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Measuring Visual Attention to Faces with Cleft Deformity[☆]

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KEYWORDS
Eye-tracking;
Facial perception;
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SUMMARY *Background:* Limited data are available regarding observers' visual attention to faces with congenital difference. We implemented eye tracking technology to examine this issue, as it pertains particularly to faces with cleft deformity.
Method: Four hundred three observers assessed 273 clinical images, while their eye movements were unobtrusively tracked using an infrared sensor. Forty-one facial images of the repaired cleft lip, 137 images of other facial conditions, and 95 images of matched controls were assessed. Twenty facial regions of interest ("lookzones") were considered for all images observed. A separate cohort of 720 raters evaluated the images for attractiveness. Observer and image demographic information was collected. Visual fixation counts and durations were computed across all 20 lookzones for all images.
The effect of a variety of variables on lookzone fixation was analyzed using factorial ANOVA testing.
Results: Cleft-repaired faces were rated as less attractive and drew observers' attention preferentially to the affected upper lip lookzone ($p<.001$). Images rated as less attractive garnered greater visual attention in the cleft-affected lookzones ($p<.001$). The eye tracking methodology demonstrated exquisite sensitivity to laterality of cleft deformity ($p<.001$). Individuals

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reporting a personal or a family history of facial deformity fixated more on the perioral region of cleft-repaired faces than did naïve observers ($p<.001$).
Conclusion: These findings highlight the utility of eye tracking measures for understanding critical variables that influence the visual processing of faces with cleft deformity. The data may provide analytical tools for assessing surgical outcome and direct priority setting during surgeons' conversations with patients.

INTRODUCTION

Attractive people elicit more positive first impressions and tend to be treated in a more positive manner than their peers.[1-3] Conversely, cleft lip facial deformity has been associated with problems in psychosocial adjustment[4] and a measured reduction in quality of life – even after surgical reconstruction.[5-7] While behavioral studies offer valuable insights into the experience of living with a facial cleft deformity, they have not explained well how other individuals visually process faces they perceive as being physically atypical. The eyes are arguably the most active of the human sense organs.[8] Rather than passively accepting sensory input, the eyes are constantly shifting as they scan objects and detect various salient structural cues. Fine movements of the eyes are necessary to properly target the fovea onto objects of interest. Because detailed information can be obtained only through the narrow foveal window, it is necessary for the eyes to move from point to point of transient concentration (*fixations*) following rapid sequential movements (*saccades*). The duration of a fixation varies from approximately 100 ms to several seconds.[9]

Initial visual processing of a face occurs 170 ms after presentation, facial recognition has been estimated to occur as early as the 300 ms timepoint, and emotion detection ensues between 400 and 600 ms.[10,11] While all of these data reflect the earliest stages of visual processing of a face, eye tracking research considers the series of movements that take place as an observer scans an image over a longer time interval. In this study, we measured observers' visual attention reflected by how their eyes tracked over facial images during a 10 s window of time.

Recordings of gaze behavior can demonstrate where in a visual scene an observer is seeking detailed information required for perception.[12,13] Numerous studies have corroborated the fact that one's eyes are generally directed toward the object of one's thoughts.[14-19] In the case of facial perception, it is understood that primary attention is paid to the eyes, nose, and mouth.[20] Despite the ample body of information about gaze behavior, there are scant data about the visual processing of facial difference. We have implemented eye tracking technology to examine this issue, as it pertains specifically to faces with cleft deformity.

MATERIALS AND METHODS

STUDY PARTICIPANTS

Three distinct groups of participants were included in this study: "*stimulus group*," "*observer group*," and "*rater group*."

Stimulus group

The stimulus group included patients presenting to the senior author's clinical practice (MAS) who had undergone cleft lip repair (N=41), as well as of those with other types of facial conditions: dermatochalasis (N=17), blepharoptosis (N=5), ear deformity (n=21), facial aging (N=23), nasal deformity (N=23), facial lipodystrophy (N=17), facial asymmetry (N=4), and various facial lesions (N=27). Images were also obtained from 95 age-/gender-matched "controls" (individuals without a defined facial diagnosis). A total of 273 images were studied (female: 141, male: 132). All participants in the stimulus group provided signed informed consent to allow their facial images to be used in the study, as per protocol approved by the Dartmouth College Committee for the Protection of Human Subjects. Nine slideshows containing 40 images each (20 experimental images and 20 control images) were created. These individual slideshows were composed to display a balanced representation of diagnosis (cleft, noncleft, and control), gender, and age range and also to present a manageable number of images to each observer (see below). Some control images were repeated in different slideshows to allow for adequate age/gender matching.

