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PRS GLOBAL OPEN

ORIGINAL ARTICLE

Craniofacial/Pediatric

The Use of Eye-tracking Technology in Cleft Lip: A Literature Review

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Background: Eye-tracking has become an increasingly popular research tool within the field of cleft lip and/or palate (CL+/−P). Despite this, there are no standardized protocols for conducting research. Our objective was to conduct a literature review of the methodology and outcomes of previous publications using eye-tracking in CL+/−P.

Methods: The PubMed, Google Scholar, and Cochrane databases were searched to identify all articles published up to August 2022. All articles were screened by two independent reviewers. Inclusion criteria included using eye-tracking, image stimuli of CL+/−P, and outcome reporting using areas of interest (AOIs). Exclusion criteria included non-English studies, conference articles, and image stimuli of conditions other than CL+/−P.

Results: Forty articles were identified, and 16 met the inclusion/exclusion criteria. Thirteen studies only displayed images of individuals following cleft lip surgery with three only displaying unrepaired cleft lips. Significant variation was found in study design, particularly in the AOIs used to report gaze outcomes. Ten studies asked participants to provide an outcome score alongside eye-tracking; however, only four compared outcome data to eye-tracking data. This review is primarily limited by the minimal number of publications in this area.

Conclusions: Eye-tracking can be a powerful tool in evaluating appearance outcomes following CL+/−P surgery. It is currently limited by the lack of standardized research methodology and varied study design. Before future work, a replicable protocol should be developed to maximize the potential of this technology. *(Plast Reconstr Surg Glob Open 2023; 11:e4980; doi: 10.1097/GOX.0000000000004980; Published online 22 May 2023.)*

INTRODUCTION

The appearance of the face is critical for many aspects of social functioning, with people perceived as "attractive" enjoying many social advantages.[1] Facial symmetry has been demonstrated as an important factor in being considered attractive. Cleft lip with or without cleft palate (CL+/−P) may cause significant facial asymmetry and visible facial differences. Children have reported teasing, bullying, and struggling to fit in due to their cleft.[2]

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Received for publication December 12, 2022; accepted March 17, 2023.

DOI: 10.1097/GOX.0000000000004980

Furthermore, parents of children with CL+/−P may experience higher levels of psychological stress compared to parents of non–CL+/−P children.[3] Such added difficulties can lead to impaired interaction between parents and their children. Impaired interaction and developmental difficulties have been shown to be worse in patients following delayed initial cleft lip surgery.[4] Therefore, it can be inferred that the appearance outcome of the operation plays an important role in the interaction and development of children born with a cleft lip. Despite the importance of appearance outcomes postrepair, there is no internationally agreed-upon system to measure them objectively and reliably.[5]

There are several types of eye-tracking hardware including screen-mounted (Fig. 1) or mobile (eye-tracking glasses).[6] Such devices often function in combination with software to record data, whereas participants gaze

Disclosure statements are at the end of this article, following the correspondence information.

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at either stationary (photographic) or moving (videographic) stimuli. Commonly, investigators collect data using areas of interest (AOIs); which are predefined selections of an image that are of particular significance to the project.[6] Furthermore, the two most common eye-tracking metrics for data reporting are fixation-based metrics and movement-based metrics.[6] Fixation metrics include fixation frequency or fixation count in an AOI or time to first fixation of a specific AOI, whereas movement metrics include scanpaths.[6] The unique ability of eye-tracking to objectively determine the most frequently gazed upon areas in an image represents an area of potential utility in cleft surgery outcome research. Comparing gaze patterns in noncleft images to unoperated and operated cleft images may provide insight into which areas of the face draw particular interest and therefore should be carefully evaluated when planning for or evaluating the appearance outcome following the cleft lip surgery.

