Evaluation of the Efficacy of Eye Tracking Software by Difference in Perception of Shade Mismatch and Dental Asymmetry in Lay-persons and Prosthodontists – A Pilot Study

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Abstract

Context: The eye is the key to understand where our attention lies. Mapping of eye movements gives a new dimension to understanding our cognition. Eye tracking can thus serve as a novel tool in the evolving world of prosthodontics. **Aims:** The aims of this study were to evaluate difference in perception of shade mismatch and dental asymmetry in lay-persons and prosthodontists using eye-tracking software. **Settings and Design:** The study design was a descriptive cross-sectional type of study. Eye tracking test was performed on two groups: Group 1 being lay persons and group 2 being prosthodontists. A series of five edited images depicting grades of shade mismatch, dental midline asymmetry along with a control image were displayed for 12 s each with separators. **Materials and Methods:** A standard image of the smile of a young patient was captured by a high-definition DSLR camera and edited by an image processing software. Eye tracking device used was Web cam-based eye tracking. The eye tracking test was performed and the data collected were subjected to statistical analysis. **Statistical Analysis:** Intergroup comparison was done using t-test. Intergroup comparison was done using one-way ANOVA followed by pair-wise comparison using post hoc test. **Results:** The abnormality best detected was midline shift by 1 mm by prosthodontists (group 2). The least detected abnormality was shade mismatch of 1°C higher chroma by Lay–persons (group 1). **Conclusions:** Prosthodontist (group 2) was able to detect dental midline asymmetry and shade mismatch faster than lay-men (group 1). Inconspicuous abnormalities in shade mismatch and slight midline asymmetry are easily caught by the trained prosthodontic eye; however, highly unesthetic restorations, obvious asymmetries are more easily perceptible to a lay-man.

Keywords: Dental midline, Esthetics, Eye tracking software, Shade selection

Introduction

Eyes are one of the most important sensory organs in the human body because it renders the vision and the power to see. When we dive into the inner workings of vision, we realize that eyes speak a unique language that communicates with the brain via nerve impulses in response to various stimuli which are projections of the eye gazing at the stimuli for varying time intervals. To understand the complexity of this language, research has evolved the eye tracking technology.

Eye tracking technology involves the study of eye movements. Eye tracking studies were first performed by Hering and Lamare in 1879.[1]

It is extensively used in the fields of academics, developers, and advertisers for gaining unparallel insight into conscious and subconscious human behavior. It has been used for qualitative and quantitative research in different fields – marketing research, website designing, human – computer interaction, and machine learning.[2]

With development in technology, compact and portable devices integrated with eye tracking softwares are available. The different eye tracking devices available are, mobile eye tracking, webcam based eye tracking, remote eye tracking, integrated, and embedded systems.[2]

Access this article online

Website: www.jrad.co.in

DOI: https://doi.org/10.53064/jrad.2022.14.2.325

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Received: Feb. 12, 2023; **Accepted:** Mar. 30, 2023; **Published:** Apr. 26, 2023

How to cite this article: Mistry SS, Nemane AS, Sampat SC, Roy MS, Bhaskar SR, Khot SV. Evaluation of the Efficacy of Eye Tracking Software by Difference in Perception of Shade Mismatch and Dental Asymmetry in Lay-persons and Prosthodontists – A Pilot Study. J Res Adv Dent 2023;14(3):1-6.

Eye tracking helps to interpret the subject's attention and fixation. The study of eye movements addresses the integration of vision and action. This integration analyses the clues that patterns of eye movements provide for examining visual and cognitive phenomena.

In medical sciences, it has found its application in the field of psychology. Gaze tracking enables the study of cognitive processes, such as – problem solving, decision making, perception, and attention. Neuroscience uses it for diagnosis of Parkinson's, Schizophrenia, Alzheimer's, and Autism. This technology helps to demonstrate and recognize comprehension of complex emotions in adults with these kinds of diseases.[3]

To explore the vistas of this technology in prosthodontics, a pilot study was undertaken in the department of prosthodontics to evaluate of the efficacy of eye tracking software by difference in perception of shade mismatch and dental asymmetry between laypersons and prosthodontists.

Materials and Methods

The study design was a descriptive cross-sectional type of study. There were 20 study participants chosen for this pilot study who had duly signed a consent form before the starting the study. They were divided into two groups: Group 1 being laypersons and group 2 being prosthodontists.

Inclusion criteria

The following criteria were included in the study:

1. Individuals having no visual impairment.
2. Individuals with glasses/contact lenses with low power prescriptions (–3.0 Diopter for individuals <40 years of age, up to +1.5 Diopter for individuals above 40 years of age)
3. Prosthodontists working in the department of prosthodontics.

