Article

PERCEPTION

Quantifying the Wollaston Illusion

Perception
2020, Vol. 49(5) 588–599

DOI: 10.1177/0301006620915421
journals.sagepub.com/home/pec
SAGE

Heiko Hecht, Stefanie Siebrand and Sven Thönes
Department of Psychology, Johannes Gutenberg-Universität Mainz, Mainz, Germany

Abstract
In the early 19th century, William H. Wollaston impressed the Royal Society of London with engravings of portraits. He manipulated facial features, such as the nose, and thereby dramatically changed the perceived gaze direction, although the eye region with iris and eye socket had remained unaltered. This Wollaston illusion has been replicated numerous times but never with the original stimuli. We took the eyes (pupil and iris) from Wollaston's most prominent engraving and measured their perceived gaze direction in an analog fashion. We then systematically added facial features (eye socket, eyebrows, nose, skull, and hair). These features had the power to divert perceived gaze direction by up to 20°, which confirms Wollaston's phenomenal observation. The effect can be thought of as an attractor effect, that is, cues that indicate a slight change in head orientation have the power to divert perceived gaze direction.

Keywords
visual perception, gaze direction, facial features, Wollaston illusion

Date Received: 2 December 2019; accepted: 3 March 2020

In 1824, the Royal Society of London published a paper containing a number of engraved portraits commissioned by William H. Wollaston, drawn by the president of the Society, Thomas Lawrence, and duplicated by way of engraving. Based on these drawings, Wollaston (1824) pointed out how perceived gaze can be altered without changing the pupil and iris of the eyes of the portrait. He manipulated facial features, such as the nose. The nose seemed to attract the perceived gaze direction, although pupil and iris (or even the entire eye socket including eye brows) had remained unaltered. In his own words: "Hence it is that a pair of eyes drawn looking at us, will best admit of being warped from

Corresponding author:
Heiko Hecht, Department of Psychology, Johannes Gutenberg-Universität Mainz, Mainz, Germany.
Email: hecht@uni-mainz.de

their intended direction by application of a new position of the other features of the face" (Wollaston, 1824, p. 251). This effect has since been researched in numerous studies (e.g., Kitaoka, 2012; Kluttz et al., 2009; Langton et al., 2004; Otsuka, Mareschal, et al., 2016) but thus far not with the original portraits commissioned by Wollaston. Before we report an experiment doing just this, we will summarize the current state of the discussion how facial features may attract or repel perceived gaze direction.

The human eye has unique features that facilitate gaze detection in an observer (Kobayashi & Kohshima, 2001). Whereas other primate eyes have evolved to camouflage gaze direction, the distinctive morphology of the human eyes points to a social advantage of being able to reveal and read gaze direction, which outweighs the costs of being found out. The amount of exposed sclera, its horizontal elongation, and the eye outline of the human eye are rather unique. We are able to exploit these cues when making judgments of gaze direction. The acuity of such gaze judgments can be rather exquisite, well within a degree of visual angle depending on lighting and other cues (see e.g., Symons et al., 2004). In their seminal paper on perceived gaze direction, Anstis et al. (1969) concluded that the degree to which the pupil is centered in the eye socket is the main determinant of judged gaze direction. This is so, if the head is oriented toward the observer. In all other cases when the head is turned, head-orientation cues (such as face eccentricity, Todorović, 2009) and iris eccentricity have to be integrated in order to compute gaze direction. It is this case of eye rotation compensating for head-turn angle, when perceptual bias enters. Even small changes in facial features appear capable of altering perceived gaze.

Even if the entire eye region is preserved, three-dimensional (3D) direction of gaze can be swayed by an alteration of a single facial feature, such as the nose. Wollaston's demonstrations to this effect continue to be quite striking. Figure 1 illustrates his observation. It depicts one of the drawings Wollaston had engraved containing identical eye regions but different noses. The eyes associated with the nose pointing to the left of the onlooker (left panel) appear to look more toward the left, as compared with the same eyes associated with the nose pointing to the right (right panel). When juxtaposed as done here in Figure 1, the discrepancy becomes obvious, and one might call this the Wollaston illusion. When seen in isolation, the Wollaston effect may go unnoticed and may not deserve to be called an illusion (see Todorović, 2014).

Thus, the perceived gaze direction does not depend on the eyes alone. Unaltered pointing direction of the eyes (or even an unaltered entire eye region as in Figure 1) does not by itself determine perceived gaze direction. Other facial cues are obviously integrated into this judgment. The first empirical paper to measure this integration was published by Gibson and Pick (1963). A few followed suit in the 1960s (notably Anstis et al., 1969; Cline, 1967). The last decade or so has seen a renewed interest in the topic of configural aspects of gaze perception (e.g., Jenkins & Langton, 2003). The discrimination of gaze direction is more

Figure 1. Wollaston's (1824, Plate X) Illustration of How the Gaze of the Same Pair of Eyes Can Be Influenced by Facial Features, Such as the Nose.

accurate when face and gaze are congruent, as compared with incongruent cases, always given unaltered eyes of course.