The age range of the stimulus group was 3.5 months to 85 years, while all of the patients with cleft lip deformity were $\leq$38 years old. Racial classification of the stimuli images were as follows: white 93%, Asian 4%, and Hispanic 3%. Laterality of the 41 cleft images was unilateral left (17), unilateral right (10), and bilateral (14).

Observer group

The observer group consisted of individuals who agreed to have their eyes tracked while observing one of nine sets of 40 images that were randomly displayed on a computer screen for 10 seconds each (N = 403). Observers also completed a demographic survey. The 403 unique observers were recruited from three different locations (in Hanover, NH: 107 adults, from the Dartmouth College and Dartmouth Hitchcock Medical Center community; in Bangkok, Thailand: 249 adults, recruited off the street in a central business district; and from Cairo, Egypt: 49 adults recruited from personal contacts of the co-author O.D.). The age range of the observers was 18-80 (mean = 24.9 years). There were 176 females, 186 males, and 41 without specified gender. Observer race/ethnicity was self-classified as Asians 65%, white 19%, multiethnic 2%, Hispanic 1%, black 0.5%, Native American 0.5%, and Native Hawaiian 0.2%. Eighteen (4.5%) of the observers reported having a personal or a family history of facial deformity. All subjects underwent visual acuity testing, and 20/40 vision or better was required in each eye for inclusion (lens correction permitted).

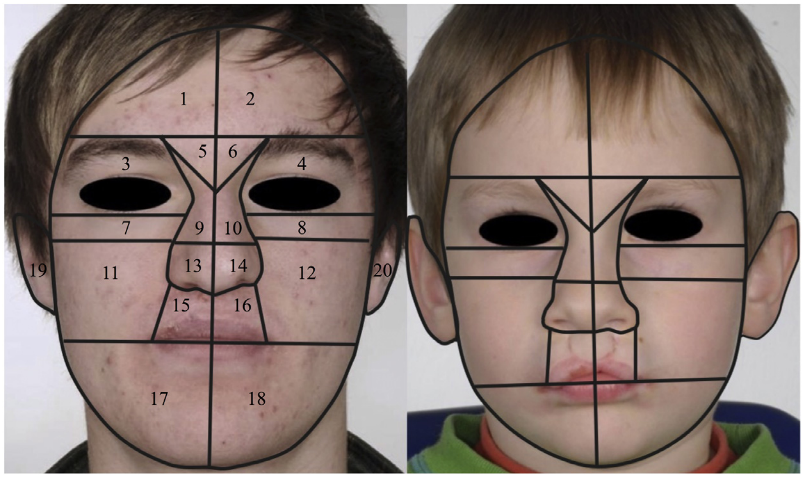

Figure 1 Lookzones were hand-drawn onto all experimental images using predetermined anatomic landmarks. Ten matching zones were identified on each side of the face, classified as follows: forehead (1,2); periorbital (3,4); glabellar (5,6); infraorbital (7,8); lateral nasal sidewall (9,10); mid-cheek (11,12); nasal tip, nares, and columella (13,14); upper lip (15,16); lower lip, chin, mandible (17,18); ear (19,20).
The above two facial images were obtained from the National Library of Medicine's open-access "Open-I" website (https://openi.nlm.nih.gov/detailedresult.php?img=PMC3924917_1746- 160X-9-38-1&query=cleft+lip&it=ph&vid=1&req=4&npos=283). The creative commons licensing rules were adhered to (https://creativecommons.org/licenses/by/4.0/). The images were altered here by adding only the outlines of the 20 lookzones used in the current study. Image source: Nkenke E, Stelzle F, Vairaktaris E, Knipfer C. Do cleft lip and palate patients opt for secondary corrective surgery of upper lip and nose, frequently? Head Face Med 2013;9:38 doi:10.1186/1746-160X-9-38.[25]

Rater group

A separate cohort of raters (N=720) were recruited by word-of-mouth and by online contact. The raters assessed all 273 stimuli photographs for attractiveness on a 1-7 point Likert scale by an online survey. To provide scale anchors, sample images of males and females representing "7" (most attractive) and "1" (least attractive) based on the authors' judgment were presented at the beginning of their survey. The rating process was performed using a web-based survey tool (SurveyGizmo, Boulder, CO).