Eye-tracking has emerged as a common research tool for assessing postoperative outcomes within appearance-changing surgery. It has been used in various subspecialities including cosmetic surgery, facial reconstructive surgery (ear, nose, cleft), and breast reconstructive surgery.[7–10] There has been significant interest in the use of eye-tracking for the assessment of appearance outcomes in cleft surgery as this is the subspeciality within plastic surgery with the greatest number of previous eye-tracking publications.[6] This may indicate that there is a lack of robust appearance measurement techniques and the ongoing interest in finding an objective method of assessment. This review synthesizes and appraises all previous publications using eye-tracking in the field of CL+/−P. The first objective of this study is to provide a comprehensive summary of the methodology and results of prior eye-tracking studies in the field of CL+/−P. The second objective is to provide guidance on study design and make recommendations to create a standardized research protocol for future studies.

Takeaways

Question: What are the current eye-tracking research methods and results used in the field of cleft lip and palate?

Findings: We found and reviewed a total of 16 articles. There was wide variation found in all aspects of study design including image presentation, areas of interest, and data reporting. Observers generally spent more time fixating the lip of cleft patients, compared to the eyes in control images.

Meaning: The variation in protocols between eye-tracking studies makes direct data comparison between them difficult; standardization of methods may allow pooling of data and greater understanding of eye-tracking patterns.

METHODS

A comprehensive search of the PubMed, Google Scholar, and Central Cochrane databases was conducted. Both string search and keyword search using terms “Cleft lip”[Majr] AND “eye-tracking” were used. Variations of the search with terms “Cleft”[Majr], “Cleft palate”[Majr], “Cleft lip and palate”[Majr], “gaze-tracking,” “eye-tracking technology,” and “gaze-tracking technology” were also completed. The search consisted of all studies published until August 2022.

Inclusion criteria included all studies published in English using a form of eye-tracking to evaluate participants’ gaze patterns while observing stimuli of patients with CL+/−P. Studies assessing multiple facial differences were included if CL+/−P was among the conditions evaluated. Only studies that reported outcomes using specified anatomical AOIs were included. Exclusion criteria included non-English studies, review and conference articles, and studies in which eye-tracking was performed to evaluate non−CL+/−P conditions.

All studies were initially screened through title and abstract evaluation. This was followed by an independent full-text evaluation by two authors (A.T.P. and R.W.F.B.), who categorized the studies as relevant based on the predefined inclusion and exclusion criteria. The data extracted from the articles were grouped into four broad categories: eye-tracking stimuli, observer characteristics, hardware, design characteristics, and reported outcomes. Data regarding eye-tracking stimuli that were assessed included the number of images, whether the images were full-face

Fig.1. Common elements utilized within eye-tracking studies. Different models of eye-trackers (A and B) and an example of a fixation cross (C). A, A participant using a model of eye-tracker (Eyelink 1000) that is mounted away and in front of a monitor. B, A screen-mounted eye-tracking device (Tobii Pro Nano). C, An example of a typical fixation cross that directs the attention of a participant to a specific point on the screen.

images, image standardization, time each image was displayed, interval and content of interval between images, and if images were shown more than once. Observer characteristics included the number of total observers, type of observer (eg, lay person, orthodontist, etc.), the task given to observers, and if they were naive to the goal of the study. Hardware and design characteristics included the eye-tracker model, use of a chin rest, distance to and size of monitor used, method of eye-tracker calibration, number of AOIs, and eye-tracking outcomes measured. Outcomes were assessed on both eye-tracking results and the use of any supplementary questionnaires or scoring systems. Data were recorded and analyzed using Microsoft Excel (Version 2210; Microsoft Inc, Redmond, Wash.).

RESULTS

A total of 40 publications were identified through the search strategy. After duplicates were removed, 38 publications were screened, and 17 did not meet the inclusion criteria and were excluded. Full-text screening of the remaining 21 publications resulted in the exclusion of a further five. Four studies[10–13] used eye-tracking to assess conditions or outcomes unrelated to CL+/−P, and one[14] used eye-tracking in CL+/−P but did not report gaze outcomes in a format allowing comparison to other publications (did not report using AOIs). This resulted in a total of 16 publications that used a form of eye-tracking in the field of CL+/−P.