Not just facial features, such as the nose, but the entire head, such as the visible parts of its contour, can alter perceived gaze direction. Thus, perceived gaze direction appears to be the product of a complex process of information integration (Langton et al., 2004). Langton (2000) found indirect evidence that head orientation and gaze direction are integrated. When the two are incongruent, reaction times to judge gaze direction and head orientation increase compared with cases where they are aligned. This is backed up by neuroscientific findings that in superior temporal sulcus many cells are tuned to both head orientation and gaze direction (Perrett et al., 1992). There is also direct perceptual evidence that cues for orientation of facial features and gaze direction are integrated. Qian et al. (2013) had subjects rate how strongly gaze appeared as directed to one side. They found higher ratings when facial cues pointed to the same side as did the eye region. Unfortunately, they did not measure specifics of this gaze-cueing effect.

The facial features, such as the prominent nose, may exert an effect in their own right, or they may indicate head orientation (Harari et al., 2016), which in turn could attract the direction of perceived gaze. The latter attraction effect of the orientation of the face on perceived gaze direction has been called the face-eccentricity effect by Todorović (2009), who used well-controlled schematic face drawings as stimuli and could thereby nicely tease apart the relevant effect of iris eccentricity and the illusory effect of face eccentricity on perceived gaze direction.

Note that although the fact of uncalled-for integration of facial cues into perceived gaze direction is not controversial, there is quite a debate about direction of this integration, that is, whether facial features and head orientation should have an attracting or a repulsing effect on perceived gaze direction. All of Wollaston's drawings seem to provide evidence for head direction attracting eye direction. And there is evidence for such attractor effects of facial features in more controlled but stylized stimuli (Maruyama & Endo, 1983; Todorović, 2009). In contrast, when using rendered pictures of heads realistically modeled with 3D software, Otsuka and Clifford (2018) found a repulsion effect of head orientation. And some even believed that the "orientation of the head...has an overall repulsive effect on the perceived direction of gaze" (Balsdon & Clifford, 2018, p. 1). Such statements need to be qualified and may have fueled the recent debate about whether attraction or repulsion is the case, not always with clear-cut language.

Fortunately, this at times confusing debate can be regarded as resolved once we qualify the would-be effects of attraction and repulsion. In our understanding, there are two effects that act simultaneously. The first effect is a *repulsing effect* resulting from an overinterpretation of the eccentricity of the eye in the eye socket (i.e., of iris eccentricity in Todorović's terms). Given a steady gaze, as the head is turned to one side, the eccentricity increases to the opposite side. Now, if the iris-eccentricity cue is weighted more heavily than are the facial cues that indicate head turn, gaze appears to be repulsed by the head turn. And the more eccentric iris and pupil become—as necessary in order to maintain fixation as head rotation becomes more extreme—the more perceived gaze is repulsed to the opposite side. Thus, when a person continues to fixate the observer, she turns her head (not the eyes) away from the observer, gaze appears to be repulsed by the head. This repulsion effect holds for significant head turns that produce large eye eccentricities (above 15° or so).

In contrast, small head turns (or mere turning of the nose, etc.) which produce only small, hard to notice changes in iris eccentricity but noticeable changes in facial features and face eccentricity produce an *attractor effect*. The latter we call the Wollaston effect. Note that the orientation of facial features can be changed—at least subtly—without changing their position relative to the face contour. Thus, when eye eccentricity is ignored and not controlled in stimuli that are used to investigate the effect of facial features on gaze direction, or in the less common case when facial features are not controlled when investigating eccentricity, inconsistent results may arise.

Balsdon and Clifford (2017) suggested that the differences among studies might be due to differences in the method used. This may well be the case, however, the empirical data appear to be rather consistent, once the dual consequences of changing head direction are considered. As one turns the head, the eyes must compensate in order to maintain fixation. Thus, often changes in head orientation are accompanied by changes in eye eccentricity. Confusion arises when the two effects are not properly separated. We claim that such a lack of separation can explain why head orientation is sometimes said to both repulse and attract perceived gaze direction. Again, a change in head orientation only repulses gaze insofar as it typically causes a more eccentric position of the pupil in the eye socket. Repulsion can be reduced to an overinterpretation of eye eccentricity. Otsuka et al. (2014) have proposed a dual route model to describe the simultaneous presence of both effects.

Here, we ignore (i.e., hold constant) eye eccentricity and are concerned with the weaker but nonetheless stunning Wollaston effect which facial features exert by attracting perceived gaze. The Wollaston effect can be understood as an attractor effect of head orientation provided that eye eccentricity remains unaltered. Although the effect has often been noticed and tested based on highly-controlled (digital) stimuli (e.g., Otsuka, Mareschal, et al., 2016), even in 4- and 8-month-old infants (Otsuka, Ichikawa, et al., 2016), its magnitude and the contribution of the different facial features had not been mapped out based on the drawings provided by Wollaston (1824). We set out to quantify this effect for the original drawings.

Experiment

Method

Subjects. Eighteen observers (14 women and 4 men) aged from 18 to 36 years ($M = 23.83$, standard deviation $[SD] = 4.91$) with normal or corrected-to-normal visual acuity participated voluntarily in the experiment. In accordance with the Declaration of Helsinki, all subjects gave their written informed consent and were debriefed after the experiment.

