Measuring attention bias in observers of strabismus subjects

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BACKGROUND Despite the known negative psychosocial impact and the importance of facial aesthetics for individuals with strabismus, the gaze pattern of the presumed attention bias has not been documented previously.

METHODS Thirty images (15 digitally reconstructed color photographs to show strabismus and 15 photographs of volunteers without strabismus) were viewed in random order by 25 naïve participants (age range, 23-63 years; 15 females). Visual scan paths of participants were recorded using an infrared corneal image eye movement recorder, and the individual parameters of saccades, fixations, and dwell time were assessed using DataViewer software.

RESULTS Viewers primarily tended to fixate on the eyes, the nose was the next most prominent point of focus (both $P < 0.001$). Time to first fixation and the presence of strabismus in the images presented were significantly associated ($P < 0.001$). When the eyes were viewed, there was more time spent looking at the strabismic eye ($P < 0.001$), although the number of fixations toward the eyes did not differ significantly between normal and strabismic faces ($P = 0.2$).

CONCLUSIONS Our results confirm that the presence of strabismus in the features of the human face draws longer attention from the average viewer to the eye region, and particularly to the strabismic eye. (J AAPOS 2019;23:143.e1-5)

The negative psychosocial impacts of strabismus in children and adults have been well documented and include lower self-esteem, less acceptance by peers, lack of confidence, perception of being less intelligent and altered interpersonal relationships, social isolation, and difficulty with employment.[1-8] Strabismus is easily recognized even by young children: Paysse and colleagues[3] demonstrated that a negative attitude toward strabismic dolls emerged at approximately 6 years of age.

In order to objectively study facial aesthetics, researchers in the field of visual perception have relied heavily on models of attention. A validated measure of attention is eye movements, which can accurately be tracked on a particular stimulus image. Integration of a subject's rapid eye movements and fixations creates what is known as a "scan path." The results of these studies on facial perception have led to the definition of the "central triangle of fixation," where the focus of attention moves from the eyes, to the nose, and the mouth.[9-11] We sought to determine whether there is any attention bias toward the eye region in individuals with strabismus. Most studies to date are based on subjective reactions to photographs.[4,12] Eye tracking has not been used previously to assess the pattern fixation that may be associated with these biases.

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Subjects and Methods

Study Design and Apparatus

A total of 25 naïve nonstrabismic adults of mixed ethnicity (age range, 23-63 years; mean, 33 years of age) viewed 30 color photographs of faces of volunteers from our clinical practice. Photographs of nonstrabismic subjects were digitally reconstructed to show horizontal deviations of 25^{Δ}-35^{Δ} (5 esotropic and 5 exotropic photographs) and vertical deviations (5 hypertropic photographs); 15 unmodified photographs of orthotropic subjects were also presented to the participants. The strabismus angles corresponded to a large enough angle to be discerned by all participants and well above the average "cosmetic threshold" angle of 7° (15^{Δ}).[13] All photographs were standardized with regard to relative size of the face, facial expressions, light exposure, background illumination, and background color. Only the subjects who did not have any other cosmetic blemish on the face were included. All adult photographic subjects provided consent for the use of photographs for research purposes, and study approval was obtained from the IWK Health Centre Institutional Review Board,