The number of images shown varied between studies (mean: 48, range: 3–273). The majority of studies used images of individuals with a CL+/−P; however, six of 16 used Photoshop or other image editing software to digitally create or alter the appearance of a cleft.[15–20] Most studies (n = 14) showed full-face images and standardized images. Of the 16 publications, 13 only displayed images of repaired CL+/−P, whereas three[17,21,22] publications only displayed unrepaired images. The display duration of each image varied, and some studies allowed participants to advance images at their own pace. Of those with a set duration per image, the range was between 3 and 10 seconds and a mode of 5 seconds. Only five studies specified the use of fixation crosses (Fig. 1C) between images to standardize the initial gaze point. Almost half (n = 7) of the studies did not specify the duration of the time interval between displayed images. Most studies did not repeat any images; however, three studies[17,23,24] mirrored images, and one study[19] used Photoshop or similar software to create controls by correcting images with a cleft lip. Two studies[25,26] displayed a neutral and smiling version of each image and one study by Guimarães et al[20] used the same patient in all their displayed images. (**See table, Supplemental Digital Content 1**, which displays eye-tracking stimuli presented to participants in publications reviewed. UCLP: unilateral cleft lip and/or palate, BCLP: bilateral cleft lip and/or palate; AP: anteroposterior; L/R: left/right; Exp 1/2: experiment 1/2; IOTN: Index of Orthodontic Treatment Need, **http://links.lww.com/PRSGO/C566**.)

The number of observers ranged from 30 to 403 with a mean of 69. In 10 studies, observers were lay adults. Other observer groups included children,[27] cleft patients,[24–26] orthodontists,[26] and a mix of specialists involved in cleft care.[28] The most common task was to freely view the images (nine studies), with one study specifying to not move while doing so to maximize precision.[18] Five studies provided a specific task for observers to complete while viewing the images.[16,20,22,28,29] Eleven studies blinded the observers to the initial study goal. (**See table, Supplemental Digital Content 2**, which displays characteristics of observers who participated in eye-tracking in the previous publications. HCWs: health care workers; Exp 1/2: experiment 1/2, **http://links.lww.com/PRSGO/C567**.)

Models of eye-tracker varied largely, with most papers utilizing a different model. Only two studies[21,27] used eye-tracking glasses rather than screen-based eye-trackers. Chin-rests were used less than half of the time [six studies used chin-rests,[16,22–24,26,30] eight studies did not use chin-rests,[15,17–20,25,28,29] and two were not applicable (glasses)[21,27]]. The distance to the screen ranged from 50 to 75 cm; however, this can be dictated by the model of eye-tracker. Screen size used to view images ranged from 15 to 23 inches (38 to 58 cm); however, this can also depend on manufacturer recommendations. All studies that specified a calibration method used the in-built eye-tracker calibration without any secondary/external validation. The number of AOIs ranged from two to 20, with the modes being three and four. Of note, studies which used between three and five AOIs often used a variation of the same three anatomic zones: eyes, mouth, and nose. The difference in the number of AOIs in these papers results from slight differences such as splitting the AOI into left/right eye[18] or upper/lower lip.[15,26] (**See table, Supplemental Digital Content 3**, which displays eye-tracking hardware and outcome measures used. [a]Number of times the participant fixated on the media prior to fixating on a specified area. AOI: area of interest; AP: anteroposterior, **http://links.lww.com/PRSGO/C568**.)

