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Analysis of gaze points for mouth images using an eye tracking system

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ABSTRACT

Purpose: We aimed to clarify whether people stare at non-esthetic restorations by analyzing the gaze point of laypersons looking at mouth images with intraoral non-esthetic restoration.
Methods: The gaze points of 47 laypersons who do not visit dentists were measured using an eye tracker. The stimuli were 18 photographs of mouths with or without a non-esthetic tooth restoration, each randomly shown for 5 s. The analysis sites included a tooth with non-esthetic restoration and the same tooth on the opposite side of the mouth. We measured the proportion of participants who first fixated on each analysis site, and total fixation time for each site.
Results: In images without non-esthetic restorations, a similar proportion of participants first fixated on each analysis site. However, more participants first fixated on non-esthetic restorations when the images contained them. Total fixation time for each site did not differ significantly between the left and right sides in the images without non-esthetic restoration ($P>0.05$). Participants fixated on the non-esthetic restoration significantly more in the images containing them ($P<0.01$).
Conclusions: Within the limitations of this study, the present findings suggest that in photographs of the mouth with non-esthetic restoration on either side, the non-esthetic restoration is first gazed before the opposite side. In addition, the non-esthetic restoration is gazed longer than the opposite side, and there was no major difference in the fixation time regarding the state of non-esthetic restoration.

1. Introduction

Patients and laypersons have a strong desire to possess esthetically pleasing teeth [1–3], which has put strong emphasis on esthetic dentistry. New esthetic materials and treatments are developed on a daily basis and applied in clinical settings [4,5]. Research on the awareness of tooth esthetics has long been conducted mainly using subjective evaluation by questionnaire [6–12]. However, when people look at the mouth of others during face-to-face interactions, it is unclear as to what extent they fixate on areas considered

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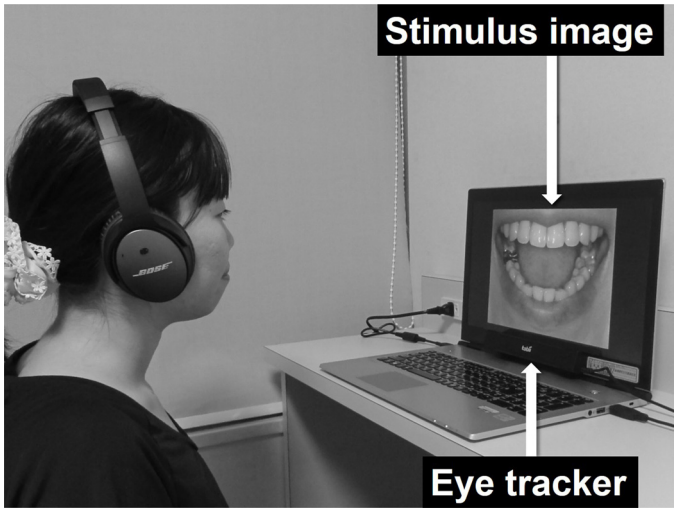

Fig. 1 – Measurement environment.

unesthetic by dentists, such as metal or discolored teeth. Restoration by means of metal crowns and other techniques is still common in the Japanese population [13]. If it is true that people stare at non-esthetic restorations, then the need for improvements in esthetic dentistry would be validated, which could lead to further developments in the field.

Line-of-sight analysis using eye-tracking is a technique used in various fields [14–18]. Eye tracking involves following the movement of a person's line of sight, which can provide information about the places people look, how long they look at these places, and the order in which they look at them. Eye tracking can also measure unconscious movements of the line of sight [19], which can provide information on people's behavior that cannot be obtained from questionnaires and interviews. In general, people move their line of sight to a subject of interest and obtain detailed visual information on this subject using foveal vision. This involves forming an image in the fovea centralis, where visual acuity is consistent with the position of the gaze point; thus, a person's visual cognitive behavior can be understood by measuring the movement of the gaze point [20]. Objective evaluation by quantifying unconscious gazing behavior is therefore needed to clarify to what extent people gaze at non-esthetic restorations in the mouth.

