Eye Tracking Technology in Plastic and Reconstructive Surgery: A Systematic Review

Abstract:

Background: The use of eye-tracking technology in plastic surgery has gained popularity over the last several years due to its ability to assess observers' visual preferences in an objective manner. The goal of this study is to provide a comprehensive review of all eye-tracking studies in plastic and reconstructive surgery, which can aid in the design and conduction of high-quality eye-tracking studies.

Methods: Applying the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA), a comprehensive search of articles published on eye-tracking across several databases was conducted from 1946 to January 2019. The resulting publications were screened by two independent reviewers, for their relevance to plastic and reconstructive surgery.

Results: A total of 586 articles were identified in the initial search, out of which 23 met our inclusion criteria. Eye-tracking was most commonly used to assess individuals with cleft lip/palate (9 studies). All 19 studies that evaluated fixation patterns among conditions vs. controls reported significant differences between the two groups. Five out of seven studies assessing visual data between pre- and post-operative patients identified significant differences between the pre- and post-operative groups, while two studies did not (facelift and rhinoplasty patients). Nine studies examined the relationship between severity indices, attractiveness scores, or personality ratings and gaze patterns. Correlation was found in seven out of the nine studies.

Conclusion: This systematic review demonstrates the utility of eye tracking technology as a quantifiable objective assessment and emerging research tool for evaluating outcomes in several domains of plastic and reconstructive surgery.

INTRODUCTION

Plastic surgeons perform a wide scope of surgical procedures ranging from elective cosmetic surgeries to reconstruction of complex defects. Different assessment methods have been used to evaluate the functional, psychological and cosmetic outcomes of these procedures.[1-6] However, standardized methods that permit an objective evaluation are limited.[2,5,6] Moreover, the majority of available scales evaluate the outcomes from the patients' and/or providers' perspective.[1,3,5,6] Although this information is valuable, assessing the outcomes from a casual observer's perspective in an objective manner would provide insight into how social perception can change after surgery.[2,7]

Visual evaluation plays an integral role in human interactions, modifying social behavior and emotional response towards the individual.[7-9] Eye movements are a proxy for visual attention and fixation. Using eye-tracking to assess eye movement patterns during social interactions can provide a window into conscious and unconscious human preference and the ability of certain procedures to restore normalcy.[7,8,10,11]

Eye-tracking has been utilized broadly in marketing to study the effect of visual attention on in-store decision making and designing products that would capture viewers' attention.[12-15] Visual fixation patterns are decisive in understanding consumer behavior.[13,15] Gidlof et al. found that the longer or more frequent we look at a product, the more likely we will buy it.[15] Eye-tracking has great potential in the field of plastic surgery due to the changes in appearance following both aesthetic and reconstructive surgery and the crucial role of viewers' evaluation of the overall success of the surgery.[10,11,16] The use of eye-tracking has expanded over the last few years in different areas of plastic surgery.[7,10,11,16,17] We aimed to summarize the available literature on the use of this technology in the field of plastic and reconstructive surgery and study the efficacy of eye-tracking in detecting differences in viewers' attention to different visual stimuli. This study can serve as a guide for designing and conducting future studies using this technology.

METHODS

Literature search strategy

A comprehensive search was conducted across several databases including Ovid MEDLINE(R), Ovid Embase, Ovid PsycINFO, Ovid Cochrane Central Register of Controlled Trials, Ovid Cochrane Database of Systematic Reviews, and Scopus for studies published from 1946 to January 2019. The search strategy was designed by an experienced librarian with an input from the authors. The following keywords were used in all combinations: "surgery", "surgical procedures", "operative", "cleft", "face", "breast", "hand", "cosmetic", "reconstruction", "plastic", "eye", "gaze", "fixation", "attention" and "tracking". Manual search of references of the included studies was conducted to identify additional articles that could meet our inclusion criteria.

Inclusion and Exclusion Criteria

Inclusion criteria included studies published in English evaluating the use of eye-tracking technology in the field of plastic and reconstructive surgery. This comprised tracking observers' eye movements to assess patients and/or outcomes of cosmetic surgery, craniofacial surgery (including cleft lip and palate), facial deformities, facial paralysis, orthognathic surgery, breast reconstruction, hand and microsurgery. Exclusion criteria included: 1) review articles, conference abstracts, correspondence or brief communications, 2) studies assessing visual attention without the use of eye-tracking technology, 3) studies using eye-tracking in fields not relevant to plastic and reconstructive surgery. When multiple articles from the same institution and/or same authors had the same subject population, only the most recent or the one that had the largest sample was included.

Selection of Articles and Data Extraction

After duplicates elimination, two authors (M.A. and B.M) independently reviewed the articles through titles and abstracts screening. This was followed by a full text review of the potentially relevant studies according to the predetermined inclusion criteria. Two independent authors (M.A. and A.M) performed the data extraction which included: field of the study, study design, number of subjects whose images were evaluated. This included conditions (patients with a particular condition), controls (normal individuals without the condition of interest), pre-operative and post-operative subjects. We also collected the number of observers whose eye movements were recorded through the eye-tracking machine. Standardization of the images used was assessed along with the type machine used, the sampling rate (Hz), distance of observers from the screen, number of areas of interest (AOIs), time considered as fixation in milliseconds, and time given per image per seconds. To evaluate the effectiveness of eye-tracking, we looked at the assessment measures used along with the ability of this technology to detect differences between control/condition, pre-/post-operative patients, and the correlation between the eye-tracking measurements and other assessments scales or indices used.

All conflicts were reviewed and resolved by a third author (J.D.). This study adhered to the guidelines outlined in the Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA)[18].

RESULTS

Study characteristics

A total of 586 studies were identified through the search strategy with additional 11 articles identified through references of the relevant studies. After duplicates removal, a total of 595 citations were screened and 37 articles were selected for full-text review. A final of 23 studies met our inclusion criteria, reporting the use of eye-tracking in the field of plastic and reconstructive surgery. **Figure 1** outlines the PRISMA flow diagram of our search strategy.