Of the 16 studies, 10 involved participants providing an outcome score for images. These outcomes generally focused on attractiveness or similar characteristics regarding the facial images. In general, cleft patients were rated as having lower facial attractiveness, cuteness, or symmetry.[17,20,22,23,25,30] Of the 10 studies, four[18,22,28,30] directly compared their scoring outcome with eye-tracking data. Boonipat et al[30] found that more time was spent fixating on the lips of cleft patients rated less attractive. Similarly, Kwong et al[28] reported more fixations and a longer duration of fixations around the lip and scar in patients who were judged to have worse aesthetic quality post-repair. Rayson et al[22] reported that participants had a longer duration of gaze on the eyes in images of children rated as "cuter" regardless of CL+/−P status. However, Van Schijndel et al[18] found no correlation between personality ratings and gaze patterns in their study. When looking at the eye-tracking outcomes of all papers in general, there was longer duration and number of fixations around the lips and nose of images of individuals with a −CL+/−P.[15,16,18,19,22–30] Furthermore, for non–CL+/−P facial images, there was increased fixation on the eyes, which was sacrificed in −CL+/−P images.[15,16,18,22–25] Initial fixation locations followed a similar pattern, with the lip being the first fixation in CL+/−P images and the eyes being the first in non–CL+/−P images.[23–25] (**See table, Supplemental Digital Content 4**, which displays primary outcomes of previous papers. UCLP: unilateral cleft lip and/or palate; BCLP: bilateral cleft lip and/or palate, AOI: area of interest; NAM: nasoalveolar molding device; Exp 1/2: experiment 1/2; IOTN: Index of Orthodontic Treatment Need, **http://links.lww.com/PRSGO/C569**.) (**See table, Supplemental Digital Content 5**, which displays the assessment of commonly used eye-tracking data reporting in selected papers. UCLP: unilateral cleft lip and/or palate; BCLP: bilateral cleft lip and/or palate; AOI: area of interest; NAM: nasoalveolar molding device; Exp 1/2: experiment 1/2, **http://links.lww.com/PRSGO/C570E**.)

Finally, common metrics of data reporting[6] in eye-tracking were assessed in the studies selected. All selected studies reported duration of fixation in AOIs,[15–30] whereas 10 (62.5%) also reported fixation counts in each AOI.[15,17,21,23,24,26–30] Only eight (50%) studies[19,20,22–26,29] reported time to first fixation[26,29] (time it took the participant to gaze at target AOI) or initial attention capture[19,20,22–25] (first AOI participant gazed at upon stimulus display) data. Three studies[15,25,29] (18.8%) reported fixation sequence/scanpath data (path the eyes moved in while viewing the image) and six[15,18,20,26,27,29] (37.5%) displayed heatmaps of fixations as figures within their articles. Detailed information regarding AOI location of fixations, AOI location of initial interest capture and scanpaths as well as further information about data reporting can be found in **Supplemental Digital Content 2 (http://links.lww.com/PRSGO/C567)**.

DISCUSSION

Eye-tracking is an increasingly utilized method to conduct research in the field of CL+/−P. The ability to record gaze patterns presents novel information on how images are processed by viewers. This can potentially be used to assess how well reconstructive surgery can restore standard gaze patterns when viewing CL+/−P faces, thus providing a subjective metric to assess aesthetic outcomes. The clinical opportunities provided by eye-tracking include appearance outcome comparison of different surgical techniques and assisting in the decision to pursue lip and nose revisional surgery. Furthermore, the psychosocial aspects of cleft care may benefit from eye-tracking data, as individuals can visualize the impact of appearance-changing surgery or gain insight into others perceptions of them, potentially alleviating any social stigma they have experienced. Due to the high potential value of this technology, the purpose of this review was designed to categorize and catalog the methodology of previous work, allowing suggestions for future standardization of eye-tracking research.

Our results demonstrate the current wide variation in the eye-tracking protocols employed, with no current consensus on the ideal methodology. The greatest sources of protocol variation between publications include the display of images and the outcome measures used. Image display time is central to any eye-tracking research, as the length of time an image is viewed for can significantly impact how participants analyze them. The interval between images also represents a crucial portion of study design. Fixation crosses in this interval allow standardization of participants' initial gaze point to a predefined point on the screen. This improves consistency of gaze patterns between images and permits for the measurement of initial attention capture. However, of the 16 studies assessed, only five[17,23–26] specifically reported using a fixation cross before each display image. Wide variation in the number of AOIs used and outcome measures was also found within the assessed publications. AOIs need to be standardized across studies, as any differences between the ways AOIs are drawn onto images can significantly alter results, as for example, the "eye" AOI in one study may be completely different to the "eye" AOI in another publication (Fig. 2). Outcome measures are also important to unify