We previously performed a gaze point analysis in dental patients using photographs of mouths with intraoral non-esthetic restorations. Our results revealed that dental patients gaze at non-esthetic restorations and that, unlike laypersons who do not visit dentists, they were found to have a stronger interest in teeth. The aim of the present study was to clarify whether laypersons who do not visit dentists at the time of enrollment in the study gaze at non-esthetic restorations. The null hypothesis were: 'There would be no difference between the first gaze point fixation on mouth images without exposed non-esthetic restorations, and that on mouth images with exposed non-esthetic restorations on the right and left sides.', 'there would be no difference in the total fixation time at the gaze point between the tooth with non-esthetic restoration and the same tooth on the opposite side' and 'there would be no difference in the total fixation time at the gaze point regardless of the state of non-esthetic restoration'.

2. Materials and methods

2.1. *Participants*

Our research protocol was reviewed and approved by Osaka Dental University and Tezukayama Gakuin University Institutional Review Board. We posted advertisements in classroom buildings on the campus of The Tezukayama Gakuin University, faculty of Human Society to recruit Forty-seven Japanese laypersons (7 men, 40 women, mean age±SD: 23.4 ±5.4 years). The sample size was calculated on the basis of a pilot study [21]. A significance level of 0.05, effect size of 0.42, and statistical power of 0.8 were set. A necessary sample size of 47 participants was included.

Our inclusion criteria were that all participants were Japanese, have unimpaired vision with or without corrective lenses and be willing to attend the eye tracking session of about 15 min. We excluded dental students and laypersons who visit dentists at the time of enrollment in the study from participating because they might be predisposed to look preferentially at the non-esthetic restorations.

2.2. *Eye tracking system*

Eye tracking was performed using an eye tracker (Tobii X2-30, Tobii Technology Japan, Ltd., Tokyo, Japan) and analysis software (Tobii Studio Version 3.2, Tobii Technology Japan, Ltd.). The eye tracker was mounted at the bottom of a display that showed the stimulus images. Each participant were asked to sit in an upright position, with a distance of approximately 60 cm between the eye tracker and eyeball (Fig. 1). After calibration, participants were instructed to relax and freely look at images displayed on the screen. To eliminate ambient noise during measurements, participants wore noise-cancelling headphones (Bose Quietcomfort 25, Bose Corporation,

Framingham, MA, USA; Fig. 1). Gaze point measurements were performed at a sampling rate of 30 Hz, and gaze point fixation was defined as the point at which eye movement reached an angular velocity of ≤30°/s [22,23].

2.3. Recording of eye movements

The stimulus images were photographs of the mouths of two young Japanese adults (one male and one female) without non-esthetic restorations. The images were made symmetrical using image processing software (Adobe Photoshop CS3, Adobe Systems, San Jose, CA, USA), following which, non-esthetic restorations, such as prosthetic devices, were added to those processed images to create 18 total images. Each participant was asked to sit in front of a display and look at the display where photographs of male and female mouths with 3 different dental esthetic condition on either right or left side were shown; a complete metal crown on the maxillary first premolar (male mouth: M1m; female mouth: M1f), a discolored resin facing metal crown on the maxillary lateral incisor (male mouth: DRm; female mouth: DRf) and a complete metal crown on the mandibular first molar (male mouth: M2m; female mouth: M2f). Photographs of a mouth without any prosthesis were shown as controls. In each experimental condition, the following three types of images were displayed; a mouth without prosthesis (control), a mouth with prosthesis on the right side (pR), and a mouth with prosthesis on the left side (pL).

The 18 stimulus images were randomly displayed to participants for measurement, along with 36 dummy images that were not for measurement (total 54 images). For the dummy images, non-image-processed photographs of the mouth of 31 different young adults were used, in which images of the mouth with and without a poor esthetic region were mixed. These were randomly presented in order to prevent becoming used to stimulus images.