Eye-tracking was most commonly used to assess individuals with cleft lip/palate (9 studies) followed by facial deformities (4 studies; 2 facial paralysis, 1 peripheral facial deformities, 1 disfigured faces), nasal conditions (3 studies; 1 crooked nose, 1 rhinoplasty, 1 nasal deformities), prominent ears (2 studies) and breast reconstruction (2 studies). Other fields included face lift (1), coronal synostosis (1), and orthognathic patients (1).

The majority of studies were cross-sectional comparing the visual attention of casual observers while viewing images of subjects with the condition of interest vs. normal controls or pre- vs. post-operative images. Casual observers are lay observers from the community that represent society and social facial perception. One study evaluated the gaze paths of plastic surgeons assessing breast reconstruction patients without controls. Another study assessed the visual attention of mothers while interacting with their children without the use of images. The median number of observers was 36 (range 3-403). **Table 1** summarizes the characteristics of the included studies.

Eye-Tracking Stimuli

We classified the evaluated images into three categories; pre- and post-operative images (median 14, range 1-32), conditions without post-operative images (median 18, range 1-178), and controls (median 13, range 1-95). To eliminate possible confounders in the photographs, controls or conditions were digitally created in 7 studies. In 5 studies the facial deformity was digitally normalized to create control images. In 2 studies, the studied condition was digitally created from normal images. Standardization of the photographs was reported in 18 studies, though standards varied.

Eye-Tracking Procedure and Apparatus

Visual gaze was recorded using different eye-tracking machines. This translated into different gaze sampling rates (median 60Hz, range 30-500Hz). Participants were seated at a conversational viewing distance (60cm) in the majority of the studies (60%) with a range of 50-75 cm. Similarly, different times were given for observers to view the images (median 8 seconds, range 2.5-10) with one study allowing participants to advance at their own pace.

Data Extraction and Analysis

Different areas of interest (AOIs) were created for each study. These were outlined by the study investigators to assess fixation patterns in a specific area of the face or the body. The median number of AOIs (also called zones of fixation) in the included studies was 4 AOIs (range 1-20). Various cutoffs were used to define fixation (the time under which views are considered saccades and of no relevance to an individuals' attention). The median time for fixation definition was 100 milliseconds (range 40-200). Different measures were used as indices for attentional patterns with fixation time (time spent fixating on a particular AOI), time to first fixation (time taken before the first fixation on a specific AOI), first fixation time (duration of the first fixation), and fixation count (number of times an observer fixated on a particular area) being the most commonly used. **Table 2** demonstrates the machines, definitions and methodology used by the different studies.

Statistical analysis was performed using ANOVA/t-test or their non-parametric variants by the majority of studies. Differences between groups (pre- vs. post-operative, conditions vs. controls) or among different AOIs were analyzed. Regression models were used in 3 studies.[7,19,20]

Differences in Fixation Patterns

Eye-tracking was used to assess differences in observer's attention to control vs condition in 19 studies. Significant differences were found in all studies in at least one of the assessment measures. Attention to pre- vs. post-operative images was evaluated in 7 studies out of which 5 found significant differences in viewers' visual gaze to the two groups of images. The two studies that did not find significant differences included one assessing facelift and the other evaluating rhinoplasty patients. **Table 3** summarizes the differences in fixation patterns between controls vs. conditions and pre- vs post-operative images.

We also looked at the correlation between the visual attention data and the different scales used by the included studies. Seven studies found correlation (which ranged from weak to strong) while no correlation was reported by two studies (Darrach et al. found no association between fixation time and attractiveness scores in rhinoplasty patients,[19] and Van Schijndel et al. found no correlation between personality traits and fixation times in cleft lip patients)[21]. Correlation between fixation patterns and other assessment scales are reported in **Table 4**.

DISCUSSION

The use of eye-tracking in plastic surgery has gained popularity over the last several years due to its ability to assess observers' visual preferences in an objective manner.[7,9-11,16,17] By measuring fixation times and counts, it opens a window into the worlds of our conscious and subconscious visual attention which is a proxy of our preferences and aversions.[9-11,20] This can help in assessing the ability of surgery to correct deformity and restore normalcy which can be shown by symmetric fixation pattern across the operated area.[7] It can also be used to compare surgical techniques, and aid in patient pre-operative counseling.[10] Our study provides a comprehensive review of all eye-tracking studies in plastic and reconstructive surgery to date, which can aid in the design and conduction of high-quality eye-tracking studies.

Eye-tracking has two important values in evaluating surgical outcomes. It can help patients comprehend how surgical intervention will change the way other people perceive their face or body and how lay observers look at their deformity compared to normal individuals without the condition. The other critical significance is related to surgeons' assessment of outcomes. How do we define a good outcome in plastic surgery? Do we need to reconstruct a facial paralysis patient to achieve perfect symmetry or just to the degree not distract the casual observer? Although patient satisfaction is a key element for evaluating outcomes, a more objective measure is needed. Therefore, eye-tracking can be a great tool for assessing outcomes.