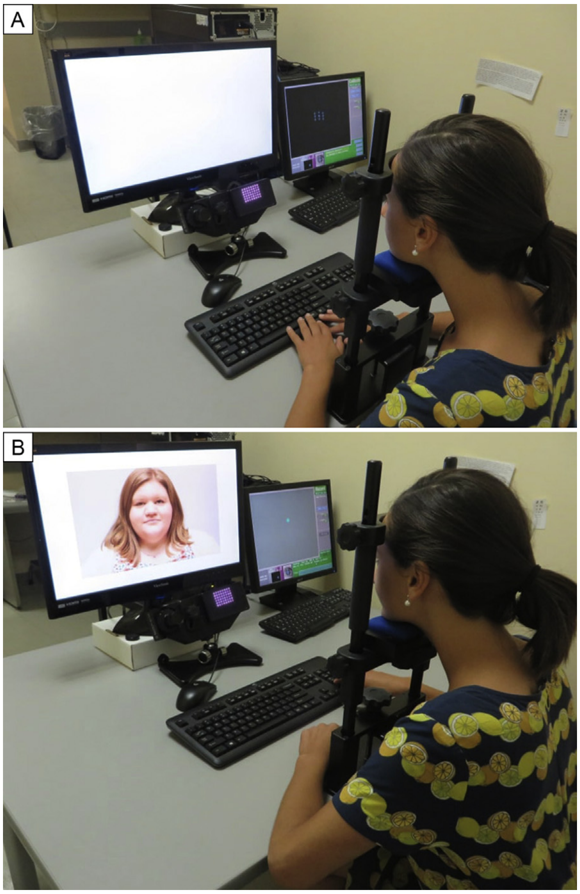

FIG 1. The EyeLink1000 tracker set-up. A, The participant completes a 9-point calibration seated in front of a 19-inch monitor at a distance of 60 cm. B, Following calibration, the participant looks at a fixation point in the center of the screen until the first image of a face appears.

Halifax, Canada. Informed consent was obtained from participants.

Visual scan paths of participants were recorded using the EyeLink1000 (SR Research Ltd, Mississauga, Ontario, Canada). The EyeLink1000 is an infrared, table-mounted eye-tracking device. Recordings were achieved by noncontact means; the EyeLink1000 tracks the participant's pupil in real time to allow for recording of eye position.

Procedure

Participants were recruited via word-of-mouth and posted advertisements. Potential participants underwent a basic vision screening to determine eligibility. Only participants who met the following criteria were included in the study: best-corrected visual acuity of 6/6 (ETDRS), orthotropic on cover test (near and distance), and full extraocular motility. Participants were provided with basic information about the test, possible risks, benefits, possibility of withdrawal, and protection of privacy information. Participants, however, were not told that the aim of the study was to explore attention biases to the different facial regions in order to avoid bias in their responses.

During testing, participants were seated in front of a monitor at a distance of 60 cm to simulate "life-size" stimuli at a conversational distance; study photographs were displayed while participants' eye movements were monitored and recorded. The participant's head was supported by a chin and forehead rest (similar to a slit-lamp) to minimize head movement. The EyeLink1000 was calibrated using a 9-point calibration sequence to ensure that pupil tracking was complete (Figure 1A). Following calibration, participants were instructed to look at a fixation cross on the screen until the image of a face appeared (Figure 1B). Following a 5-second presentation of each image, participants were asked to rate on a scale of 1-3 how "approachable/friendly" the person in the photograph was. Once a rating was provided, another fixation cross appeared, and the next photograph was presented. This approachability rating was subjective and was used only to actively engage the participants, so that all participants were viewing the photographs with the same presumed goal in mind. Following presentation of the images, participants were briefed on the true purpose of the study immediately following the EyeLink recording session; a combined educational and post-deception debriefing session followed, with discussion of any deception in the study and an explanation of the study purpose. After debriefing, participants were given the opportunity to provide informed consent.

Data Analysis

From the eye movement recordings, the individual parameters of saccades, fixation count, fixation duration, time to first/last fixation, first/last fixation duration, dwell time, and key response variable, were assessed using DataViewer software (SR Research Ltd). The variables measured were the location of the first fixation, the location of the area of maximum fixation duration, and the location of the area receiving the maximum number of fixations (Figure 2A-B). Repeated measures analysis of variance was used to determine how fixation duration and dwell times varied among the 4 facial interest areas (right eye, left eye, mouth, nose). Tukey's post hoc analysis was used as well. Descriptive statistics (median, standard error, and interquartile range [IQR]) were used to describe the dwell times.