EYE TRACKING PROTOCOL

Each study image was presented to the observers on a 17 inch flat-screen computer monitor for 10 seconds. It required just less than 9 min for the subjects to complete the entire 40 image slideshow, including 3 s intervals of a blank, black screen displayed in between the images. No specific instructions were given to the observers; they were simply asked to freely view the images. Quick Screen Capture software (version 3.0, Etrusoft, Kaysville, UT) was used to present PowerPoint (Microsoft, Redmond, WA) slideshows containing the image stimuli displayed in a random order from one subject to another. An EyeTech TM4 desktop-mounted, high-resolution eye tracking system was used (EyeTech Digital Systems, Mesa, AZ), which captures infrared light reflected off the cornea at a binocular data tracking rate of 30 Hz and an accuracy of 0.5 degrees visual angle. The low-profile TM4 console was placed unobtrusively at the base of the computer monitor. Each participant's head was held stationary in an optometric chinrest 60 cm from the monitor. At that distance, and with the eye tracking system reporting an accuracy of +/- 0.5 degree visual angle, the maximum eye tracking error is calculated to be +/- 5 mm. Even the smallest study lookzones when projected onto the 17 inch monitor measured at least 1.4 cm in each dimension, with an area of at least 2 cm^2. The eye tracking procedure started with a calibration/validation sequence in which participants were asked to follow a dot presented randomly at nine different locations on the screen. The system was calibrated on a per-subject basis at the beginning of the experiment. Twenty esthetic regions of interest ("lookzones") using predetermined anatomic landmarks were traced onto each facial image in advance of the study (Figure 1).[21] The lookzones were unseen to the observers. EyeTech's Quick Link API software was used to compute real-time data from the eye tracking system, which captured the x,y position of the eye every 33 ms. The software program computed the fixation counts and durations with time and relative to each facial esthetic lookzone. A fixation was defined as a gaze duration of >100 ms. All information was imported from Excel (Microsoft, Redmond, WA) files to SPSS v.22.0 (IBM, Armonk, NY) and analyzed in relation to the demographic/diagnostic details of the stimulus, observer, and rater groups.

DATA ANALYSES

All data analyses were conducted in SPSS v.22.0. Visualization of data was facilitated with Tableau version 8.3.3 (Tableau Software, Seattle, WA). Mean fixation counts and durations were computed across all 20 lookzones for the experimental and control stimuli. The interaction effect of a variety of independent variables on lookzone fixation was

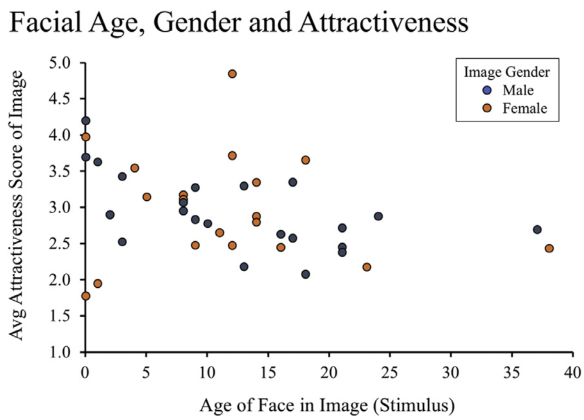

Figure 2 The distribution of cleft images (stimuli) by age, gender, and attractiveness rating.