To assess whether patients with a particular condition were looked at differently, studies have used eye-tracking to compare visual attentional patterns in conditions vs. controls. Eye-tracking was able to detect differences in fixation data in all the studies that reported comparisons between these two groups. This reflects differences in the way people look at patients with the studied conditions when compared to normal individuals, which justifies surgical intervention to correct these attentional differences. Most studies found that an abnormality distorts the symmetric fixation pattern of normal individuals and draws more attention towards the area of the deformity.[8,16,17,22,23] This is in contrast to the findings in facial paralysis patients where the functional side captures more fixation especially while smiling.[20]

For evaluating the efficacy of surgery in restoring normalcy, attentional differences in pre- vs. post-operative images were analyzed. Five out of the 7 studies found significant differences in gaze patterns between the two operative groups.[7,22,24-26] Haworth et al., and Godoy et al. found that correction of a deformity after surgery translated into decreased attentional bias on that area.[22,24] In order to assess if surgery successfully restored perceived normalcy, post-operative patients should be compared to normal controls. This can also be done through a comparison of the normal side and abnormal side after surgery. Dey et al. found that in facial paralysis patients, surgery restored symmetry of gaze pattern between the two halves of the face during smiling.[7] The lack of differences in fixation patterns in 2 studies (after facelift and rhinoplasty) could raise the question about the utility of these procedures since surgery did not influence where observers directed their attention.[10,19] This should be interpreted, however, in the light of the change in attractiveness scores after surgery. Facelift and rhinoplasty are cosmetic procedures and patients present for aesthetic reasons which in most case may not rise up to the level of a deformity that distorts the symmetry of a casual observers' attention.

Eye-tracking can complement and help us understand already established assessment measurements. Nine studies evaluated the correlation between fixation data and the mentioned scales with an association found in 7 studies. The utilized scales included attractiveness scores, symmetry ratings, emotional experience, cleft severity and personality ratings.[9,11,16,17,19,21,27-29] The strength of the correlation varied from weak to strong.[17,28] This provides an insight into which assessment measures actually correlate with viewers' attentional bias and can help us better understand certain scales prior to implementation. One study did not find an association between attractiveness scores of rhinoplasty patients and fixation times while another study failed to find a correlation between relative fixation times and personality ratings of cleft lips patients.[19,21] This could potentially reflect a deficiency in the assessment measure used or the inability of eye-tracking to detect certain aspects of outcome evaluation. Further studies are needed to determine this value implication of eye-tracking technology.

Another point that warrants discussion is the distinct methodologies utilized by the various studies. Different definitions were used for fixation time, AOIs, and time given per image in addition to the various eye-tracking machines which differ in their sampling rate. Different findings are likely to result if the same study is performed under different definitions, since what is considered fixation by one study is not so in another. This highlights the importance of unified consensus or at least similar criteria when designing eye-tracking studies to draw results that could be comparable across multiple studies.

Limitations

Our study has notable limitations. The lack of a standardized method for measuring and assessing visual attention data across the included studies precluded a meta-analysis. Studies also varied in the power to detect differences between the studied groups due the variable number of images and observers. Moreover, all the included studies assessed fixation differences for observers looking at constant images. Future studies should evaluate visual attention differences for videos which are more reflective of real-life social interaction.

Conclusion

Eye-tracking offers a powerful tool for assessing outcomes of plastic and reconstructive surgery. Differences were found between patients with a particular condition vs. normal controls and between pre- and post-operative patients. Eye-tracking can also be used as an objective complementary method for established assessment scales reflecting observers' conscious and subconscious visual attentional bias.

References:

1. Bella H, Kornmann NS, Hardwicke JT, et al. Facial aesthetic outcome analysis in unilateral cleft lip and palate surgery using web-based extended panel assessment. *Journal of plastic, reconstructive & aesthetic surgery : JPRAS.* 2016;69(11):1537-1543.
2. Deall CE, Kornmann NS, Bella H, et al. Facial Aesthetic Outcomes of Cleft Surgery: Assessment of Discrete Lip and Nose Images Compared with Digital Symmetry Analysis. *Plastic and reconstructive surgery.* 2016;138(4):855-862.
3. Jagsi R, Li Y, Morrow M, et al. Patient-reported Quality of Life and Satisfaction With Cosmetic Outcomes After Breast Conservation and Mastectomy With and Without Reconstruction: Results of a Survey of Breast Cancer Survivors. *Annals of surgery.* 2015;261(6):1198-1206.
4. Lee C, Sunu C, Pignone M. Patient-reported outcomes of breast reconstruction after mastectomy: a systematic review. *Journal of the American College of Surgeons.* 2009;209(1):123-133.
5. Pusic AL, Klassen AF, Scott AM, Klok JA, Cordeiro PG, Cano SJ. Development of a new patient-reported outcome measure for breast surgery: the BREAST-Q. *Plastic and reconstructive surgery.* 2009;124(2):345-353.
6. Revenaugh PC, Smith RM, Plitt MA, Ishii L, Boahene K, Byrne PJ. Use of Objective Metrics in Dynamic Facial Reanimation: A Systematic Review. *JAMA facial plastic surgery.* 2018;20(6):501-508.
7. Dey JK, Ishii LE, Byrne PJ, Boahene KD, Ishii M. Seeing is believing: objectively evaluating the impact of facial reanimation surgery on social perception. *The Laryngoscope.* 2014;124(11):2489-2497.

8. Morzycki A, Wong A, Hong P, Bezuhly M. Assessing Attentional Bias in Secondary Cleft Lip Deformities: An Eye-Tracking Study. *The Cleft palate-craniofacial journal : official publication of the American Cleft Palate-Craniofacial Association.* 2019;56(2):257-264.

9. Warne CN, Hallac RR, Kane AA, Derderian CA, Seaward JR. Eye Tracking as a Proxy for Perceptual Evaluation of Repaired Cleft Lip. *The Journal of craniofacial surgery.* 2018.

10. Cai LZ, Kwong JW, Azad AD, Kahn D, Lee GK, Nazerali RS. Where Do We Look? Assessing Gaze Patterns in Cosmetic Facelift Surgery with Eye Tracking Technology. *Plastic and reconstructive surgery.* 2019.

11. Cai LZ, Paro JAM, Lee GK, Nazerali RS. Where Do We Look? Assessing Gaze Patterns in Breast Reconstructive Surgery with Eye-Tracking Technology. *Plastic and reconstructive surgery.* 2018;141(3):331e-340e.