Results

A univariate generalized linear model demonstrated that there was a significant association between time to first fixation and the different areas of interest in the images shown ($P < 0.001$). For instance, time to first fixation was delayed most to the mouth (1413 ± 518 ms), followed by the nose (166 ± 632 ms), and then the eyes (820 ± 662 ms). However, there was no significant association between time to first fixation and different strabismus types. We then considered dwell times for these three facial areas of interest. There was significant variability in duration and proportion of time spent by viewers looking at different facial regions (Figure 3A). While viewers primarily tended to fixate upon eyes, the nose was the next area of focus (both $P < 0.001$). When these parameters were stratified by the presence or absence of strabismus, observers tended to

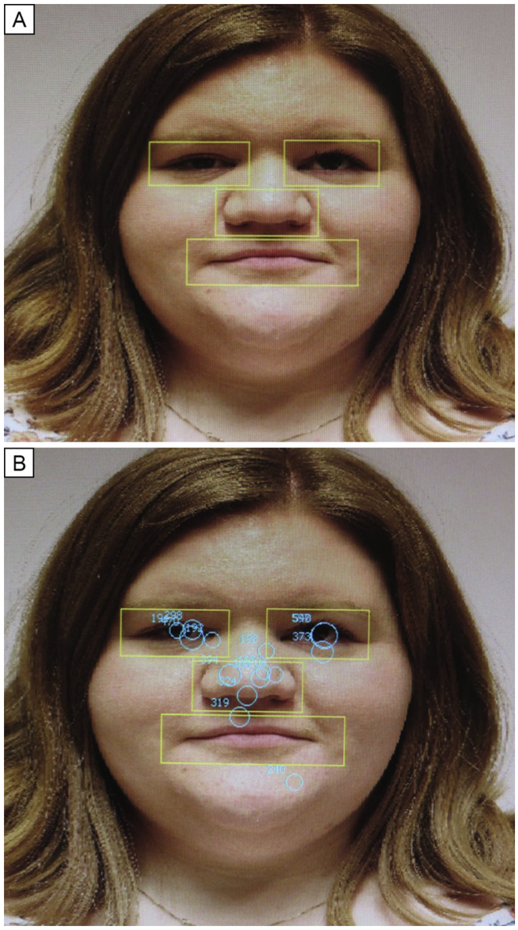

FIG 2. A, Photograph of a digitally reconstructed subject showing a vertical strabismus with the four areas of visual interest (right eye, left eye, nose, mouth); fixations of these four areas are counted/analyzed. B, Photograph of the same subject with blue circles representing fixations of one observer; the bigger the circle, the longer the dwell time (in milliseconds).