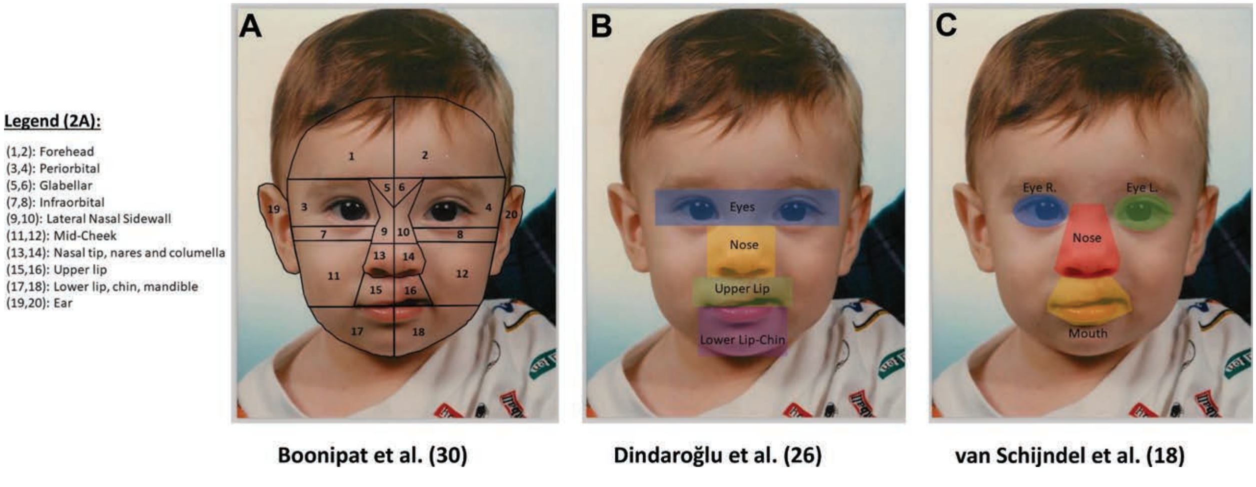

Fig. 2. Selection of different AOI patterns from prior studies. The AOI patterns have been replicated and transposed onto the same image to compare the significant differences between similar AOIs in different publications. A, Pattern as published by Boonipat et al; legend on left refers to this pattern. B, Pattern as published by Dindaroğlu et al. C, Pattern as published by van Schijndel et al.

across publications. Since different eye-trackers sample at different rates, the length of one fixation may largely vary, obscuring results of total number of fixations, which is commonly reported. Despite these issues, the publications assessed often reported similar outcomes as displayed in **Supplemental Digital Content 1** (**http://links.lww.com/PRSGO/C566**); however, the need for improvement is evident.

We recommend a few measures be taken to address the above issues and to begin the standardization process of eye-tracking studies in CL+/−P. We suggest the most common image display time of 5 seconds be adopted as the standard. There is a precedent to continue to use it due to previous popularity; furthermore, it also represents a period that allows adequate time to analyze the image, while not being so long as to cause viewers to lose concentration. All future studies should utilize fixation crosses to unify participants' gaze to a point prior to each image. Based on our experience in using eye-tracking, we suggest that an "advance on gaze" feature be used so that participants must fixate on a cross for a set amount of time before moving to the next image. The required fixation time should be brief (around 500 ms) as longer periods may be uncomfortable since the eye-tracker requires continuous fixation without blinking. AOIs should be based on anatomic regions of the face rather than nonspecific areas such as "eye" or "nose." The publication by Boonipat et al[30] represents use of anatomic AOIs to report results, and future studies should report in a similar manner to ensure consistency.

Finally, we suggest the development of more sensitive metrics and outcome measures. Most have simply reported the total time spent fixating or total number of fixations in each AOI. We recommend modifying this to be the proportion of total fixation time, rather than a raw value. For example, some participants may blink more, reducing their total number or duration of fixations compared to others, even given the same stimulus duration. Thus, rather than reporting the number or total duration of fixations the participant made in an AOI, reporting the proportion of total fixations or duration in that AOI would represent a better method of comparison between participants. However, even these suggestions represent a very crude metric which fails to exploit the information potentially present in the rich, two-dimensional time-series data provided by eye-tracking. New metrics should aim to capture information present in the pattern of fixations and saccades over the viewing period, for example, how often the gaze returns to a given area. The use of anatomical landmarks to register individual faces with a common standard would enable more detailed comparison between scan paths.