Exclusion criteria

The following criteria were excluded from the study:

1. Individuals having severe visual impairment, bifocal glasses, high power prescriptions, and color blindness.

A standard image of the natural smile of a young female patient having no restorations or malocclusion in the anterior teeth was captured by a high-definition camera (Canon EOS 200 D) and edited by (Adobe Photoshop CC20™ , Adobe systems, San Jose , CA). This image was cropped and the contralateral side was mirrored and merged with original image to eliminate any asymmetries, to form the control image [Figure 1].

Figure 1: Control image

The control image was edited to give us the stimulus images. For shade mismatch, the shade of the maxillary right lateral incisor was changed by 1°C and 2°C higher chroma forming Image 1 and 2 [Figures 2 and 3], respectively. For dental

Figure 2: Image of maxillary right lateral incisor with 1°C higher chroma

Figure 3: Image of right maxillary lateral incisor with 2°C higher chroma

Figure 4: Image of 1 mm dental midline asymmetry

Figure 5: Image of 2 mm dental midline asymmetry

midline asymmetry, a midline shift of 1 and 2 mm to the left were created using the image editing software, forming Images A and B [Figures 4 and 5], respectively. The part of the image undergoing editing subsequently formed the area of interest and was the main point of focus in the study. Eye tracking device used in this study was Web cam-based eye tracking. Eye tracking software used was Real-Eye 8.14 Eye Tracking Software. The edited images were uploaded on the software and the format of the eye tracking test was designed by the software. The software created a presentation of the images in random order with a separator between each image.

All participants were made to sit upright at a standard distance of 90 cm from the laptop screen (which was at a predetermined angulation of 15°) in a controlled environment of light and sound (a common light source used, no noise and movement for distraction). After calibration, participants were instructed to relax and look at the presentation with images of shade mismatch and midline asymmetry and were asked to gaze at them [Figure 6]. A total of five images (including the control image) were viewed by the participant for 12 s each. A separator was displayed between each image to prevent eye fatigue. The gaze path of each participant was recorded by the eye tracking software, utilizing the laptops web-camera. The recordings were displayed in the form of heat maps with color variations where red symbolizing the most viewed zone, yellow/green- intermediately viewed zones, and blue/violet – least viewed zone[4] [Figures 7 and 8].

The heatmap generation with time was provided in a video format by the software and was analyzed for each participant. The time at which the gaze first landed on the area of interest for each participant was their primary fixation for that abnormality.

Figure 6: Participant undergoing eye tracking test

The maximum time they viewed the abnormality was their maximum fixation for the same. This was performed for every participant per image and a total of 100 such heatmaps were subjected to interpretation. Primary and maximum fixation for areas viewed other than the area of interest for each participant per image was also recorded. The data were collected on the basis of the heat maps generated for primary fixation and maximum fixation for each participant and were subjected to statistical analysis.

All data were entered into a computer by giving coding system, proofed for entry errors. Data obtained were compiled on a MS Office Excel Sheet (v 2019, Microsoft Redmond Campus, Redmond, Washington, United States). Data were subjected to statistical analysis using the Statistical Package for the Social Sciences (SPSS v 26.0, IBM). Descriptive statistics such as frequencies and percentage for categorical data, mean, and SD for numerical data has been depicted. Intergroup comparison (2 groups) was done using t test. Intergroup comparison (>2 groups) was done using one-way ANOVA followed by pair-wise comparison using *post hoc* test. For all the statistical tests, $P < 0.05$ was considered to be statistically significant, keeping α error at 5% and β error at 20%, and thus giving a power to the study as 80%. Statistical analysis is as follows [Tables 1 and 2].

Results

Group 2 – Prosthodontists were able to detect the abnormality faster than group 1-layperson. Subtle abnormalities in shade mismatch and slight midline asymmetry are easily caught by the trained prosthodontic eye. The abnormality best detected was Image A (midline shift by 1mm) [Figure 4] by Group 2 – prosthodontists. The least detected abnormality was Image 1 (shade mismatch of 1°C higher chroma) [Figure 2] by Group 1 – Laypersons. Group 1 – Lay persons identified abnormalities showing maximum discrepancy faster as compared to subtle abnormalities. This indicates that, highly unesthetic restorations, obvious asymmetries are more easily perceptible to a layperson. It was also observed that Group 1 – Lay persons focused more on areas other than the area of interest.