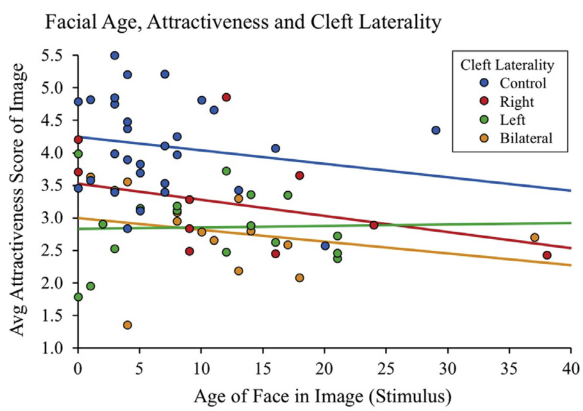

Figure 3 The distribution of cleft images (stimuli) by gender, attractiveness rating, and laterality.

analyzed using factorial ANOVA testing. Significance was set at the $p < .05$ level.

RESULTS

The distribution of the 41 cleft images (stimuli) in terms of age, gender, and attractiveness rating is shown in Figure 2. The mean age in the female images was 11.76 years and in male images was 13.55 years. The mean attractiveness rating of the female faces was 2.94 and of male faces was 2.93. There was no statistically significant difference in age distribution or attractiveness rating between female and male images.

When cleft images were compared to their matched control images, a notable difference in attractiveness was detected. This was seen for both unilateral and bilateral cleft lip. Similar to control images, there was a trend toward lower attractiveness rating with advancing age (Figure 3).

Our eye tracking analysis confirmed that observers preferentially fixate on the orbital region of all faces.[20] Of particular interest in our findings, however, was the marked increase in fixation identified in the upper lip lookzone of images displaying a cleft lip (Figure 4). With added observer attention paid to lookzones of cleft deformity, there was a secondary "steal" effect seen away from some of the other lookzones compared to the eye tracking of control images. Subjects fixated 17.42% of the time within upper lip lookzones of cleft images compared to 8.49% of the time for the control image. This effect carried over to fixation in the lower lip lookzone (cleft,11.54% vs. control, 8.62%) and to the nasal tip and columella (10.08% vs. 8.4%). For all comparisons between cleft and control images, the interaction effect across lookzones was significant, $F(9, 73{,}620) = 81.621$, $p<0.001$.

These findings were seen with more granularity and consistency when the cleft images and lookzones were broken out by laterality (Figure 5). For right unilateral cleft lip, attention was drawn preferentially to the right upper lip (12.72%) versus the noncleft left upper lip (4.87%). For left unilateral cleft lip, this effect was reversed, with left upper lip fixation (11.28%) greater than fixation on the noncleft right upper lip (7.41%). This laterality interaction effect was significant, $F(38, 36{,}556)=10.576$, $p<.001$. A similar laterality effect was seen in the nasal tip/nares/columella and lower lip lookzones. While images of bilateral cleft lip drew more attention to the perioral and perinasal regions than did control images, when compared to the images of right or left unilateral cleft lip, the fixation durations tended to be shorter than the affected side and longer than the noncleft side. Of note, our data showed a highly consistent "left gaze bias" (i.e., the right side of the face tends to be looked at first and for longer periods of time), which has been previously documented.[22-24]

While considering the attractiveness ratings of the faces with a cleft lip, we found that less attractive faces garnered greater attention than more attractive faces in the upper and lower lip lookzones. Of the 41 cleft images, average attractiveness ratings ranged from 2.08 to 4.85. For purposes of data visualization (Figure 6), the attractiveness rating score was rounded to the nearest whole number. We detected a relationship between attractiveness and percent time fixating on the upper and lower lip zones in the cleft images. Subjects spent 19.05% of the time fixating on the upper lip lookzone of the least attractive cleft images (category 2) vs. 8.52% for the most attractive cleft images (category 5). A similar effect was seen in the lower lip lookzone (13.89% vs. 6.65%). The interaction between attractiveness ratings and lookzones was significant for the cleft images, $F(35, 36{,}567) = 5.797$, $p<.001$. For the control images, attractiveness ratings demonstrated no discernible effect of attractiveness across our defined lookzones.

Eighteen observers indicated that they had a personal or a family history of significant facial deformity (e.g., facial clefts, traumatic facial accidents, and vascular or pigmented birthmarks). These subjects paid greater attention to the upper lip lookzone of cleft images (24.6% of fixation time) than did subjects without that particular personal background (16.78% of fixation time) (Figure 7).