Images were presented one at a time for 5 s each. Between each stimulus image, participants were shown a full-screen black rest image for 1 s. For the dummy images, photographs of the mouths of different young adults were used. All people represented in the photographs gave informed consent. The analysis sites were bilateral maxillary first premolars in M1m and M1f, the maxillary lateral incisors in DRm and DRf, and the mandibular first molars in M2m and M2f, respectively.

2.4. Outcome parameters and statistics

The following three outcome parameters were chosen for measurement:

1) Proportion of participants who first fixated on each analysis site.

   To test this parameter, each stimulus image was examined using the chi-square test with the presence or absence of a visible non-esthetic restoration as a factor ($\alpha=0.05$). Residual analysis was performed to test the hypothesis 1. In addition, the effect size (Cramer's V) was calculated using Cohen's index as a determining factor [21].
2) Rate of total fixation time at gaze point in each region

   First, heat maps of each stimulus image for all participants were created. Then, the rate of total fixation time at the gaze point was calculated in each region and compared between the bilateral sides using the Wilcoxon signed-rank test ($\alpha=0.05$). In addition, the effect size (γ) was calculated to be determined using Cohen's index [21], the pR and pL-combined rate of fixation time at each non-esthetic restoration was compared. For statistical analysis, the Friedman test was used. When a significant difference was observed, multiple comparisons were performed using the Wilcoxon signed-rank test ($\alpha=0.05$). In addition, the effect size (γ) was calculated to be determined using Cohen's index [21].

Statistical analysis of the analysis items was performed using IBM SPSS Statistics (version 19) software (IBM Corporation, Armonk, NY, USA).

3. Results

3.1. Proportion of participants who first fixated on each analysis site (Fig. 2)

The result of M1m are shown below (Fig. 2a). In the control, the first fixation point was equally on the right and left sides (30% vs. 28% of participants, respectively), whereas in the pR, the fixation point was more on the right side (74%) than on the left side (9%), and in the pL, the fixation point was more on the left side (57%) than on the right side (13%; $P<0.05$). The results of the residual analysis revealed that participants fixated significantly more on the right side (adjusted residual=4.2) and significantly less on the left side (adjusted residual=−2.6) in the pR. However, in the pL, participants fixated significantly less on the right side (adjusted residual=−2.1) and significantly more on the left side (adjusted residual=2.5). Cramer's V was large at 0.71.

The result of M1f are shown in the following (Fig. 2b). In the control, the first fixation point was equally on the right and left sides (13% vs. 15% of participants, respectively), whereas in the pR, the fixation point was more on the right side (75%) than on the left side (4%), and in the pL, the fixation point was more on the left side (55%) than on the right side (9%; $P<0.05$). The results of the residual analysis revealed that participants fixated significantly less on the right side (adjusted residual=−2.1) and significantly more on neither side (adjusted residual=4.0) in the control. In the pR, participants fixated significantly more on the right side (adjusted residual=−4.2) and significantly less on the left side (adjusted residual=−3.0). In the pL, participants fixated significantly less on the right side (adjusted residual=−2.6) and significantly more on the left side (adjusted residual=2.3). Cramer's V was large at 0.92.

The result of DRm are shown below (Fig. 2c). In the control, the first fixation point was slightly more on the right side than on the left side (41% vs. 21% of participants, respectively). In the pR, the fixation point was more on the right side (79%) than on the left side (2%), whereas in the pL, the fixation point was more on the left side (72%) than on the right side (15%; $P<0.05$). The results of the residual analysis revealed that participants fixated significantly more on the right side (adjusted residual=4.7) and significantly less on the left side (adjusted residual=−3.2) in the pR. In the pL, participants fixated