12. Chandon P, Hutchinson JW, Bradlow ET, Young SH. Does In-Store Marketing Work? Effects of the Number and Position of Shelf Facings on Brand Attention and Evaluation at the Point of Purchase. *Journal of Marketing.* 2009;73(6):1-17.

13. Clement J, Aastrup J, Charlotte Forsberg S. Decisive visual saliency and consumers' in-store decisions. *Journal of Retailing and Consumer Services.* 2015;22:187-194.

14. Clement J, Kristensen T, Grønhaug K. Understanding consumers' in-store visual perception: The influence of package design features on visual attention. *Journal of Retailing and Consumer Services.* 2013;20(2):234-239.

15. Gidlöf K, Anikin A, Lingonblad M, Wallin A. Looking is buying. How visual attention and choice are affected by consumer preferences and properties of the supermarket shelf. *Appetite.* 2017;116:29-38.

16. Boonipat T, Brazile TL, Darwish OA, Montana P, Fleming KK, Stotland MA. Measuring Visual Attention to Faces with Cleft Deformity. *Journal of plastic, reconstructive & aesthetic surgery : JPRAS.* 2018.

17. van Schijndel O, Tasman AJ, Litschel R. The Nose Influences Visual and Personality Perception. *Facial plastic surgery : FPS.* 2015;31(5):439-445.

18. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS medicine.* 2009;6(7):e1000097.

19. Darrach H, Ishii LE, Liao D, et al. Assessment of the Influence of "Other-Race Effect" on Visual Attention and Perception of Attractiveness Before and After Rhinoplasty. *JAMA facial plastic surgery.* 2019.

20. Ishii L, Dey J, Boahene KD, Byrne PJ, Ishii M. The social distraction of facial paralysis: Objective measurement of social attention using eye-tracking. *The Laryngoscope.* 2016;126(2):334-339.

21. van Schijndel O, Litschel R, Maal TJ, Berge SJ, Tasman AJ. Eye tracker based study: Perception of faces with a cleft lip and nose deformity. *Journal of cranio-maxillo-facial surgery : official publication of the European Association for Cranio-Maxillo-Facial Surgery.* 2015;43(8):1620-1625.

22. Godoy A, Ishii M, Byrne PJ, Boahene KD, Encarnacion CO, Ishii LE. The straight truth: measuring observer attention to the crooked nose. *The Laryngoscope.* 2011;121(5):937-941.

23. Quast A, Waschkau J, Saptschak J, et al. Facial perception of infants with cleft lip and palate with/without the NAM appliance. *Journal of orofacial orthopedics = Fortschritte der Kieferorthopadie : Organ/official journal Deutsche Gesellschaft fur Kieferorthopadie.* 2018;79(6):380-388.

24. Haworth R, Sobey S, Chorney JM, Bezuhly M, Hong P. Measuring attentional bias in children with prominent ears: A prospective eye-tracking study. *Journal of plastic, reconstructive & aesthetic surgery : JPRAS.* 2015;68(12):1662-1666.

25. Ishii L, Carey J, Byrne P, Zee DS, Ishii M. Measuring attentional bias to peripheral facial deformities. *The Laryngoscope.* 2009;119(3):459-465.

26. Linz C, Gerdes AB, Meyer-Marcotty P, et al. Perception of children's faces with unilateral coronal synostosis--an eye-tracking investigation. *Child's nervous system : ChNS : official journal of the International Society for Pediatric Neurosurgery.* 2016;32(1):135-141.

27. Litschel R, Majoor J, Tasman AJ. Effect of protruding ears on visual fixation time and perception of personality. *JAMA facial plastic surgery.* 2015;17(3):183-189.

28. Rayson H, Parsons CE, Young KS, et al. Effects of Infant Cleft Lip on Adult Gaze and Perceptions of "Cuteness". *The Cleft palate-craniofacial journal : official publication of the American Cleft Palate-Craniofacial Association.* 2017;54(5):562-570.

29. Stone A, Potton A. Emotional responses to disfigured faces and Disgust Sensitivity: An eye-tracking study. *Journal of Health Psychology.* 2017:1359105317692856.

30. Dindaroglu F, Dogan S, Amado S, Dogan E. Visual perception of faces with unilateral and bilateral cleft lip and palate: An Eye-Tracking Study. *Orthodontics & craniofacial research.* 2017;20(1):44-54.

31. De Pascalis L, Kkeli N, Chakrabarti B, et al. Maternal gaze to the infant face: Effects of infant age and facial configuration during mother-infant engagement in the first nine weeks. *Infant behavior & development.* 2017;46:91-99.

32. Kim MS, Burgess A, Waters AJ, et al. A pilot study on using eye tracking to understand assessment of surgical outcomes from clinical photography. *Journal of digital imaging.* 2011;24(5):778-786.

33. Meyer-Marcotty P, Gerdes AB, Stellzig-Eisenhauer A, Alpers GW. Visual face perception of adults with unilateral cleft lip and palate in comparison to controls--an eye-tracking study. *The Cleft palate-craniofacial journal : official publication of the American Cleft Palate-Craniofacial Association.* 2011;48(2):210-216.

34. Meyer-Marcotty P, Alpers GW, Gerdes AB, Stellzig-Eisenhauer A. How others perceive orthognathic patients: an eye-tracking study. *World journal of orthodontics.* 2010;11(2):153-159.