Material and Apparatus. We used copies of four of Wollaston's (1824) original drawings for the experiment (see Figure 2). Each of these four drawings contains a copy of the exact same pair of eyes.

Based on these four drawings from Wollaston (1824), we created seven more stimuli using Photoshop CS5 Extended 12.0 x32 (Adobe). These stimuli consisted of different assemblies of the facial features in these drawings. Thus, we took the same pair of eyes from the original drawings for all newly created stimuli. In total, this study contained 11 subsequently described stimuli, differing in number and orientation of their facial features. Figure 3 depicts all of these 11 stimuli.

Stimulus 1 contained only pupil and iris. Another stimulus consisted of pupil, iris, and orbit (Stimulus 2). Stimulus 3 shows a gaze containing pupil, iris, orbit, and eyebrows. One of the original drawings used by Wollaston (1824) showed the pupil, iris, orbit, eyebrows, and a nose pointing to the left side of a potential observer, this was our Stimulus 4. The fifth stimulus, which consisted of pupil, iris, orbit, eyebrows, and a nose pointing to the right side of the observer, was also taken from Wollaston's paper from 1824. Another two of the original drawings from Wollaston included pupil, iris, eye socket, eyebrows, and a roughly

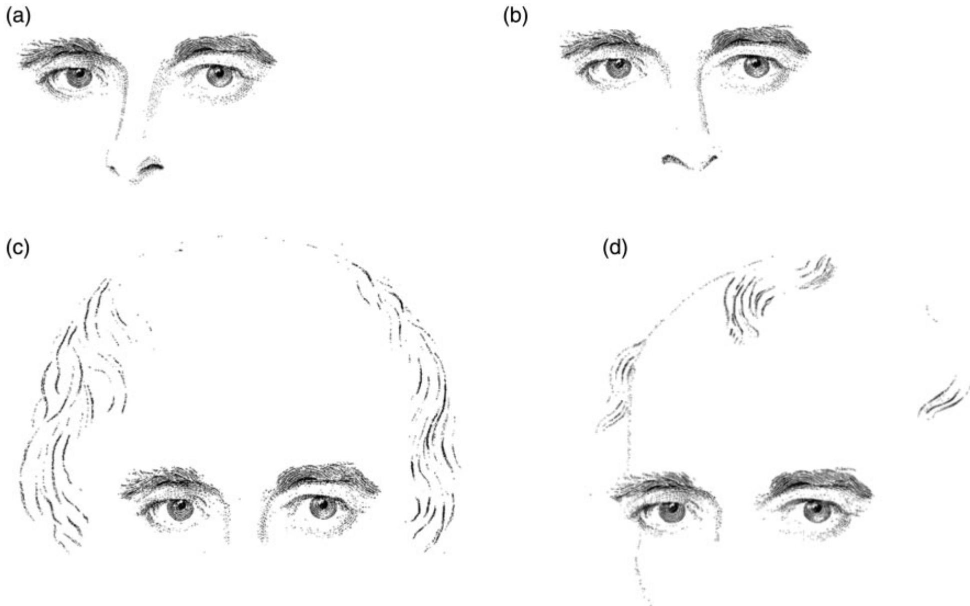

Figure 2. Original Drawings From Wollaston (1824). Wollaston assumed that a change of the nose's orientation was sufficient to induce an altered perception of the eyes' viewing direction (A and B). Likewise, he took head orientation to sway perceived gaze direction toward the orientation of the nose or hairdo (C and D).

sketched head contour oriented to the right side of the observer (Stimulus 6) or to their left side (Stimulus 7). In addition, there was a stimulus consisting of pupil, iris, orbit, eyebrows, a nose oriented to the right side, and a head contour oriented to the right side of the observer (Stimulus 8). Another stimulus displays pupil, iris, orbit, eyebrows, a nose oriented to the left side, and a head contour oriented to the left side of the observer (Stimulus 9). Stimulus 10 featured pupil, iris, orbit, eyebrows, a nose oriented to the left side, and a head contour oriented to the right side of the observer. Finally, the 11th stimulus showed pupil, iris, orbit, eyebrows, a nose oriented to the right side, and a head contour oriented to the left side of the observer.

We ascertained that position and size of the eye area were identical for each of the 11 stimuli. On the computer monitor used to display the stimuli, the pupil and iris of the eye pair measured 2.7° of visual angle in width and 0.28° in height. The maximally visible area including hair and facial features (Stimulus 11) subtended a visual angle of 7.02° in the horizontal direction and 5.96° in the vertical direction.

Procedure. All 11 stimuli were presented 5 times on a white background, resulting in 55 trials all together. The program IrfanView 4.40 was used to show all stimuli in randomized orders on a laptop display (Sony Vaio Notebook model VPC-EE3J1E/WI). Participants were seated 1 m in front of the 15.5-in. screen which had a resolution of $1,366 \times 768$ pixels. A height-adjustable chair and a chin rest ensured that the subjects' eye level was identical for every individual session. The screen's position was adjusted such that the eye level of the stimuli was matched with the subjects' eye level. An aluminum measuring bar was mounted horizontally on a tripod and placed 100 cm from the monitor directly in front of the subject.