Discussion

Eye tracking technology analyses gaze points and fixations. It provides insights in human mind when combined with

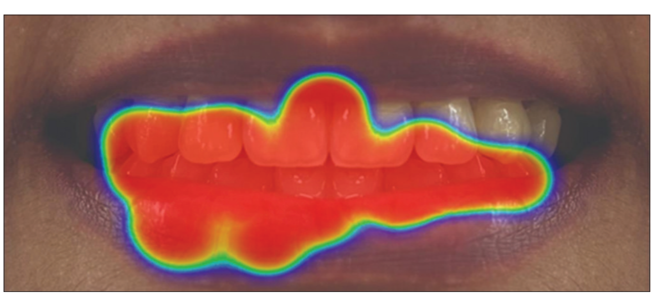

Figure 7: Heatmap generated for group 1

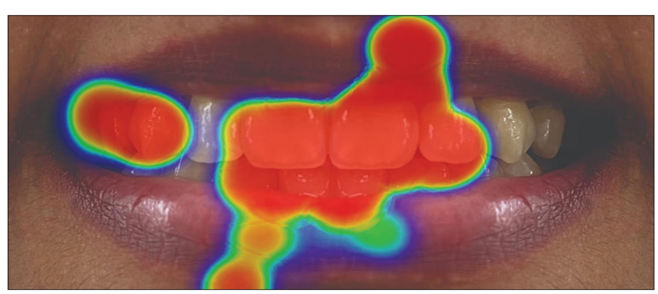

Figure 8: Heatmap generated for group 2

Table 1: Statistical analysis is as follows

Parameter	Group	Mean deviation	SD	P
AOI control image primary fixation at	1	3.050000	1.3834337	0.006**
	2	1.590000	0.5404730	
AOI control image maximum fixation for	1	1.490000	1.0608697	0.067
	2	2.434000	1.1011126	
AOI lateral incisor image 1 primary fixation at	1	3.790	1.2369	0.000**
	2	1.190	0.1853	
AOI lateral incisor image 1 maximum fixation for	1	0.826000	0.5136406	0.000**
	2	3.220000	0.6679987	
AOI lateral incisor image 2 primary fixation at	1	3.930	2.5910	0.002**
	2	0.970	0.1636	
AOI lateral incisor image 2 maximum fixation for	1	1.1500	0.47434	0.000**
	2	3.6020	0.73032	
AOI dental midline image A primary fixation at	1	4.440000	0.9167576	0.000**
	2	1.410000	0.6919377	
AOI dental midline image A maximum fixation for	1	2.180000	1.0549355	0.077
	2	2.970000	0.8138386	
AOI dental midline image B primary fixation at	1	3.900	1.8529	0.000**
	2	0.770	0.3199	
AOI dental midline image B maximum fixation for	1	1.800000	0.6749486	0.000**
	2	3.650000	1.0865337	

SD: Standard deviation, AOI: Area of Interest

Table 2: Statistical analysis is as follows

Primary fixation	Mean	SD	SE	P value of one way ANOVA
Control image-group 1	3.530000	2.0784877	0.6572755	
Image 1-group 1	2.751000	2.2871644	0.7232649	
Image 2-group 1	2.020000	1.8207447	0.5757700	
Image A-group 1	2.020000	1.3339998	0.4218478	
Image B-group 1	2.720000	2.3789820	0.7523002	
Control image-group 2	5.630000	1.9966917	0.6314094	0.000
Image 1-group 2	5.440000	1.3268174	0.4195765	
Image 2-group 2	4.800000	1.7669811	0.5587685	
Image A-group 2	6.460000	0.8783824	0.2777689	
Image B-group 2	5.640000	1.5370968	0.4860727	
Image 1-group 1	2.160000	1.2997436	0.4110150	
Image 2-group 1	2.220000	0.8916900	0.2819771	
Image A-group 1	1.720000	0.8066391	0.2550817	
Image B-group 1	1.900000	0.9944289	0.3144660	0.592
Control image-group 2	1.570000	0.6147267	0.1943936	
Image 1-group 2	1.670000	0.4762119	0.1505914	
Image 2-group 2	1.840000	0.5561774	0.1758787	
Image A-group 2	1.720000	0.4211096	0.1331666	
Image B-group 2	1.550000	0.3807887	0.1204159	

SE: Standard deviation, SE: Standard error

biosensors such as ECG, EEG, EGA, and EMG.[5] Applications of eye tracking technology can be broadly divided into 1. Human factor based and 2. neuroscience based. Human factor-based applications include – human machine interaction, human computer interaction, and brain computer interaction, which improves user interaction user experience.[6] Neuroscience based applications include – Psychology, cognition, identification of developmental disorders in children, and understanding of eye physiology.[3] Eye tracking is used as an important tool and can be integrated with multiple technologies independently or within their set of parameters.