Another subject that needs to be addressed is the use of digitally created images in CL+/−P eye-tracking studies. Although designers with proficiency in software may be able to create images that are very similar to "organic" images of patients with CL+/−P, they cannot be expected to synthesize images truly representative of an individual with a cleft lip, potentially altering results. The use of such images by previous authors may stem from a variety of reasons; however, the most likely explanation is a lack of standardized CL+/−P images with ethical approval for use. Lack of a standard image database has been previously identified[31] as a significant barrier to aesthetic outcome research, and future initiatives need to be undertaken to rectify this issue. If a standardized image database were available, widespread data collection would become possible, potentially allowing the implementation of neural networks and machine learning to create a robust appearance evaluation system, as has been implemented in other areas of plastic surgery.[32] A database may also encourage further eye-tracking research, possibly leading to publications with greater numbers of observers, as a mean of 69 observers represents a small sample size on average.

Although 10 publications[15,17,18,20,22,23,25,28–30] asked participants directly to provide a score or asked them questions in addition to the eye-tracking, only four[18,22,28,30] publications provided a comparison of this data to eye-tracking data. Of note, Warne et al[19] compared their eye-tracking data to Asher-McDade scores provided by two plastic surgeons who did not participate in eye-tracking. This represents a significant weakness in study design of the previous publications. Without comparing the two datasets, the publication reads as two parallel experiments rather than a homogenous study. We believe that there is little value in having participants provide a score without further comparison to their eye-tracking data.[33–35] Value from eye-tracking as a research tool comes from comparing how participants view images with different scores, as these data can form the basis of a standardized outcome measurement tool. We suggest that future work that incorporates a form of scoring into eye-tracking research should directly compare the scoring data to the eye-tracking data, as this represents the ideal way to further advance work in this field. We hope the suggestions proposed through this review can provide future investigators with a baseline to improve the methodology of any eye-tracking work undertaken. All the recommendations described above are summarized in Figure 3.

This review is limited primarily by the limited number of included publications, as eye-tracking is an emerging technology, and the fact we limited the review solely to the field of CL+/−P. As previously discussed, the absence of a standardized protocol to conduct eye-tracking studies limits our ability to synthesize the results into a meta-analysis or systematic review. The lack of standardized AOIs, makes reporting outcomes difficult and potentially unreliable as an AOI with the same name may represent two different areas of the face between publications. For a future systematic review to be completed, multiple studies with comparable eye-tracking protocols need to be completed. Furthermore, the inclusion of only English language articles is another limiting factor; selection bias may have been introduced through exclusion of non-English articles. Regrettably, no resources were available for searching and translation of non-English articles.

Summary of Recommendations

1. Image display time of 5 seconds be adopted as the standard.
2. Utilization of central fixation crosses prior to each image to standardize centralization of gaze.
3. AOIs should be based on anatomic regions of the face.
4. Reporting data as a proportion of total fixations or fixation time.
5. The use of more complex data reporting metrics such as fixation patterns or gaze returns to each AOI.
6. Use of real patient photographs rather than digitally created/manipulated images.
7. Direct comparison of any rating data to eye-tracking data.

Fig. 3. Summary of recommendations made for future eye-tracking research work.

CONCLUSIONS

Eye-tracking as a research tool provides a novel way to assess appearance outcomes in CL+/−P surgery. It has gained increasing popularity among researchers, but study design has been varied, making direct comparison difficult. Although current publications have reported similar results, for further advancement of eye-tracking work in CL+/−P, a standardized eye-tracking protocol is required to allow for comparison and synthesis of results.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

ACKNOWLEDGMENTS

We would like to thank Mr. Bruce M. Richard for providing the patient image used in Figure 2. This image was originally part of a database owned by the estate of Dr. Ralph Millard but is now curated by Mr. Richard. Both Mr. Richard and the patient have consented to the use of the image in research.

PATIENT CONSENT

The patient provided written consent for the use of his image.

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