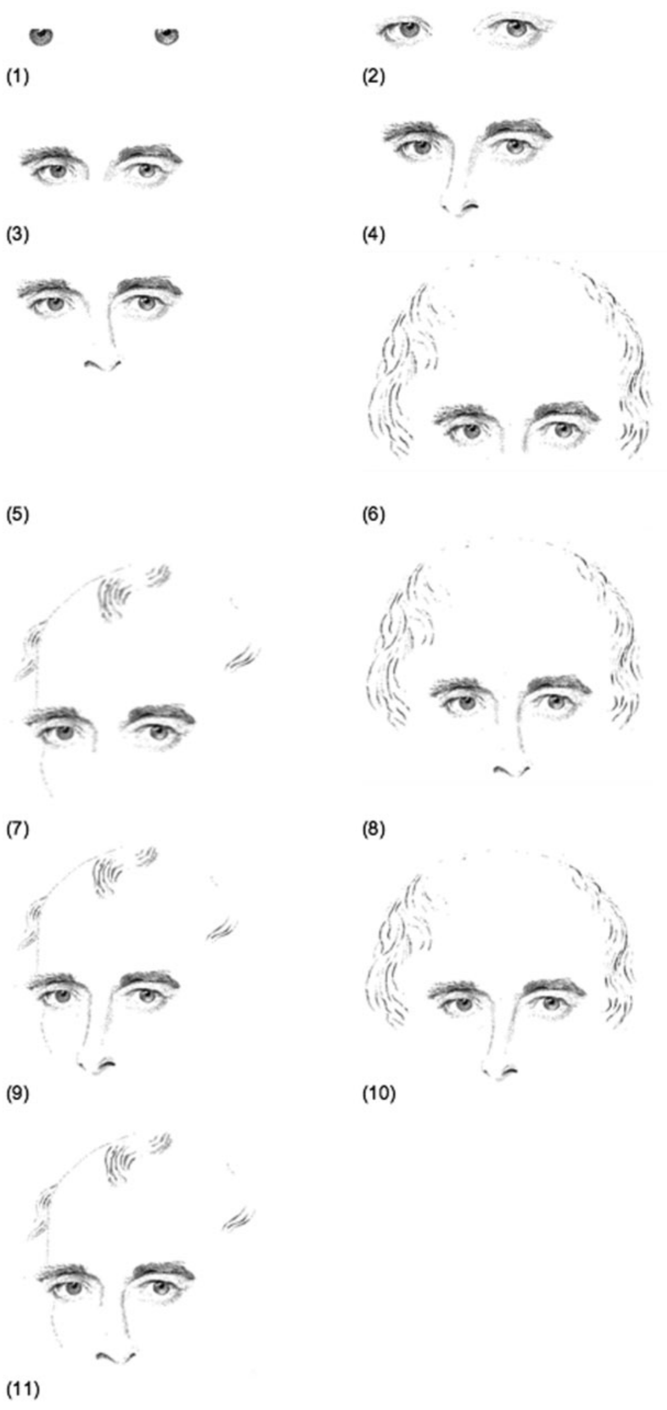

Figure 3. The 11 Stimuli Used in This Study. They differ in number and orientation of their facial features. Some of them contain only eyes (Stimuli 1 and 2) or the area around the eyes (Stimuli 3). Stimuli 4 to 7 represent the original drawings from Wollaston (1824). For two more stimuli, nose and head contour are consistently oriented in one direction (Stimuli 8 and 9). Stimuli 10 and 11 display two stimuli with noses and head contours oriented in different directions.

It extended from 100 cm to their left to 100 cm to the right side. A sliding pointer was fitted to the bar, which was at about chin height 100 cm above the ground. Test subjects sat in the middle of the bar and in front of the screen. The measurement units on the bar were visible to the experimenter but not to the subjects. The latter were allowed to touch the pointer on the bar with their index finger only to judge the perceived gaze direction of the stimulus. The participants were asked to adjust the pointer so that it indicated the location where the perceived gaze direction of the face stimulus intersected with the bar. This method had been used successfully before to capture perceived gaze direction of a portrait (see Boyarskaya & Hecht, 2012). After each trial, participants were asked to verbally state how confident they were of their judgment regarding the estimated viewing direction. The scale ranged from "0" (*not confident at all*) to "9" (*very confident*). Every stimulus was followed by a white screen lasting 1 second, before the next stimulus was displayed. In total, the experiment lasted about 25 minutes.

Results

Gaze Direction Judgments. Given that the eyes remained unchanged, the range of mean perceived gaze directions was remarkably broad. It ranged from slightly toward the subject's left (−1.25°) to quite blatantly to the right (18.79°). Figure 4 shows the mean gaze directions for the eyes only as well as for eyes with eye socket and eyebrows plus nose. Note the large effect of the nose, which is pointing to the left in Stimulus 4 and to the right in Stimulus 5. Figure 5 provides the mean judged gaze directions for Stimuli 6 to 11, which contained hair outlining the head with and without the nose.