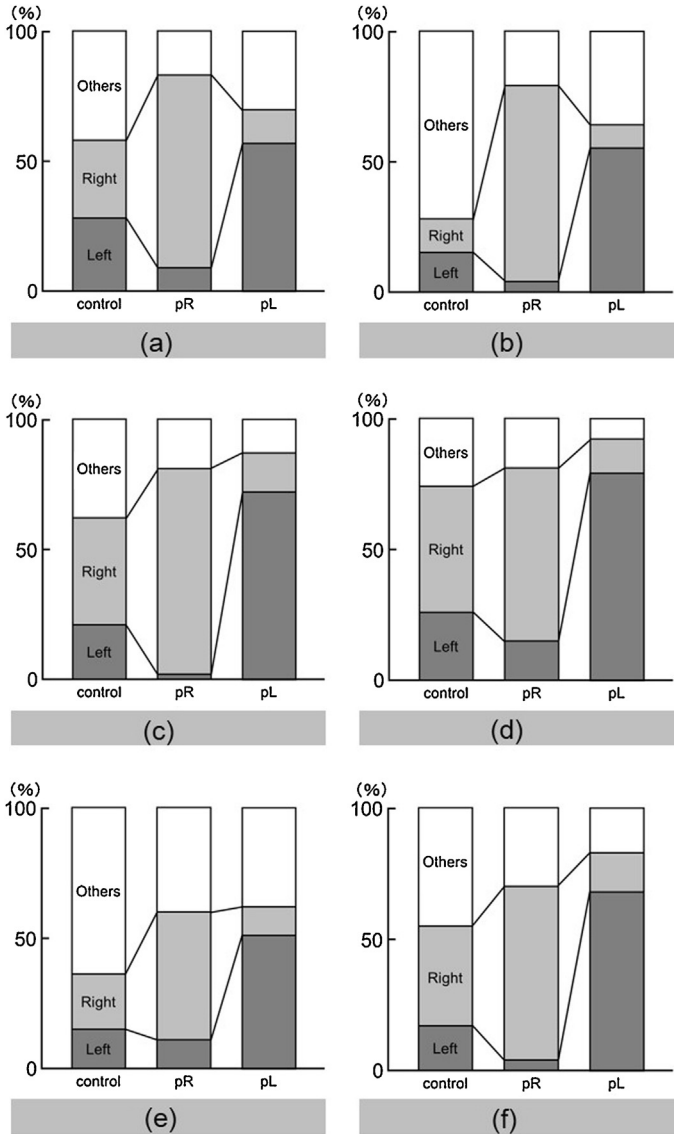

Fig. 2 – Proportion of participants who first fixated on each analysis site. (a) M1m, the case of a complete metal crown on the maxillary first premolar that was visible when smiling in male mouth; (b) M1f, the case of a complete metal crown on the maxillary first premolar that was visible when smiling in female mouth; (c) DRm, the case of a discolored resin facing metal crown on the maxillary lateral incisor that was visible when smiling in male mouth; (d) DRf, the case of a discolored resin facing metal crown on the maxillary lateral incisor that was visible when smiling in female mouth; (e) M2m, the case of a complete metal crown on the mandibular first molar that was visible when the mouth was open in male mouth; (f) M2f, the case of a complete metal crown on the mandibular first molar that was visible when the mouth was open in female mouth. In the pR, the fixation point was more on the right side than on the left side, and in the pL, the fixation point was more on the left side than on the right side ($p < 0.05$, respectively).

significantly more on the left side (adjusted residual=4.0) and significantly less on neither side (adjusted residual=−2.1). Cramer's V was large at 0.89.

The result of DRf are shown in the following (Fig. 2d). In the control, the first fixation point was slightly more on the right side than on the left side (48% vs. 26% of participants, respectively). In the pR, the fixation point was more on the right side (66%) than on the left side (15%), whereas in the pL, the fixation point was more on the left side (79%) than on the right side (13%; $P < 0.05$). The results of the residual analysis revealed that participants fixated significantly more on the right side (adjusted residual=3.4) in the pR. In the pL, participants fixated significantly less on the right side (adjusted residual=−2.1), significantly more on the left side (adjusted residual=4.7), and significantly less on neither side (adjusted residual=−2.6). Cramer's V was large at 0.84.