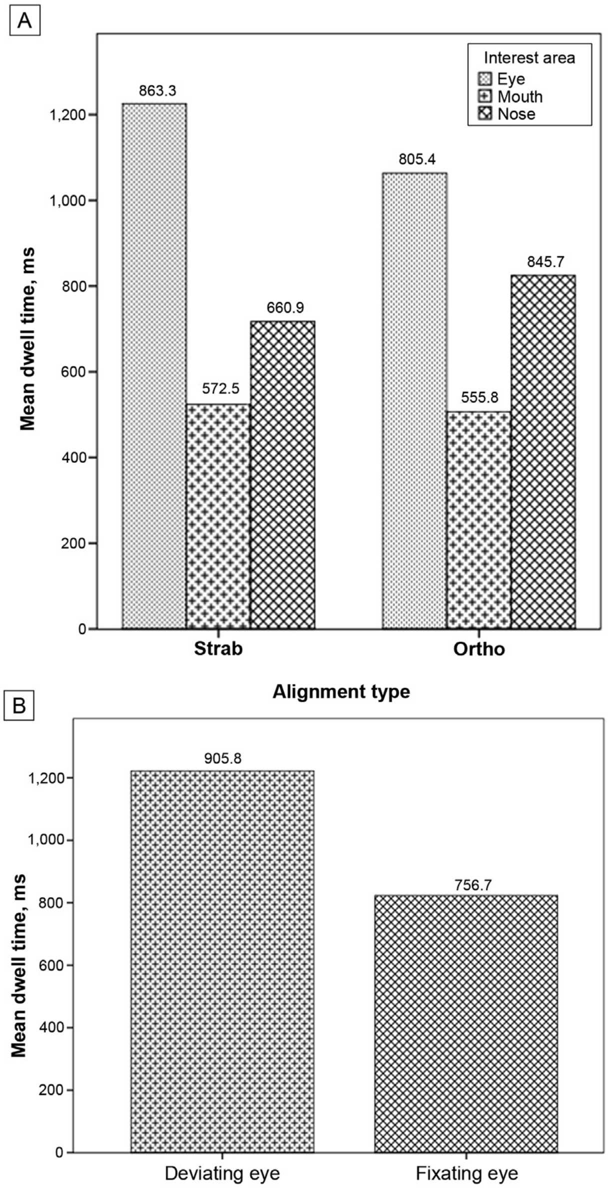

FIG 3. A, Bar graph demonstrating variability in mean duration of time spent by viewers looking at different facial regions (dwell time ± standard deviation) in orthotropic and strabismic subjects. B, Bar graph demonstrating mean dwell time and standard deviation of observers looking at deviated eyes compared to fixating eyes in subjects with strabismus.

spend more time looking at the strabismic eye compared with orthotropic images ($P < 0.001$), although the number of fixations did not differ significantly between the two groups ($P = 0.2$). Mean dwell time was shown to be prolonged looking at the deviated eye compared to the fixating eye (Figure 3B). This was similar for all three types of misalignment presented: esotropia ($P = 0.37$), exotropia ($P = 0.41$), and hypertropia ($P = 0.93$).

We also assessed whether participants were initially more likely to look at the deviated eye before the fixating eye, and whether they were more likely to look at the deviated eye for longer. We found no such preference. Furthermore, there was no significant difference in duration of first fixation on the deviated eye compared with the duration of first fixation on the fixating (straight) eye in all three types of misalignments—esotropia, exotropia, and hypertropia ($P = 0.59$). Participants were questioned on how approachable they rated the photographs, that is, very approachable, neutral, and not approachable (Figure 4).

Discussion

Although it is commonly held that strabismic eyes attract attention, this has not really been documented objectively. Eye tracking analysis has been used to objectively demonstrate attentional bias toward the ear region when faces of children with prominauris are viewed.[14] Similar eye technology has also shown that cleft lip and cleft nose draw attention.[15]

Human observers scan the face in a predictable triangular fashion, focusing on the eyes, then the mouth and nose. We observed that pattern in this study, where

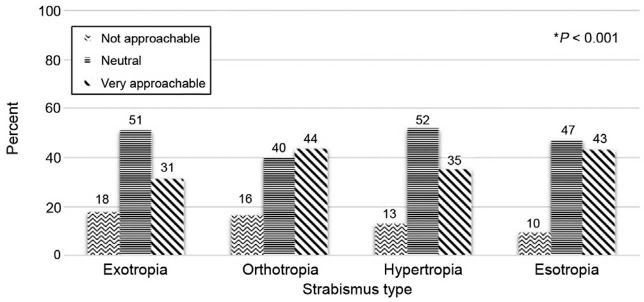

FIG 4. Bar graph demonstrating approachability key responses of participants to different strabismus types.

subjects were presented with human facial images with and without strabismus, the eyes overwhelmingly being most salient with regard to number and duration of fixations.

When presented with photographs of faces with and without strabismus, observers generally spent more time looking at the eye region, in particular the strabismic eye. However, subjects were not more likely to look at the deviated eye before the "fixating" (straight) eye, neither did the participants spend a longer duration of first fixation on the deviated eye. In other words, it appears that a strabismic face is looked upon initially in the same way as a face with straight eyes would be but that once the strabismic eye is identified, it is targeted, no matter the direction of misalignment.