Table 1. Study Characteristics

Study	Study Design	Field	Number of patient images evaluated	Number of observers	Standardization of photos
Cai et al, 2019[10]	Cross sectional	Face lift	30 (15 pre-op and 15 post op)	36	Yes
Darrach et al, 2019[19]	Cross sectional	Rhinoplasty	64 (32 pre-op and 32 post-op)	134	Yes
Morzycki et al, 2019[8]	Cross sectional	Secondary cleft lip deformities	19 (2 control, 9 condition 'digitally created', 8 mirrored images)[1]	46	Yes
Boonipat et al, 2018[16]	Cross sectional	Cleft lip and other facial conditions	273 (95 controls, 178 condition)	403	NA
Warne et al, 2018[9]	Cross sectional	Cleft lip	Experiment 1: 40 (20 control, 20 condition[2]) Experiment 2: (24 control 'digitally corrected', 24 condition)	Experiment 1: 11 Experiment 2: 42	Yes
Quast et al, 2018[23]	Cross sectional	Cleft lip and palate	30 (10 control 'digitally corrected', 10 UCLP and 10 UCLP with NAM)	30	Yes
Cai et al, 2018[11]	Cross sectional	Breast Reconstruction	20[3]	29	NA
Rayson et al, 2017[28]	Cross sectional	Cleft lip	26 (13 control, 13 condition)	36	Yes
Dindaroglu et al, 2017[30]	Cross sectional	Cleft lip and palate	30 (10 control, 20 condition)	80	Yes
De Pascalis et al, 2017[31]	Cross sectional	Cleft lip	30 (20 control, 10 condition)	30	Mothers looking at their children
Stone et al, 2017[29]	Cross sectional	Disfigured faces	6 (2 controls, 4 condition[4] 'digitally created')	29	Yes
Ishii et al, 2016[20]	Cross sectional	Facial Paralysis	18 (6 control, 6 condition smiling, 6 condition repose)	60	Yes
Linz et al, 2015[26]	Cross sectional	Coronal synostosis	56 (28 control, 14 condition pre-op and 14 condition post-op)	30	Yes
Haworth et al, 2015[24]	Cross sectional	Prominent ears	15 (5 control, 10 condition, 2 of whom with pre and post-op photographs)	24	No
van Schijndel et al, 2015[21] lip	Cross sectional	cleft lip and nose	36 (18 control 'digitally corrected', 18 condition)	40	Yes
van Schijndel et al, 2015[17] nose	Cross sectional	Nasal deformities	40 (20 control 'digitally corrected', 20 condition)	40	Yes
Litschel et al, 2015[27]	Cross sectional	Prominent ears	40 (20 control 'digitally corrected', 20 condition)	20	Yes
Dey et al, 2014[7]	Cross sectional	Facial Reanimation	48 (8 control, 20 condition pre-op and 20	86	NA

			condition post-op)		
Kim et al, 2011[32]	Cross sectional	Breast reconstruction	8 condition (5 images in different positions for each condition)	3	Yes
Godoy et al, 2011[22]	Cross sectional	Crooked nose	21 (7 control, 7 condition pre-op and 7 condition post-op)	60	Yes
Meyer-Marcotty et al, 2011[33]	Cross sectional	Cleft lip and palate	36 (18 control, 18 condition)	63	Yes
Meyer-Marcotty et al, 2010[34] HOW OTHERS	Cross sectional	Orthognathic patients	36 (18 control '*Class I* 'occlusion , 18 condition '*Class III'*)	24	Yes
Ishii et al, 2009[25]	Cross sectional	Peripheral facial deformities (Moh's surgery defects)	4 (1 normal, 1 normal pre-op, 1 abnormal post-op, 1 abnormal)[5]	8	NA

UCLP, Unilateral cleft lip and palate; NAM, Nasoalveolar molding

[1]This included: 4 scarless lips (2 standards and 2 oriented in their mirrored position), 1 scarred lip with no other deformity, 6 short lips (1 standard and 1 mirrored in mild, moderate, and severe forms), 6 long lips (1 standard and 1 mirrored in mild, moderate, and severe forms), 1 lip with vermilion excess (VE), and 1 lip with a red-white disjunction (RWD). All images were created by modifying a stock photograph of young male child using Photoshop. [2] 10 who had undergone previous repair of unilateral cleft lip group; and 10 with hemifacial macrosomia (HFM group) who had received no surgical treatment. [3] Breasts were grouped into one of three categories: a control group of breasts with nipples and no reconstruction scars (normal breasts), breasts with both reconstruction scars and nipples (completed reconstructions), and breasts with reconstruction scars and no nipples (incomplete reconstruction); number of each individual group is NA. [4] 2 structural disfigurement to the internal expressive feature (IEF) (eyes, mouth, nose), 2 skin blemish on the forehead. [5] 1 normal, no obvious defect; 1 normal, with temple nevus pre-op, 1 abnormal, temple nevus post-op, 1 abnormal, cheek defect;

Table 2. Eye-Tracking Procedure and Apparatus

Study	Machine Used	Sampling Rate (Hz)	Distance of Observer from the Screen (cm)	Number of Zones of Fixation or Areas of Interest	Time Considered as Fixation (msec)	Time Given per Image (sec)	Assessment Measure Used in Analyses
Cai et al, 2019[10]	Tobii Pro X2-60 screen-based	60	60 (24 inch)	10	Fixation algorithm (below a threshold of 30 degrees per second is considered fixation)	Variable amounts (Subjects were allowed to advance at their own pace).	Fixation time, time to first fixation, number of fixations
Darrach et al, 2019[19]	iViewXRED screen-based	60	60	2	200	4	Fixation time
Morzycki et al, 2019[8]	EyeLink 1000	NA	60	7	NA	3	Fixation time
Boonipat et al, 2018[16]	EyeTech TM4	30	60	20	100	10	Fixation time
Warne et al, 2018[9]	SMI RED250mobile	250	50-75	14	NA	3	Experiment 1: Fixation time Experiment 2: Fixation time, first gaze time, time to first fixation
Quast et al, 2018[23]	SMI iView XTM	60	70	2	NA	NA	Fixation time
Cai et al, 2018[11]	Tobii Pro X2-60	NA	60 (24 inch)	4	100	8	Time to first fixation and total number of fixations
Rayson et al, 2017[28]	Eyelink II,SR Research head-mounted eye tracker	500	57	2	40	10	Fixation time
Dindaroglu et al, 2017[30]	Tobii T60 Eye Tracker	60	60	4	100	4	Time to first fixation, fixation before, data fixation count and