DISCUSSION

We have implemented eye tracking technology to track observers' visual processing of facial images with cleft lip deformity. We considered a number of variables that could potentially influence facial perception: presence of cleft,

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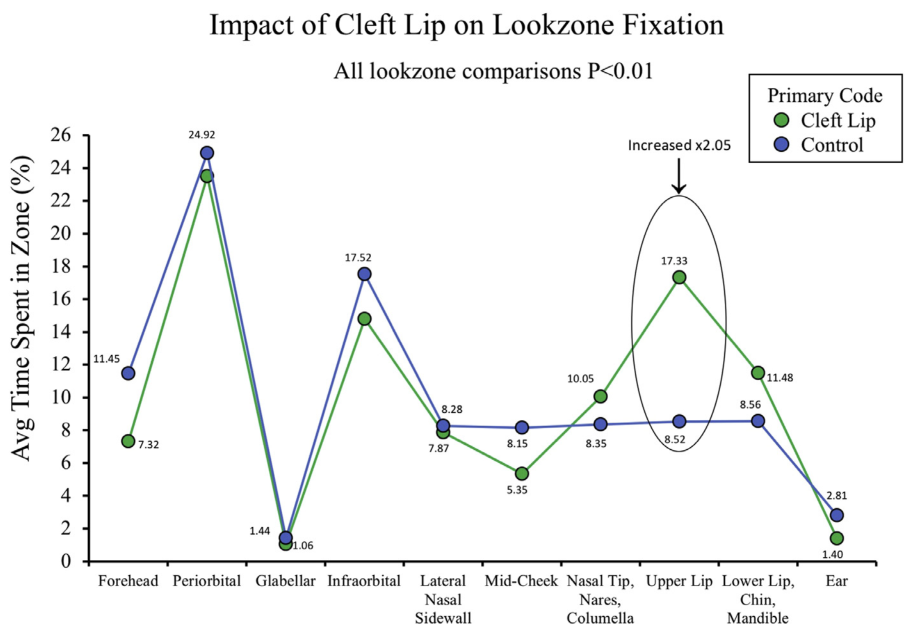

Figure 4 While the orbital region was predictably the primary attraction on the face, the presence of a cleft lip resulted in a doubling of fixation time in the upper lip lookzone.

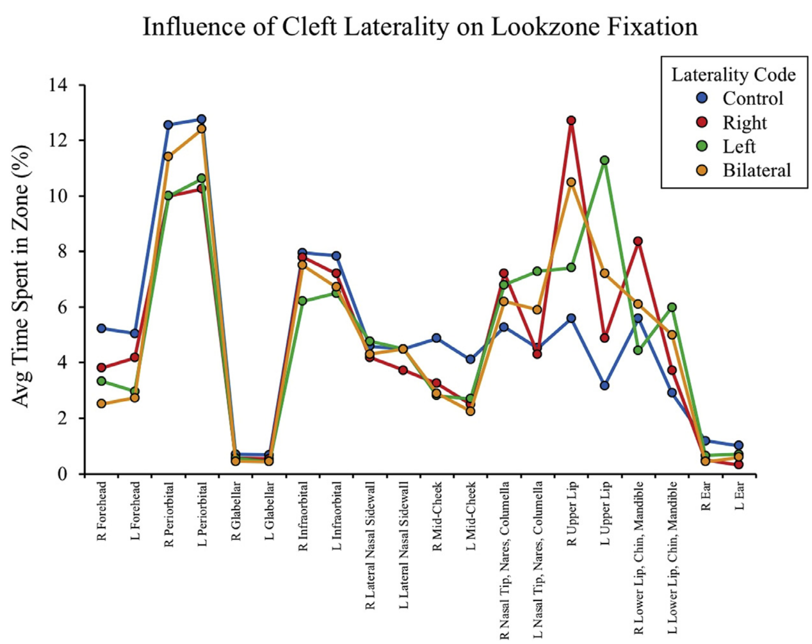

Figure 5 Preferential attention was paid to affected facial lookzones, with a predictable association with cleft laterality. An associated "steal" effect away from other lookzones is noted.

laterality of cleft, image attractiveness, and observer's personal/family history of a facial deformity. Both the scale and scope of our study differentiate it from prior research.[25-28] Meyer-Marcotty et al. studied 18 black and white images of adults with repaired unilateral cleft lip (and 18 control images), whereas Schijndel et al. analyzed 18 color images of adults with repaired cleft lip (laterality unspecified and digitally corrected controls). Dindaroglu et al. considered a total of 30 adult black and white images: 10 images with repaired unilateral cleft, 10 images with repaired bilateral cleft, and 10 images as control. The aforementioned studies all examined only 4 facial lookzones without any consideration of laterality of gaze.