The negative psychosocial impact of strabismus on quality of life is well documented. Patients with "noticeable strabismus" have higher impact scores, indicating less psychological well-being, than patients without noticeable strabismus.[16] Studies have found that the threshold for lay observers to detect both exotropia and esotropia is 12^{Δ}-19^{Δ}, although several other factors were found to affect the ability to detect strabismus, including observer's age, sex, and ethnicity.[13,17] Larson and colleagues[13] demonstrated that the statistically significant threshold to detect esotropia, exotropia and hypertropia was 12.5^{Δ}. Hypotropia on the other hand, had a higher threshold (20^{Δ}). Chan and colleagues[17] noted that the threshold allowing for 70% detection rate among lay observers was lower for exotropia than for esotropia (16.3^{Δ} vs 19.4^{Δ}). On the contrary, this was not observed in our study; attention was quickly drawn on first encounter to the eye area first, followed by the nose and the mouth, but no significant difference was observed between the different groups based on strabismus type. This might be due to the small numbers of each strabismus type and lack of variation in angles of strabismus. Few studies have evaluated whether there is a relationship between size of deviation and psychological impact perceived by the strabismic subject. Nelson and colleagues[18] found that people with deviation $>25^{\Delta}$ reported more frequently that their strabismus had a negative impact on their self-esteem than patients who had smaller angle strabismus. The decreased time to first fixation observed in our study on the eye region in faces with large-angle strabismus could indeed support a causative relationship between initial gaze and subjective self-perception. In addition, although not a key aim of the study, a significant correlation between dwell time in different strabismus types and approachability indicate that strabismus can negatively affect social response, highlighting the importance of strabismus differences in how faces are viewed. Other subjective studies found no correlation between the angle of deviation and the psychological impact of strabismus.[19] However, Ritchie and colleagues[19] used a psychological impact questionnaire designed for a younger population (16- to 18-year-old amblyopic subjects with and without strabismus) on an overall older population (15-84 years of age), with higher mean of the strabismus angles of deviation (33^{Δ}).

A major limitation of our study is the use of two-dimensional still photographs instead of three-dimensional live faces as targets. A photograph does not fully reflect the nuances of a real-life social setting, where eye or facial expression movements or angle of observation can make the strabismus more or less apparent. We believe we created the worst-case scenario of a "first head-on encounter" in our experiment, whereby the observer is presented with a stable, fully visible and easily inspected strabismic face. Ethnicity was not accounted for in our study; this was a factor found to alter the perception of visually significant strabismus by Chan and colleagues.[17] Another limitation of the current study is the small sample size, which did not permit comparison of various angles of strabismus. Finally, we analyzed the visual behavior of non-strabismic observers only, and one could speculate that these individuals would be less "tolerant" to the presence of a deviated eye in the facial features observed as opposed to strabismic observers whose visual observation pattern might be different.

The strength of this study resides in our use of an objective tool to study the pattern of visual attention to faces with strabismus. This represents the first such analysis using an eye tracking device to demonstrate how faces with strabismus are visualized through the detection of subtle changes of visual attention strategies undetected through classic self-observation methods.[20] Finally, this study uses sex standardization of the observed targets as well as of the observer subjects: the same number of strabismic male and female faces and an equal distribution of male and female evaluators were used, eliminating any gender bias in the observation scoring. Whereas other studies had the observers evaluate the strabismic photograph and compared it with the orthotropic photograph of the same subjects, thereby neutralizing an individual evaluator's bias for specific facial features of the subject, we could not use this paradigm. By keeping the observers naïve of the study aim, we were not able to present them with the same face twice with and without strabismus. By avoiding this, however, we ensured the objectivity of the visual fixation behavior measured.

Despite its limitations, this study demonstrates the existence of an attentional bias toward the deviated eye of a strabismic subject, no matter the orientation of the angle or the sex of the strabismus sufferer. These findings objectivize the reports of strabismus patients who feel uncomfortable when looked at by others. Further studies will be needed to find the angle threshold of these findings to challenge the notion that angles of $<15^{\Delta}$ are not noticeable.

Literature Search

PubMed was searched without date restriction, for English-language results, using the following terms: *strabismus* AND *perception* OR *eye tracking* OR *psychosocial* OR *attention bias*.

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