							fixation duration***
De Pascalis et al, 2017[31]	Tobii Glasses 1 Eye Tracker	NA	NA	6*	NA	NA	Fixation time and number of fixations
Stone et al, 2017[29]	Applied Science Laboratories model 504	NA	60	2	NA	5	Fixation time
Ishii et al, 2016[20]	SMI iView X RED	60	60	5	200	10	Fixation time
Linz et al, 2015[26]	iView X RED250	250	50	4	80	2.5	Mean number of the initial two fixations, mean number of ongoing fixations, mean duration of fixations
Haworth et al, 2015[24]	EyeLink 1000	NA	60	4	NA	5	Dwell time****
van Schijndel et al, 2015[21] lip	Tobii X120	50	65	3	100	10	Fixation time
van Schijndel et al, 2015[17] nose	Tobii 2.2.8	50	NA	1**	200	10	Fixation time
Litschel et al, 2015[27]	Tobii X120 eye tracker (TobiiTechnology AB)	NA	NA	2	200	10	Fixation time
Dey et al, 2014[7]	SMI RED-X	NA	60	NA	NA	10	Fixation time and number of fixations
Kim et al, 2011[32]	Model 504	60	63.5	11	100	NA	Fixation time
Godoy et al, 2011[22]	SMI IView XRED	60	60	NA	200	10	Fixation duration
Meyer-Marcotty et al, 2011[33]	iView XTM Hi-Speed	238	50	3	80	5	Fixation time Percentage of first three fixations
Meyer-Marcotty et al, 2010[34] HOW OTHERS	iView X Hi-Speed	238	50	5	80	5	Fixation time Percentage of first three fixations
Ishii et al, 2009[25]	SMI IView XRED screen-based	60	60	3	200	10	Fixation time

*3 general areas of interest and 3 facial areas of interest **for subdivision analysis, 4 lookzones were chosen for hump noses; and 5 lookzones for saddle noses. ** the number of times the participant fixated on the media before fixating on an area for the first time *** dividing total fixation duration by the total number of fixations on that AOI **** Time (in ms) that participants spent looking at three interest areas and the face as a whole (excludes time spent looking off the screen)

Table 3. Differences in Fixation Patterns between Controls vs. Conditions and Pre- vs. Post-operative Images

Control vs. Condition			
Study	**Field**	**Any Significant Difference Detected**	**Explanation**
Morzycki et al, 2019[8]	Secondary cleft lip deformities	Yes	Participants spent significantly more time focused on the upper lip regions in patients with simulated secondary deformities relative to those who did not.
Boonipat et al, 2018[16]	Cleft lip and other facial conditions	Yes	Significantly more fixation time on the upper lip, lower lip, and nasal tip and columella lookzones in cleft images compared to controls.
Warne et al, 2018[9] Experiment 1	Cleft lip and hemifacial microsomia	Yes	The mean fixation duration in the repaired cleft lip group was significantly longer than in the control group on the nostrils upper lip, and central triangle. Evaluators also gazed significantly longer on the area of the face around the cleft compared with the contralateral side. Participants gazed for less time on the superior half of the face and the central triangle in photographs of the hemifacial microsomia group compared to control groups. There was a significant difference in mean fixation duration between the temples within the HFM group
Warne et al, 2018[9] Experiment 2	Cleft lip	Yes	The total fixation time in the upper lip region of the photographs was significantly longer in the Cleft Lip Group than the Control Group. This was also true when comparing total fixation times on the cleft and non-cleft sides of the lip between the 2 groups Participants were more likely to fixate earlier on the upper lip in the Cleft Lip Group than in the Corrected Group. The average duration of the first fixation in the upper lip was also significantly longer in the Cleft Lip Group compared with the Corrected Group
Quast et al, 2018[23]	Cleft lip and palate	Yes	Infants with UCLP or UCLP and NAM appliance had significant longer total fixation time than unaffected infants. No significant differences were found between infants with UCLP versus infants with UCLP and NAM appliance. The same applies to fixation times on the lower face.
Cai et al, 2018[11]	Breast Reconstruction	Yes (one was significant and one was non-significant)	The time to first fixation was longest in images with natural, unreconstructed breasts and shortest in images with only reconstruction scars and no nipples. Reconstructions with both scarring and either one or two nipples had intermediate first-fixation times. (no significance) Compared to images with scars and no nipples, images with scars and nipples led to both fewer fixations on scar-related areas of interest and also fewer overall fixations of the entire image (significant)