The result of M2m are shown below (Fig. 2e). In the control, the first fixation point was slightly more on the right side than on the left side (21% vs. 15% of participants, respectively). In the pR, the fixation point was more on the right side (49%) than on the left side (11%), whereas in the pL, the fixation point was more on the left side (51%) than on the right side (11%; $P < 0.05$).

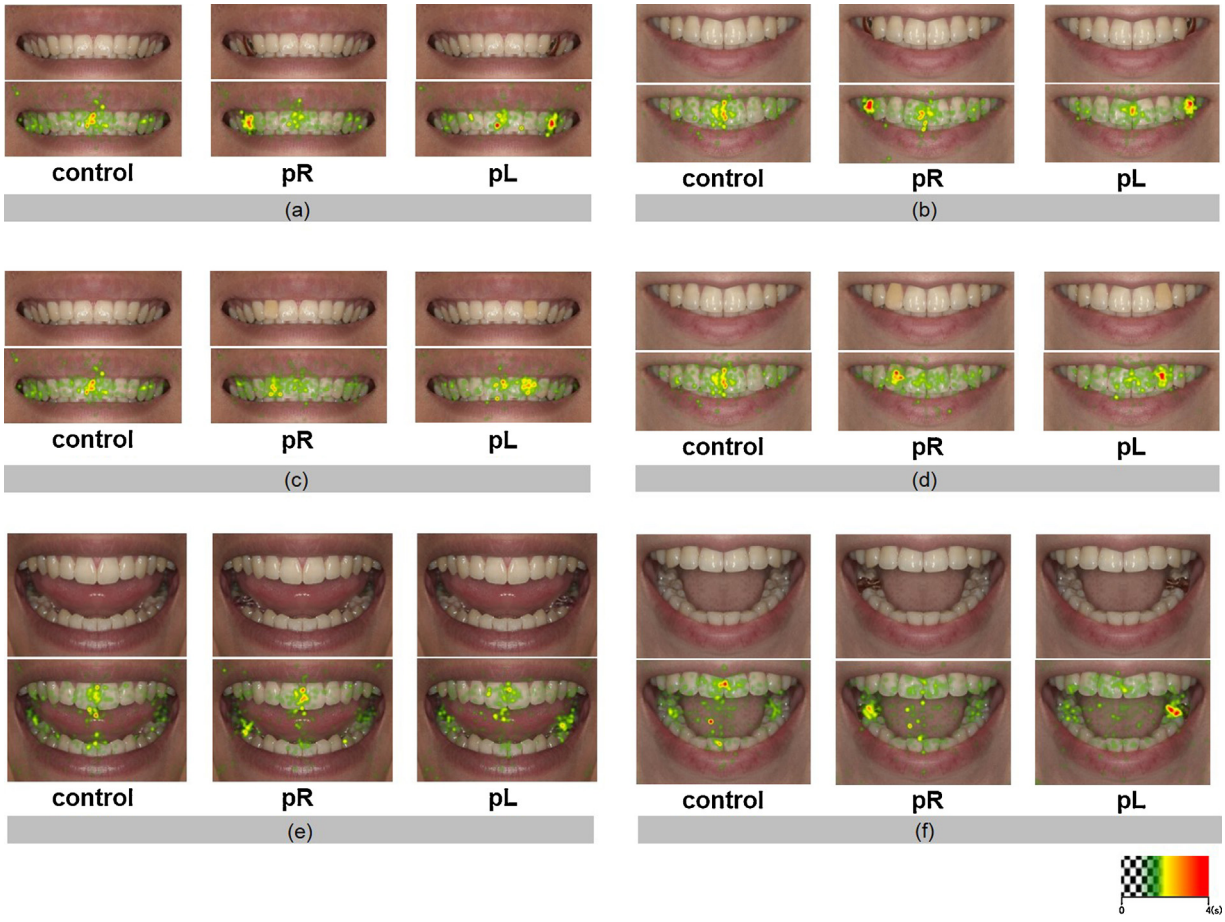

Fig. 3 – Heat maps of the total fixation time for each analysis site. (a) M1m, the case of a complete metal crown on the maxillary first premolar that was visible when smiling in male mouth; (b) M1f, the case of a complete metal crown on the maxillary first premolar that was visible when smiling in female mouth; (c) DRm, the case of a discolored resin facing metal crown on the maxillary lateral incisor that was visible when smiling in male mouth; (d) DRf, the case of a discolored resin facing metal crown on the maxillary lateral incisor that was visible when smiling in female mouth; (e) M2m, the case of a complete metal crown on the mandibular first molar that was visible when the mouth was open in male mouth; (f) M2f, the case of a complete metal crown on the mandibular first molar that was visible when the mouth was open in female mouth.

The results of the residual analysis revealed that participants fixated significantly more on neither side (adjusted residual=3.1) in the control. In the pR, participants fixated significantly less on the left side (adjusted residual=−2.3), whereas in the pL, participants fixated significantly less on the right side (adjusted residual=−2.3). Cramer's V was large at 0.64.

The result of M2f are shown in the following (Fig. 2f). In the control, the first fixation point was slightly more on the right side than on the left side (38% vs. 17% of participants, respectively). In the pR, the fixation point was more on the right side (66%) than on the left side (4%), whereas in the pL, the fixation point was more on the left side (68%) than on the right