved by the Ethical Review Committee of Gunma Prefectural College of Health Sciences (approval no.: 2020-16). This work was not previously published in part or its entirety.

8. DECLARATION OF CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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