We entered the eye direction judgments with stimulus as a factor (11 levels) into a repeated-measures analysis of variance (ANOVA) using a Greenhouse–Geisser correction. The stimuli differed significantly from one another, $F(3.57, 60.76) = 25.68$, $\varepsilon = .36$, $p < .001$, $\eta_p^2 = .60$. The factor repetition (five levels) was found to have no effect on perceived viewing direction, $F(2.61, 44.34) = 2.18$, $\varepsilon = .65$, $p = .112$. The interaction between the factors

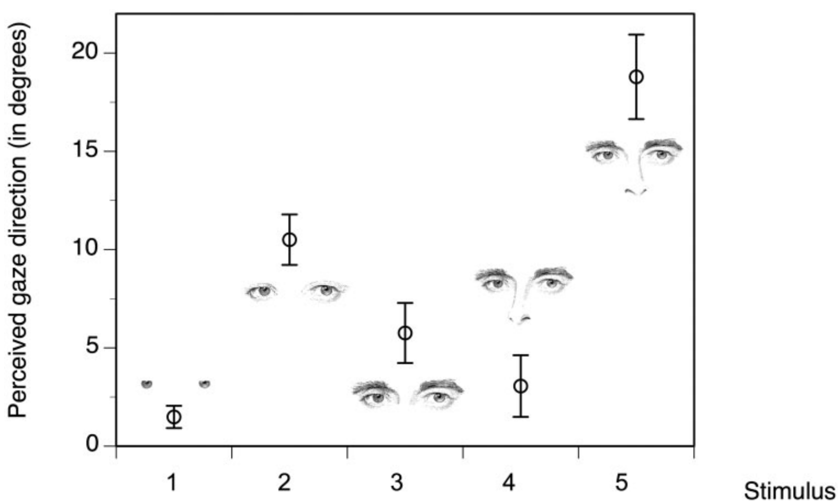

Figure 4. Mean Perceived Gaze Direction of Differently Cropped Versions of Wollaston's Illustration. Iris and pupil of the eye region were identical in all cases. Stimuli 4 and 5 merely differ in nose direction. Positive numbers signify gaze to the right as seen from the subject. Error bars indicate standard errors of the mean.

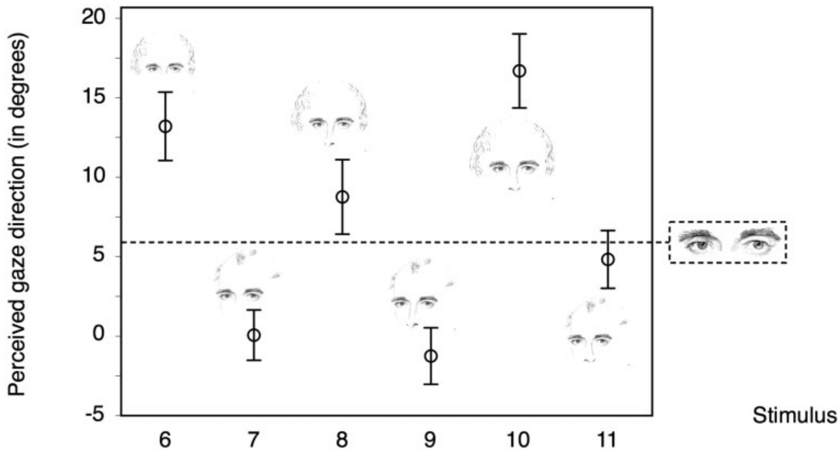

Figure 5. Mean Perceived Gaze Direction. The eyes region including eye brows is identical in all cases. Nose direction and hair were changed. Positive numbers signify gaze to the right as seen from the subject, negative numbers signify gaze to the left. Error bars indicate standard errors of the mean. The reference Stimulus 3 (no nose and no hair) is indicated by the dotted line.

stimulus and repetition did not reach statistical significance, $F(10.12, 172.09) = 0.85$, $\varepsilon = .25$, $p = .585$.

To make pairwise comparisons among individual stimuli, we conduced t tests for dependent samples, for which we chose to set the criterion for significance to $\alpha = .005$ in order to account for multiple testing. Note that for these tests, the five repetitions per stimulus were averaged. We report Cohen's (1988) d_z as an indicator of effect size. Despite its small positive value, the reference stimulus of eyes only (Stimulus 1) appeared to look straight at the subjects ($M = 1.49°$, $SD = 2.41$), that is, its associated mean judged gaze did not significantly differ from 0°, $t(17) = 2.62$, $p = .018$ (one-sample t test to zero). Merely adding the eye socket did sway perceived gaze to the right ($M = 10.51°$, $SD = 5.45$), and significantly so, $t(17) = 6.32$, $p < .001$, $d_z = 1.49$ (t test between Stimuli 2 and 1). This rightward shift was less pronounced ($M = 5.76°$, $SD = 6.48$) once eyebrows were added (Stimulus 3), $t(17) = 4.05$, $p = .001$, $d_z = .96$ (t test between Stimuli 3 and 1).