side (15%; $P<0.05$). The results of the residual analysis revealed that participants fixated significantly more on the right side (adjusted residual=3.4) and significantly less on the left side (adjusted residual=−3.0) in the pR. In the pL, participants fixated significantly more on the left side (adjusted residual=3.6). Cramer's V was large at 0.75.

3.2. *Rate of total fixation time at gaze point in each region*

The heat maps are shown in Fig. 3. There was no significant difference in the fixation time between sides (left/right) in the control, whereas there was a tendency to gaze at the non-esthetic restoration both on the right and left side (Fig. 3).

In the control, no significant differences in M1m were observed between sides (left/right) in M1m, DRm, M2m, M1f, and M2f (Tables 1 and 2). On the other hand, in the control, participants fixated significantly longer on the right side than on the left side only in DRf (Tables 1 and 2).

In the pR, participants fixated significantly longer on the right side than on the left side, whereas in the pL, participants fixated significantly longer on the left side than on the right side in each stimulus images (Tables 1 and 2).

The rate of total fixation time at each non-esthetic restoration was significantly shorter in M2m than in DRm in photographs of the male mouth ($P<0.01$) (Fig. 4a). In

Table 1 – Comparison of each region (right/left) (male mouth).

	Right median (IQR)	Left median (IQR)	P	γ
M1m				
Control	50.0 (23.9, 54.5)	50.0 (45.5, 76.1)	0.67	0.06
pR	100 (50.0, 100)	0.0 (0.0, 50.0)	0.00**	0.61
pL	27.0 (0.0, 50.0)	73.0 (50.0, 100)	0.00**	0.53
DRm				
Control	50.0 (46.6, 100)	50.0 (0.0, 53.4)	0.20	0.19
pR	100 (54.0, 100)	0.0 (0.0, 46.0)	0.00**	0.78
pL	0.0 (0.0, 38.8)	100 (61.2, 100)	0.00**	0.73
M2m				
Control	50.0 (50.0, 50.0)	50.0 (50.0, 50.0)	0.61	0.08
pR	51.7 (50.0, 100)	48.3 (0.0, 50.0)	0.00**	0.60
pL	50.0 (0.0, 50.0)	50.0 (50.0, 100)	0.02**	0.35

IQR, interquartile range.
** $P<0.01$.

Table 2 – Comparison of each region (right/left) (female mouth).