Rayson et al, 2017[28]	Cleft lip	Yes	Total fixation duration on the eyes of infants with cleft lip was significantly less and on mouths significantly more compared with unaffected infants.
Dindaroglu et al, 2017[30]	Cleft lip and palate	Yes	Time to first fixation was significantly shorter for images of both unilateral cleft lip and palate and bilateral cleft lip and palate compared with control images This was also true for time to first fixation on the upper-lip while smiling. The upper-lip area of the control images received fewer fixations than did the UCLP images.
De Pascalis et al, 2017[31]	Cleft lip	Yes	For general AOIs: Fixation time and counts were less for the face and more for the body for condition compared to controls. For Facial AOIs: Fixation count was similar between controls and condition for the eyes; less at the mouth, and more for other facial regions in condition compared to controls. Fixation duration on the eyes was similar between control and condition, marginally less for the mouth in condition and less for other facial regions in controls.
Ishii et al, 2016[20]	Facial Paralysis	Yes	Smiling and paralysis both independently increased fixation on the mouth. Observers looked equally at the paralyzed and non-paralyzed hemiface and mouth when the displayed face was in repose; however, when the face was smiling, observers gazed more at the non-paralyzed hemiface and mouth than the paralyzed hemiface.
linz et al, 2015[26]	Coronal synostosis	Yes	First fixations in the postoperative group involved the eyes less often than the control groups. Fixation durations involving the heads shown in the preoperative pictures were significantly longer than those of the control group. The number of head fixations in the preoperative pictures was significantly higher than the control group.
Haworth et al, 2015[24]	Prominent ears	Yes	Participants spent more time looking at the ear regions for faces with prominent ears in comparison to faces without prominent ears
van Schijndel et al, 2015[21] lip	cleft lip and nose	Yes	Observers spent significantly more time observing the cleft lip compared with the corrected lip. No significant difference was found for attention for the cleft nose compared with the corrected nose. In patients with cleft stigmata, observers spent more time at the oronasal region than the eyes. No significant difference in attention directed toward the oronasal region and the eyes was found for corrected faces.
van Schijndel et al, 2015[17] nose	Nasal deformities	Yes	Patients with computer-morphed noses had significant less mean relative fixation duration on the nose than patients with deformed noses.
Litschel et al, 2015[27]	Protruding ears	Yes	Fixation time of both auricles was significantly longer for protruding ears when compared to nonprotruding ears
Dey et al, 2014[7]	Facial Reanimation	Yes	Preoperative paralysis patients had significantly less fixation on the nose and more fixation on the mouth compared to normals.

Kim et al, 2011[32]	Breast reconstruction	-	This study was done to investigate how plastic surgeons assess breast morphology after breast reconstruction. Dwell-time analysis showed that all three surgeons spent the majority of their time on the anterior–posterior (AP) views. Similarly, transition frequency analysis between regions showed that there were substantially more transitions between the breast regions in the AP view, relative to the number of transitions between other views. The results of both the conditional and joint probability analyses between the breast regions showed that the highest probabilities of transitions were observed between the breast regions in the AP view (APRB, APLB) followed by the oblique views and the lateral views to complete evaluation of breast surgical outcomes.
Godoy et al, 2011[22]	Crooked nose	Yes	Preoperative crooked noses had statistically significant longer fixation times than the normal noses. No significant differences were found between the normal and postoperative groups
Meyer-Marcotty et al, 2011[33]	cleft lip and palate	Yes	Regarding the cumulative duration of all fixations , UCLP were viewed significantly longer in the nose and mouth and shorter in the eyes than the control pictures
Meyer-Marcotty et al, 2010[34] HOW OTHERS	Orthognathic patients	Yes	The mean fixation duration on the central AOI was significantly shorter in Class III patients, than in Class I individuals. Regarding percentage of first three fixations, class III patients had significantly less fixation in the mouth region than those of the Class I individuals but no significant difference was found between the two groups for the eyes and nose.
Ishii et al, 2009[25]	Peripheral facial defromities (Moh's surgery defects)	Yes	Fixation time on the central triangle was significantly longer in the male face with the nevus compared to a male face with a cheek defect from a Mohs procedure.
Pre-op vs. Post-operative			
Study	**Field**	**Any Significant Difference Detected**	**Explanation**
Cai et al, 2019[10]	Face lift	No	No significant differences were found in time to first fixation, fixation time, fixation time in defined AOIs, and fixation counts between pre and post-operative patients.
Darrach et al, 2019[19]	Rhinoplasty	No	Fixation time was not associated with rhinoplasty status
linz et al, 2015[26]	Coronal synostosis	Yes	First fixations in the postoperative group involved the eyes less often than those in the preoperative group. The fixation duration on the mouth was less in the preoperative compared to postoperative pictures. In the preoperative pictures, the nose was significantly less fixated upon than in the postoperative pictures. Conclusion: correction of unilateral coronal synostosis results in the normalization of the asymmetry of the fronto-orbital region, whereas the C-shaped deformity of the midface, which is not addressed via surgery, subsequently attracts more attention.

Haworth et al, 2015[24]	Prominent ears	Yes	The attentional bias to the ear region of the patient who underwent bilateral otoplasty was significantly reduced in the post-operative photograph. The patient who underwent unilateral otoplasty had no significant change in fixation times towards the ear region
Dey et al, 2014[7]	Facial Reanimation	Yes	For preoperative paralyzed faces, observers looked equally on both sides in repose, and significantly more on the nonparalyzed/functional side when smiling. This asymmetric gaze pattern was eliminated after reanimation surgery, and attention was equally distributed with no statistically significant difference in gaze between the paralyzed and functional sides of the face, smiling and in repose.
Godoy et al, 2011[22]	Crooked nose	Yes	Preoperative crooked noses had longer fixation times than the postoperative crooked noses which was statistically significant.
Ishii et al, 2009[25]	Peripheral facial defromities (Moh's surgery defects)	Yes	The mean fixation time in the defect region was significantly longer in the post-op (after nevus resection) compared to the pre-op (prior to resection). The mean central triangle fixation times were longer in the preoperative normal face and the difference approached statistical significance.

UCLP, Unilateral cleft lip and palate; NAM, Nasoalveolar molding; AOI, Area of Interest