In contrast, our stimuli included 41 color facial images of patients with repaired unilateral or bilateral cleft lip. The present study is the first to include the facial images of children, with the stimuli dataset ranging in age from 3.5 months to 38 years of age (mean: 12.7 years). We examined the eye tracking patterns of 403 subjects who observed the cleft images, and also the facial images of 232

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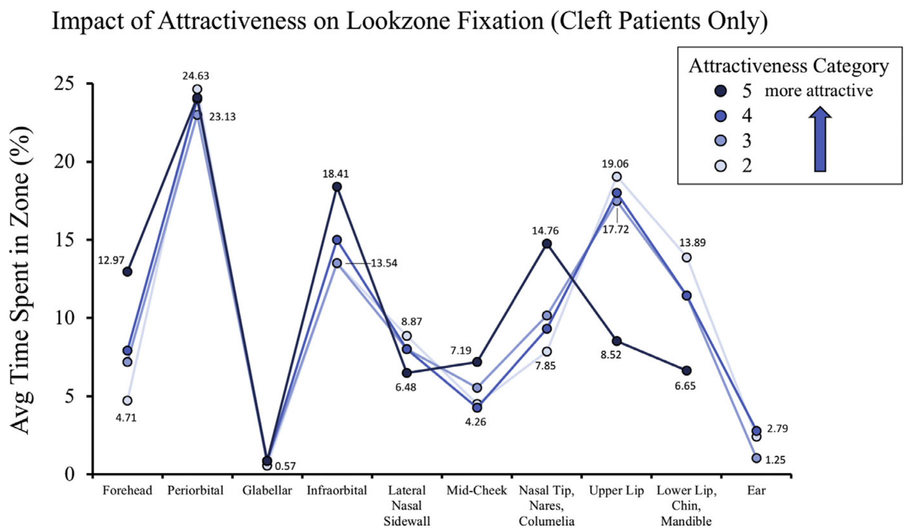

Figure 6 Cleft images that were rated as less attractive garnered greater visual attention in the upper and lower lip lookzones.

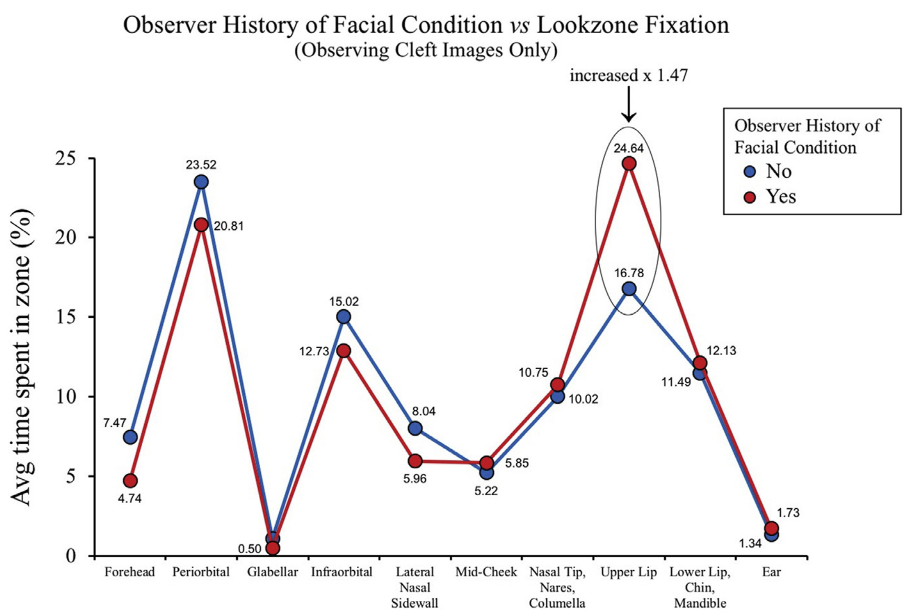

Figure 7 Observers with a personal or a family history of facial deformity fixated more on the perioral region of cleft faces.

age- and gender-matched non-cleft individuals. We established 20 bilateral facial lookzones reflecting the accepted esthetic units of the face critical to reconstructive surgeons[29] (Figure 1). Analyzing the entire face systematically with regard to esthetic units allowed us to broadly consider the anatomic distribution of gaze and to report eye tracking data of far greater granularity than prior studies.