	Right median (IQR)	Left median (IQR)	P	γ
M1f				
Control	50.0 (50.0, 50.0)	50.0 (50.0, 50.0)	0.851	0.03
pR	100 (50.0, 100)	0.0 (0.0, 50.0)	0.00**	0.71
pL	22.7 (0.0, 50.0)	77.3 (50.0, 100)	0.00**	0.58
DRf				
Control	50.0 (45.0, 100)	50.0 (0.0, 55.0)	0.02*	0.34
pR	78.7 (50.0, 100)	21.3 (0.0, 50.0)	0.00**	0.65
pL	0.0 (0.0, 32.6)	84.5 (67.4, 100)	0.00**	0.72
M2f				
Control	50.0 (50.0, 83.8)	50.0 (16.2, 50.0)	0.11	0.23
pR	72.3 (50.0, 100)	27.7 (0.0, 50.0)	0.00**	0.65
pL	24.8 (0.0, 50.0)	75.2 (50.0, 100)	0.00**	0.46

IQR, interquartile range.
* $P<0.05$.
** $P<0.01$.

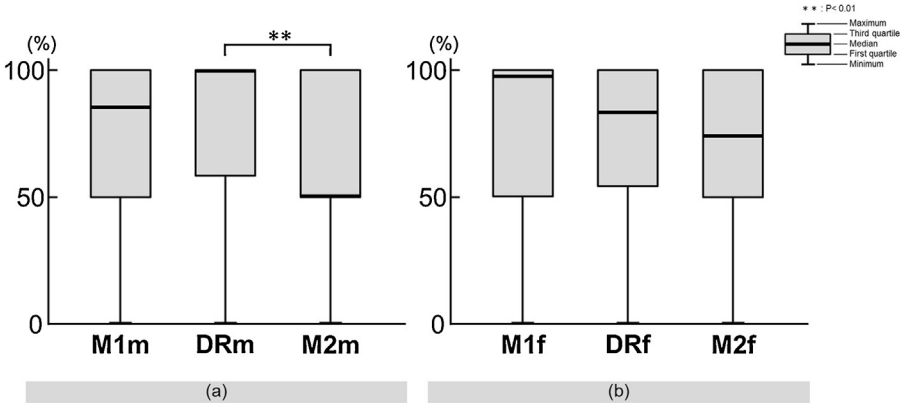

Fig. 4 – Comparison of each non-esthetic restoration (a) male mouth; (b) female mouth.

photographs of the female mouth, no significant difference was noted (Fig. 4b). The effect size was γ=0.41 between DRm and M2m and γ<0.3 in all others.

4. Discussions

4.1. *Eye tracking recordings*

The Eye tracking system used in this study enable to evaluate unconscious "gazing" behavior objectively. Gazing is quantified by gaze point analysis, which is also used in the field of dentistry [24–32]. We previously used gaze point analysis to evaluate the response to facial photographs taken with the lips closed and while smiling [31]. In the field of esthetic dentistry, this is the first attempt to use eye tracking to examine the response to prosthodontics and esthetic dentistry. We believe that this field of study requires more attention in the future for further development.

The gaze point was measured using the corneal reflection method to detect eye movement in the present study. The eye tracker shone infrared light onto the eyeball and captured the reflected image (first Purkinje image) using a camera [32]. The corneal reflection method is the most common method for measuring the line of sight without placing a large burden on participants or causing damage to health. In the present study, the eye tracker was mounted on a personal computer and highly accurate (0.5° accuracy) [32] measurements were obtained by maintaining a distance of approximately 60cm between the eye tracker and the participant's eyeball. Measurements were performed after the accuracy of gaze point analysis was guaranteed by calibrating the eye tracker using analysis software.

It is difficult to quantify the gaze point because it moves rapidly as a result of saccadic movement [33–35]. To address this, we defined gaze point fixation as an eye movement with an angular velocity of ≤30°/s, in accordance with previous reports [21,22].