Table 4. Correlation between Fixation Patterns and Other Assessment Scales

Study	Field	Assessment Scale	Correlation Detected	Explanation
Darrach et al, 2019[19]	Rhinoplasty	Attractiveness scores	No	Fixation time was not associated with attractiveness scores
Boonipat et al, 2018[16]	Cleft lip and other facial conditions	Attractiveness scores	Yes, significant	Subjects spent significant more time fixating on the upper lip and lower lip lookzones of the least attractive cleft images compared to the most attractive cleft images.
Warne et al, 2018[9]	Cleft lip	Asher–McDade Aesthetic Index score	Experiment 2: Yes, moderate	There was a moderate positive correlation between the Asher–McDade Aesthetic Index score and the difference in total fixation duration between the Cleft Lip Group and Corrected Group for both the whole upper lip and the cleft side upper lip
Cai et al, 2018[10]	Breast reconstruction	Appearance and symmetry ratings	Yes, moderate and weak	Moderate correlation between appearance ratings and the total area-of-interest gaze time (overall favorable outcome had less overall area-of interest gaze time) A weak correlation was found between overall symmetry ratings and the number of fixations between the right and left (where asymmetry translated to more fixation on one half of the image)
Rayson et al, 2017[28]	Cleft lip	Cleft severity and infant cuteness ratings	Yes, strong	Strong and significant negative relationship between cleft severity and total fixation duration for eyes, but a strong and significant positive relationship between cleft severity and fixation on the mouth The cuter an infant was rated, the greater the ratio was between time spent fixating on eyes versus mouth
Stone et al, 2017[29]	Disfigured faces	Emotional experience and Disgust Sensitivity Scale	Yes, significant	Heightened attention to a disfigured feature compared to the equivalent feature in a non-disfigured face is associated with a stronger experience of negative emotion.
van Schijndel et al, 2015[21] lip	cleft lip and nose	Personality ratings	No	No correlations were observed between relative fixation times and personality ratings.
van Schijndel et al, 2015[17] nose	Nasal deformities	Personality ratings	Yes, weak	Weak negative correlations with significant values were observed between the mean relative fixation duration and ratings of personality traits in computer-morphed photographs for the personality traits withdrawn-sociable, unsatisfied-satisfied, and unlikeable-likeable No relevant correlations were found between the relative fixation durations and the individual personality traits. For deformed noses, the mean relative fixation duration did not correlate with the cumulative personality score
Litschel et al, 2015[27]	Protruding ears	Personality ratings	Yes	Faces in which the protruding auricles received the highest percentage of visual attention scored higher than average for the overall personality scores and for assiduousness, intelligence, and likeability

PRISMA 2009 Flow Diagram

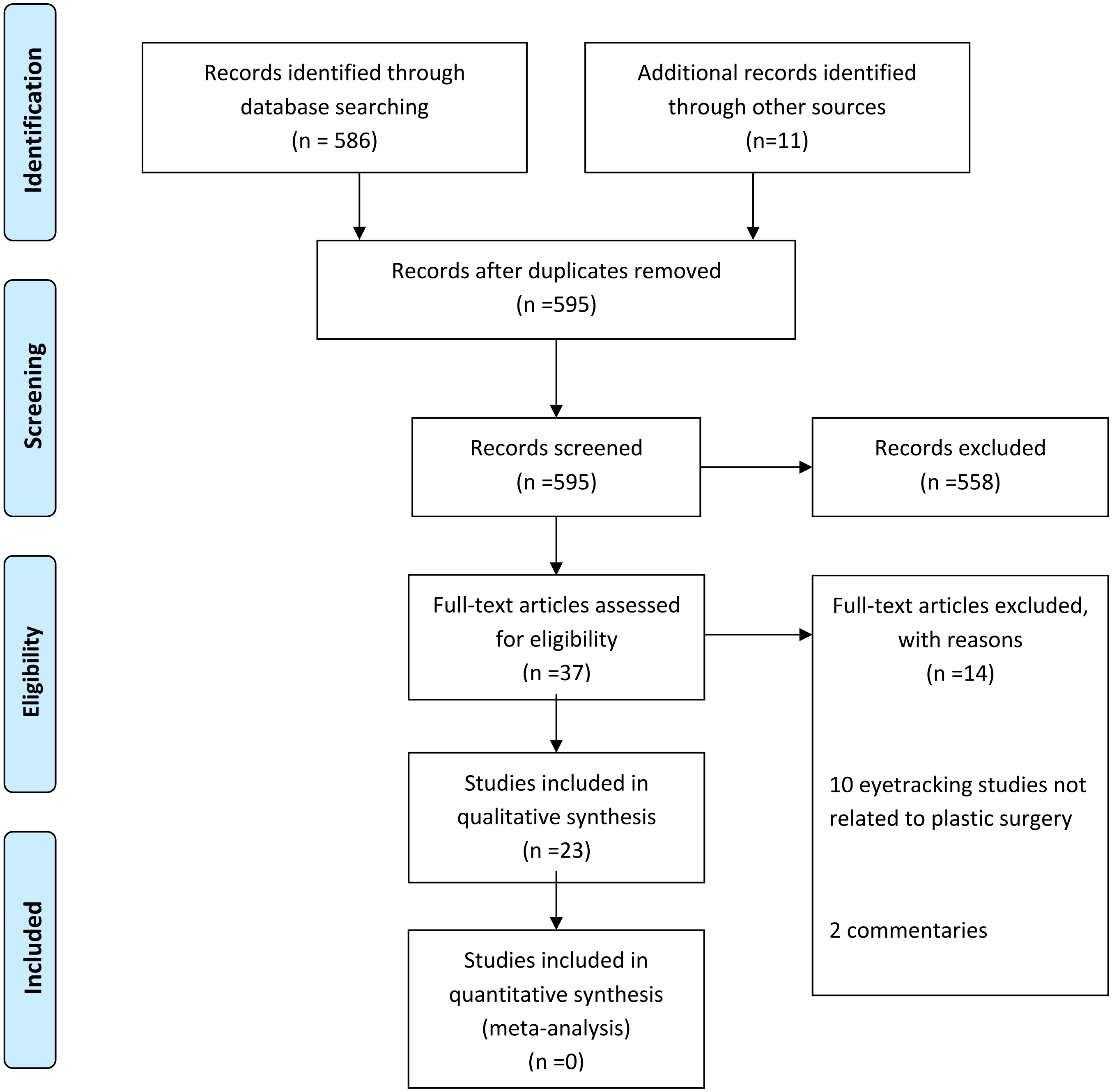

Figure 2. Time line of studies