Notably, in our protocol, the cleft faces were incorporated into a much larger stimuli dataset, including 137 images depicting other diagnosed facial conditions and 95 control images. By embedding the cleft images within the slideshow presentations, we aimed to limit observer habituation to the structural cues inherent in repaired cleft faces during the eye tracking procedure. In the previous reports, observers gazed upon experimental images of only repaired cleft lips and hence may have reflexively tracked to the lip regions once they detected a pattern to the images being displayed.

While we detected an inverse relationship between age and attractiveness ratings (Figure 2), observers' gaze was consistently drawn to the cleft deformities in a manner similar to that previously demonstrated for adult faces. However, it is interesting to note that almost no attention was paid to the glabellar region of the cleft images or their matched controls (or to the larger cohort of control images within our dataset). While it is well appreciated that resting and dynamic lines in the glabellar region play an important role in adults' nonverbal expression of anger and disgust/contempt,[30,31] it is possible that the two-dimensional, static nature of the images displayed in the current study do not adequately convey emotional valence.

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Our key findings can be summarized as follows: (1) cleft-repaired faces were rated as less attractive across the broad age distribution studied, (2) cleft-repaired faces significantly drew observers' attention to affected areas, most strongly to the upper lip lookzone, (3) the eye tracking methodology that we employed confirmed a left-gaze bias, demonstrated exquisite sensitivity to the laterality of cleft deformity, and revealed a relative "steal" effect away from the typically more alluring peri/infraorbital regions of the face, (4) cleft-repaired images that were rated as less attractive by an independent rater group garnered greater visual attention by our observer group in the upper and lower lip lookzones, and (5) as compared to naïve observers, individuals with a personal or a family history of facial deformity visually fixated more on the perioral region of faces with repaired cleft lip.

The implications of this work to the reconstructive surgeon are significant. It is understood that the human capacity for facial recognition is highly sensitive, with most adults able to recognize and differentiate one face among a large multitude. While the relative contribution of nonverbal versus verbal communication to impression formation is uncertain,[32-35] there can be little question as to the importance of facial structural cues in human social interaction. Multilayered information is instinctively interpreted from faces, including age, gender, ethnicity, attitude/emotion, well-being, trustworthiness, and social status.[36-38] While experimental psychologists have studied the importance of the face in social judgments for decades, there has recently been increased attention paid to facial analysis. Modern facial recognition systems employing machine learning algorithms are rapidly being developed to match – or even improve upon – the human capacity to interpret faces.[39] Meanwhile, the reconstructive surgeon's ultimate goal in treating individuals with cleft deformity is to conceal the stigmata of facial difference so that they become undetectable to either cognitive or technological methods of perception. That is, the better the outcome, the less detectable the defect. Available methods to measure the outcome of facial reconstruction are subjective and may not accurately determine how an affected face is interpreted. Evaluations submitted by external raters, or by patient self-report, may be influenced by expert knowledge, emotional antecedent, or implicit attitude,[40] unreliably conveying how one is perceived by others.[41-43] By establishing a normative pattern of facial eye tracking across 20 facial lookzones in an age- and gender-matched control group, we have created a reference distribution against which to compare the perception of reconstructed faces deformed by cleft or other conditions. While routine eye tracking analysis is not a feasible approach to implement in a clinical setting, our data may help inform surgeons' conversations with patients by objectively demonstrating the pattern of cleft face perception. The impact of this work would be amplified by a comparative analysis of eye tracking changes following surgical reconstruction of cleft stigmata, a focus of our ongoing research.

Finally, while the algorithms for facial recognition systems extract landmarks to analyze size, shape, proportion, and spacing of features, they are not constructed to incorporate the human patterns of gaze preference. It is possible that in the future artificial intelligence technology intended to mimic human facial perception will integrate the type of eye tracking data generated in this study.

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