It has provided unique insight into user interaction and user experience. It hence has been used widely in high quality market research findings.[6] Its application has been established in medical science; with further development, this technology could revolutionize dental sciences as well. This technology has provided application in using artificial intelligence in prosthodontics. Eye tracking has been used to improve functionality of myoelectric prosthetic hands and studies are being carried out to improve the scope of this technology in prosthodontics.[7]

In the present study, webcam-based eye tracking technology was utilized due to its ease in use, portability, easier metrics, and no requirement of any specialized hardware and has an accuracy up to 113 pixels.[8]

The smile of an individual is the first feature noticed, during human interaction. Therefore, an image of the natural smile of a young female patient was chosen. The two parameters chosen, that is, shade mismatch and dental midline asymmetry are the most subjective and maybe perceived differently among prosthodontists with varying experiences as well as between laypersons and prosthodontists. The central incisor is the most viewed tooth, to avoid this bias the lateral incisor was chosen for shade mismatch.[9] For this study, the two parameters were chosen – change in chroma of lateral incisor by 1°C and 2°C and dental midline asymmetry by 1 mm and 2 mm, respectively and the series of images were modified. These were chosen because subtle shade mismatches and slight midline asymmetries cannot be perceived by layperson, but it can be perceived by only experienced prosthodontist. The response to the slightest abnormality/difference in shades will differ between a prosthodontist and lay person, which was objectively demonstrated by eye tracking software.

The eyes determine areas with informational value within a presented image and quickly gaze at incongruous objects. Studies by Suwa *et al.*, 2001[10] and Yamamoto *et al.*, 2015[11] have found that people gaze incisors most often in photographs of the mouth and a similar trend was observed in this study. In this study, significant differences were observed in the gaze pattern and heatmaps of both groups. Heatmaps can be based on fixation duration or fixation count, both relative and absolute. Heat maps show how looking is distributed over the stimulus.

Heat maps are a visualization that can effectively reveal the focus of visual attention. Esthetics is an important consideration in any rehabilitation procedure. The trained eye of a prosthodontist could detect easily the subtle abnormalities. The primary fixation for the same was found to occur faster than Laypersons. However, intragroup differences were observed in the two groups as well. In the present study, it was seen that there is corelation between years of clinical experience and the ease in detection of abnormality. A more experienced prosthodontists primary fixation on the area of interest was faster than that of a novice. Laypersons gazed easily and for a longer time at obvious asymmetries. Subtle discrepancies and minor asymmetries were not easily perceptible to them. Prosthodontists were able to detect subtle asymmetries easily as compared to lay persons. This study demonstrates accuracy of the prosthodontic eye which was measured objectively by eye tracking software in dentistry for the first time. It is a fast and non-invasive technology giving results in real time. Eye tracking technology has certain limitations like the Hawthorne effect (change in an individual's behavior when the know they are under observation),[12] Midas touch problem (unintentional eye movements cause generation of gaze fixations on the interface which will lead to its activation even when the user has no such intention),[13] higher or lower number of fixation can state different conclusions and is ineffective when the user squints his/her eyes. Limitations of the study include, the inability of the software to not process unintentional eye movements by the user and availability of more sophisticated devices to perform eye tracking tests. Certain challenges encountered during this study were lower pixel quality of the software used (Real-Eye 8.14 Eye Tracking Software) and difficulty in heatmap evaluation due to its subjectivity as it was individual operator based.

With development of technology, more sophisticated devices (Mobile eye tracking, Remote eye tracking, and Integrated and Embedded systems) integrated with advanced eye tracking softwares are now available. These devices have high precision, high-definition spatial acuity can detect eye movements in all types of lighting. These devices are programmed to compensate for unintentional head movements and prevent loss of calibration in such cases. These devices can be used on a range of participants from infants to geriatric patients. The degree of accuracy ranges from 0.4 to 0.1° whereas, that of webcam-based eye tracking is 5–6°. Devices with higher accuracy capture gaze points at a higher frequency meaning a higher number of frames are captured per second as compared to web cam based systems thus improving the precision of eye tracking test. Webcam-based eye tracking systems, which were used in this study are not dedicated stereo-based systems to capture and measure 2D objects.[14]

The limitations of this study were that, it was a pilot study; however, more definitive research including a larger study population as well use of more sophisticated eye- tracking devices and softwares are necessary to be performed to explore the applications of this novel technology in prosthodontics. Future scope of this technology includes application in maxillofacial prosthodontics, smile designing, shade selection, patient education and awareness, and improved communication between clinician and patient. Eye tracking technology can be further explored to create standard devices equipped with eye tracking technology, designing of more efficient systems, deeper insight into neurosciences, enhanced user interaction and user experience, and transforming the world of prosthodontics. Thus, this novel technology can help us talk of our mind through our eyes.

Conclusions

Prosthodontist (Group 2) were able to detect dental midline asymmetry and shade mismatch faster than lay-men (Group1). Inconspicuous abnormalities in shade mismatch and slight midline asymmetry are easily caught by the trained prosthodontic eye; however, highly unesthetic restorations, obvious asymmetries are more easily perceptible to a lay-man.

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