Oral photographs of young adults without any non-esthetic restorations such as malocclusion, crown restoration, discoloration, or other intraoral issues were chosen as stimulus images. The stimulus images were made symmetrical, and processed such that they included a complete metal crown or a discolored resin facing metal crown. Making the images

symmetrical allowed comparison between the left and right sides of the same image. Photographs of the entire face, and not just the mouth, should be shown when assuming interpersonal communication; however, we used stimulus images of the mouth alone in the present study to improve eye tracker accuracy. Future studies should perform eye tracking analysis under conditions closer to those in actual communication. Considering the differences between male and female participants in the awareness of the external appearance of teeth [8], photographs of an individual of both sexes were used as stimulus images. Although we did not compare males and females in the present study, this will be investigated in the future.

The sites chosen for analysis were the maxillary lateral incisor and maxillary first premolar in smiling mouths, and the mandibular first molar in open mouths. Many patients worry about metallic color being visible on the maxillary premolars when smiling, and on the mandibular molars when the mouth is open. Therefore, we examined mesial teeth in the present study. We also examined the discoloration of a resin facing crown in the incisors, where esthetics are considered more important. It has already been demonstrated that central incisors attract gaze [30,31] Therefore, we only examined the lateral incisors in the present study.

A single tooth was analyzed for each participant. Previous studies have found that people gaze at the incisors most often in photographs of the mouth [30,31], and we also observed the same trend in the present study. However, to better clarify the effects of non-esthetic restorations on gazing behavior, other areas were not analyzed in the present study.

In addition to finding the significance level p, it has been pointed out that the effect size representing the size of the substantial difference should also be calculated when comparing differences [21,36–38]. Using the chi-square test, we were able to ascertain only the presence or absence of a difference in the ratio between each stimulus image. Therefore, we evaluated the relative size between each stimulus image and each analysis site using residual analysis. We also calculated the respective effect sizes. Cramer's V was calculated using the chi-square test, and γ was calculated using the Wilcoxon signed-rank test. Cohen's index was used to determine whether the effect size was large (0.5), medium (0.3), or small (0.1) [21].

4.2. *Fixation of gaze points*

The eyes determine areas with informational value within a presented image, and quickly gaze at any incongruous objects within the viewed scene [39]. In stimulus images with non-esthetic restoration, many participants first fixated on the non-esthetic side. This may be because they felt a sense of disharmony toward the non-esthetic restoration in the mouths of the photographs, which first attracted their gaze.

Fixations last longest on more important or interesting objects [39]. In other words, people fixate on a particular object to gather more information. The results showed that participants fixated significantly longer on the non-esthetic side of stimulus images showing non-esthetic restorations. Furthermore, the heat maps also clearly demonstrated that participants gaze longer at non-esthetic restorations. Patients are often worried about outwardly visible non-esthetic restorations [2], which likely explains why they consider non-esthetic restorations to be unnatural. In stimulus images without non-esthetic restoration, participants gazed at the right side significantly longer in the control of DRf. People are more likely to notice the left side than the right side in their field of vision [40], which may have resulted in markedly more gazing to the left.

A significant difference was noted in the rate of total fixation time at each non-esthetic restoration in photographs of the male mouth, but there was no overall specific tendency. The fixation time shortened in M2m, and this may have been due to a dark view of the lower molar region in M2m, being difficult for the subjects to recognize.

In the present study, laypersons who do not visit dentists were chosen as participants to objectively demonstrate that people stare at non-esthetic restorations. When planning treatment in clinical settings, conveying these facts to patients may facilitate the understanding of the need for and significance of evidence-based esthetic restoration and may improve patient quality of life. Reports of employers receiving the impression during job recruitment that those with intraoral non-esthetic restoration cannot be employed [6], and reports of young adults with normal dental appearance being more socially attractive [41] suggest that mouths with non-esthetic restoration may give a negative impression. Further research into the relationship between impressions made by non-esthetic restorations and the gaze point of others should also be performed in the future.

5. Conclusions

Within the limitations of this study using mouth images, we conclude that in photographs of the mouth with non-esthetic restoration on either side, the non-esthetic restoration is first gazed before the opposite side. In addition, the non-esthetic restoration is gazed longer than the opposite side, and there was no major difference in the fixation time regarding the state of non-esthetic restoration.

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