To evaluate the effects of nose and hairdo on perceived gaze direction, we made additional comparisons in which Stimulus 3 (full eye region containing pupil, iris, orbit, and eyebrows) served as a reference in an additional ANOVA and further t tests with the same criterion for significance at $\alpha = .005$. In the ANOVA, we considered the two factors nose orientation and head orientation each with three-factor levels: left, right, and absent. Correspondingly, this analysis was based on Stimuli 3 to 11. As visible in Figure 5, hair orientation, $F(1.24, 28.54) = 40.01$, $\varepsilon = .62$, $p < .001$, $\eta_p^2 = .70$, as well as nose orientation, $F(1.84, 28.54) = 22.34$, $\varepsilon = .84$, $p < .001$, $\eta_p^2 = .57$, both had strong effects. The interaction effect was also significant, $F(1.78, 30.32) = 21.1$, $\varepsilon = .45$, $p < .001$, $\eta_p^2 = .55$. The subjects' estimated viewing direction was moved to the right by the hair or head contour of Stimulus 6, which was oriented to the right side of the observer ($M = 13.20°$, $SD = 9.13$). This right shift was significant with respect to the reference of Stimulus 3, $t(17) = 4.65$, $p < .001$, $d_z = 1.10$. The nose appeared to have an additive effect, when likewise oriented to the right side of the observer (Stimulus 10), it swayed perceived eye direction even farther to the right ($M = 16.69°$, $SD = 9.88$), adding to the significant difference with respect to the

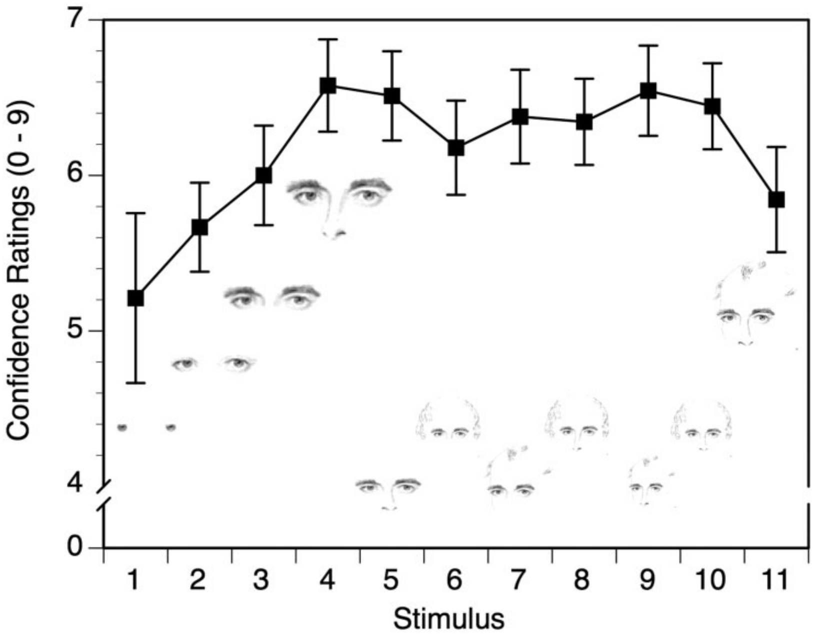

Figure 6. Mean Confidence Ratings. Note that confidence rises as facial features around the eye region are added. Stimulus miniatures for Stimuli 5 to 10 have been moved toward the bottom merely to avoid clutter. Error bars indicate standard errors of the mean.

baseline (Stimulus 3), $t(17) = 5.24$, $p < .001$, $d_z = 1.24$. When the nose was pointing to the subject's left, it counteracted the hair effect, but not entirely so (Stimulus 8). Note that a different hairdo with a leftward pointing direction, as indicated merely by a few pencil marks (Stimuli 7, 9, and 11) moved the entire pattern of perceived gaze direction toward the left, reducing but not annihilating the effect of the nose. When we pooled the unsigned shift of gaze judgments for the stimuli that added a nose to the eye region (left pointing or right pointing; $M = 8.24°$, $SD = 4.79$) and compared it with the pooled unsigned gaze shift produced by the added hair (left pointing or right pointing; $M = 6.89°$, $SD = 3.61$), the effects of nose versus hair did not differ in magnitude, $t(17) = 1.77$, $p = .094$.

Confidence Judgments. We conducted an additional two-factor repeated-measures ANOVA on the confidence ratings, which were provided after each gaze direction judgment. The two factors were the 11 stimuli and the five levels of repetition, and results were Greenhouse–Geisser corrected. We found a significant main effect for stimulus, $F(2.71, 46.03) = 3.57$, $\varepsilon = .27$, $p = .024$, $\eta_p^2 = .17$. The factor repetition had no effect on the confidence judgments, $F(2.46, 41.83) = 0.43$, $\varepsilon = .62$, $p = .695$, neither did the interaction between both factors reach significance, $F(10.52, 178.91) = 1.66$, $\varepsilon = .26$, $p = .090$. Figure 6 illustrates the slight increase of confidence as more facial features were added to the stimulus, but note the large standard deviation for Stimulus 1 (iris only, $SD = 2.3$). For illustration purposes, miniatures of the stimuli are presented below the respective mean confidence scores. Once the eye region is localized in the face, adding more features does not seem to influence confidence. An ex post t test for dependent samples showed that the difference in confidence between Stimuli 1 and 4 failed to attain significance according to our criterion, $t(17) = 2.287$ $p = .035$. In contrast, the judged difference in confidence between Stimuli 4 and 11, where nose and hair direction pull perceived gaze in opposite directions, was significant, $t(17) = 3.667$, $p = .002$.

Discussion

We have explored how the perceived gaze direction of a portrait can be altered by facial features outside the eye region. To do so, we have used and modified the original drawings by Wollaston (1824). Gaze direction should be thought of as a cone rather than a ray, such that the closer one steps toward a portrait, the less likely one should experience mutual gaze (see e.g., Boyarskaya et al., 2015; Gamer & Hecht, 2007). The actual horizontal gaze direction of a two-dimensional head may deviate by approximately 5° to the left or to the right before the impression of mutual gaze breaks down. This 10° range may be somewhat narrower when a 3D-head is used (Gamer & Hecht, 2007) or it can widen somewhat when the stimulus is degraded or visibility is poor (Hecht et al., 2015; Mareschal et al., 2013) or if the person alters the criterion for mutual gaze (Gamer et al., 2011).

When we manipulated the facial features in the drawings of Wollaston while holding eye eccentricity constant, we observed changes in perceived gaze direction of up to 20°. When nose and hair were pointing toward the onlooker's right, the unaltered eyes appeared to also look further to the right. Thus, this attractor effect was of a magnitude capable of moving the perceived gaze direction outside the range of mutual gaze when it had been inside to begin with. And it was able to push perceived gaze direction into the range of mutual gaze when it had been outside. The stimuli based on the Wollaston drawings were lacking detail common to normal viewing or viewing of typical photographs. In fact, very sketchy if not minimalistic changes of the hair were capable of altering perceived gaze direction. This effect is thus relevant for everyday perception.

The impact of head orientation as implied by nose and hair direction was roughly additive. Given that we only had two nose orientations and two hairdos to work with, it is likely that drawings could be devised to augment the attractor effect. It is also likely that additional facial features such as a pronounced chin bone or the ears will contribute to the effect. Also, based on the abovementioned findings about how the visual system deals with information loss, we can predict that obscuring the eye region would put more emphasis on the facial features, thus the attractor effect should become larger as the eyes lose salience.

As to be expected, confidence in perceived gaze direction increased with the number of facial features added. However, the addition of hair did not further increase judged confidence, and incongruent orientations of nose and hair, as realized by means of Stimulus 11, may even reduce confidence due to a perceptual conflict or because it depicts a face that is less biologically plausible.

A note on pupil eccentricity is in place. Based on the current data, we can be confident that the pupils and irises as sketched by Wollaston produce a roughly centered gaze (see stimuli in Figure 3 and corresponding data in Figure 4). The eye socket, in contrast, is drawn such that the iris is off-center to the observer's right. Consequently, it shifts perceived gaze to the right. Note that this is the iris-eccentricity effect we referred to earlier (Todorović, 2009). An iris shifted by a few millimeters in the drawing had an effect of about 4°. When the eyebrows and the bridge of the nose were added, this right shift was reduced. Thus, facial features unrelated to eccentricity were able to counteract the iris-eccentricity effect. In the case where a nose was added pointing in the same direction as the iris eccentricity, this facial feature added about as large a rightward shift. Most likely, the features do not add in a linear fashion. This may have to do with the high degree of correlation of some but not other features. Nose and hair may be in a more or less fixed relationship, whereas eyebrows can be moved relative to the eye ball to a larger extent. Anstis (2018) has recently explored what happens in the unlikely event that pupil and iris become dissociated and found that contrast is an important variable, that is, the pupil is likely to win the competition between iris and pupil, as the latter has a higher contrast to the sclera (see also Ando, 2002).

In conclusion, facial features outside the eye region can exert a sizable influence on the perceived direction of gaze in a portrait. Whereas the eye region determines the initial gaze direction by way of the eccentricity of pupil and iris with respect to the eye socket, other facial features that should be irrelevant can avert perceived gaze by a significant amount, which is large enough to shift perceived gaze into or out of the cone of gaze. The general rule by which these extraneous features (nose, hair, and facial contours) attract gaze is that perceived gaze is shifted toward their orientation (Wollaston effect). In cases where the head is turned to the side more pronouncedly, such that iris eccentricity becomes very prominent, the perceived direction of gaze goes in the opposite direction (repulsion effect) of the head's orientation.

Acknowledgements

The authors would like to thank Agens Münch for help with the stimulus presentation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Heiko Hecht https://orcid.org/0000-0001-9418-862X

References

Ando, S. (2002). Luminance-induced shift in the apparent direction of gaze. *Perception*, *31*, 657–674.

Anstis, S. (2018). The role of the pupil, corneal reflex, and iris in determining the perceived direction of gaze. *i-Perception*, *9*, 2041669518765852.

Anstis, S. M., Mayhew, J. W., & Morley, T. (1969). The perception of where a face or television 'portrait' is looking. *American Journal of Psychology*, *82*, 474–489.

Balsdon, T., & Clifford, C. W. (2017). A bias-minimising measure of the influence of head orientation on perceived gaze direction. *Scientific Reports*, *7*, 41685.

Balsdon, T., & Clifford, C. W. (2018). Task dependent effects of head orientation on perceived gaze direction. *Frontiers in Psychology*, *9*, 2491.

Boyarskaya, E., & Hecht, H. (2012). Differentiating the differential rotation effect. *Acta Psychologica*, *140*, 252–265.

Boyarskaya, E., Sebastian, A., Bauermann, T., Hecht, H., & Tüscher, O. (2015). The Mona Lisa effect: Neural correlates of centered and off-centered gaze. *Human Brain Mapping*, *36*, 619–632.

Cline, M. G. (1967). The perception of where a person is looking. *American Journal of Psychology*, *80*, 41–50.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Erlbaum.

Gamer, M., & Hecht, H. (2007). Are you looking at me? Measuring the cone of gaze. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 705–715.

Gamer, M., Hecht, H., Seipp, N., & Hiller, W. (2011). Who is looking at me? The cone of gaze widens in social phobia. *Cognition & Emotion*, *25*, 756–764.

Gibson, J. J., & Pick, A. D. (1963). Perception of another person's looking behavior. *The American Journal of Psychology*, *76*, 386–394.

Harari, D., Gao, T., Kanwisher, N., Tenenbaum, J., & Ullman, S. (2016). Measuring and modeling the perception of natural and unconstrained gaze in humans and machines. *arXiv preprint*. https://arxiv.org/abs/1611.09819.

Hecht, H., Hörichs, J., Sheldon, S., Quint, J., & Bowers, A. (2015). The effects of simulated vision impairments on the cone of gaze. *Attention, Perception & Psychophysics*, *77*, 2399–2408.

Jenkins, J., & Langton, S. R. H. (2003). Configural processing in the perception of eye-gaze direction. *Perception*, *32*, 1181–1188.

Kitaoka, A. (2012). A review of face illusions. *Brain and Nerve [Shinkei Kenkyu No Shinpo]*, *64*, 779–791.

Kluttz, N. L., Mayes, B. R., West, R. W., & Kerby, D. S. (2009). The effect of head turn on the perception of gaze. *Vision Research*, *49*, 1979–1993.

Kobayashi, H., & Kohshima, S. (2001). Unique morphology of the human eye and its adaptive meaning: Comparative studies on external morphology of the primate eye. *Journal of Human Evolution*, *40*, 419–435.

Langton, S. R. H. (2000). The mutual influence of gaze and head orientation in the analysis of social attention direction. *Quarterly Journal of Experimental Psychology: Section A*, *53*, 825–845.

Langton, S. R. H., Honeyman, H., & Tessler, E. (2004). The influence of head contour and nose angle on the perception of eye-gaze direction. *Perception & Psychophysics*, *66*, 752–771.

Mareschal, I., Calder, A. J., & Clifford, C. W. (2013). Humans have an expectation that gaze is directed toward them. *Current Biology*, *23*, 717–721.

Maruyama, K., & Endo, M. (1983). The effect of face orientation upon apparent direction of gaze. *Tohoku Psychologica Folia*, *42*, 126–138.

Otsuka, Y., & Clifford, C. W. (2018). Influence of head orientation on perceived gaze direction and eye-region information. *Journal of Vision*, *18*, 15–15.

Otsuka, Y., Ichikawa, H., Clifford, C. W. G., Kanazawa, S., & Yamaguchi, M. K. (2016). Wollaston's effect in infants: Do infants integrate eye and head information in gaze perception? *Journal of Vision*, *16*, 4.

Otsuka, Y., Mareschal, I., Calder, A. J., & Clifford, C. W. (2014). Dual-route model of the effect of head orientation on perceived gaze direction. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 1425–1439.

Otsuka, Y., Mareschal, I., & Clifford, C. W. (2016). Testing the dual-route model of perceived gaze direction: Linear combination of eye and head cues. *Journal of Vision*, *16*, 8–8.

Perrett, D. I., Hietanen, J. K., Oram, M. W., Benson, P. J., & Rolls, E. T. (1992). Organization and functions of cells responsive to faces in the temporal cortex. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *335*, 23–30.

Qian, Q., Song, M., & Shinomori, K. (2013). Gaze cueing as a function of perceived gaze direction. *Japanese Psychological Research*, *55*, 264–272.

Symons, L. A., Lee, K., Cedrone, C. C., & Nishimura, M. (2004). What are you looking at? Acuity for triadic eye gaze. *Journal of General Psychology*, *131*, 451.

Todorović, D. (2009). The effect of face eccentricity on the perception of gaze direction. *Perception*, *38*, 109–132.

Todorović, D. (2014). On the notion of visual illusions. *Psihologija*, *47*, 359–367.

Wollaston, W. H. (1824). On the apparent direction of eyes in a portrait. *Philosophical Transactions of the Royal Society of London*, *114*, 247–256.