Title

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Journal
Optometry and Vision Science, 93(5)

ISSN
1040-5488

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Publication Date
2016-05-01

DOI
10.1097/opx.0000000000000819

Peer reviewed

1040-5488/16/9305-0510/0 VOL. 93, NO. 5, PP. 510–520
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

The Role of External Features in Face Recognition with Central Vision Loss

Jean-Baptiste Bernard* and Susana T. L. Chung†

ABSTRACT

Purpose. We evaluated how the performance of recognizing familiar face images depends on the internal (eyebrows, eyes, nose, mouth) and external face features (chin, outline of face, hairline) in individuals with central vision loss.

Methods. In experiment 1, we measured eye movements for four observers with central vision loss to determine whether they fixated more often on the internal or the external features of face images while attempting to recognize the images. We then measured the accuracy for recognizing face images that contained only the internal, only the external, or both internal and external features (experiment 2) and for hybrid images where the internal and external features came from two different source images (experiment 3) for five observers with central vision loss and four age-matched control observers.

Results. When recognizing familiar face images, approximately 40% of the fixations of observers with central vision loss was centered on the external features of faces. The recognition accuracy was higher for images containing only external features (66.8 ± 3.3% correct) than for images containing only internal features (35.8 ± 15.0%), a finding contradicting that of control observers. For hybrid face images, observers with central vision loss responded more accurately to the external features (50.4 ± 17.8%) than to the internal features (9.3 ± 4.9%), whereas control observers did not show the same bias toward responding to the external features.

Conclusions. Contrary to people with normal vision who rely more on the internal features of face images for recognizing familiar faces, individuals with central vision loss show a higher dependence on using external features of face images. (Optom Vis Sci 2016;93:510–520)

Key Words: low vision, central vision loss, face recognition, eye movements

People with normal vision are able to identify familiar faces with great accuracy in only one or two fixations near the center of the face.[1] These fixations, performed using the fovea, are usually centered close to the internal features of the face (eyes, nose, mouth, and eyebrows), suggesting that these internal features are more useful than external features (hair, chin, face outline) for the recognition of familiar faces in normal vision, even in the presence of normal aging.[2–8] When people cannot use their foveal (central) vision, for instance, as in the case of age-related macular degeneration, familiar face recognition becomes challenging, strongly limiting social interactions of patients.[9] One account for the difficulty in face recognition is that people who lose their central vision usually have to rely on an extrafoveal retinal location for seeing, the preferred retinal locus (PRL).[10,11] Because the PRL is located away from the fovea, vision at the PRL can be limited by the eccentricity effects on factors such as acuity,[12] contrast sensitivity,[13] and crowding.[14] In addition, people with central vision loss also suffer from poor oculomotor control,[15,16] including difficulties maintaining precise fixations.[15,17,18] Therefore, what are the fixation strategies of patients with central vision loss when they look at familiar faces? In a recent study, Seiple et al.[19] asked patients with central vision loss to look at the face of a famous painting (*Mona Lisa* by Leonard da Vinci) for a few seconds during which the retinal locations corresponding to where the patients fixated were recorded using an optical coherence tomography (OCT)/scanning laser ophthalmoscope (SLO). Their results showed that the proportion of fixations centered on the internal features of Mona Lisa's face (nose, mouth, and eyes) was significantly lower in patients with central vision loss (62%) than in normally sighted subjects using their fovea (87%). In contrast, the proportion of fixations centered on the external features of the face (defined as the features of a face that were not internal features) was significantly higher in patients with central vision loss (38%) than in normally sighted subjects using their fovea (13%). The authors interpreted these interesting results as a consequence of an abnormal oculomotor behavior in patients with central

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vision loss who failed to fixate steadily on the internal features of the familiar face. However, there exist other possible explanations why patients with central vision loss appear to fixate less frequently on the internal features of a face. First, several studies suggested that patients with central vision loss may use more than one PRL to perform a task.[20–22] In other words, there may be several local retinal areas from which patients extract information. If so, it is possible that some of these PRLs might have fallen on the internal features of a face image, while the fixation PRL (the PRL that is being recorded) is directed to an external feature of the face. An alternative possibility is that external features may carry useful information for patients with central vision loss, information that normally sighted subjects may not rely on for the task of recognizing familiar faces. Specifically, the internal features of a familiar face may not be as important when viewed in the periphery compared with viewing using the fovea because crowding, a phenomenon that is more prominent in the periphery than in the fovea, has been shown to strongly affect internal features of faces[23] and also fine details from internal face features could be easily degraded by low spatial resolution in the periphery.[24] In contrast, external features (hair, chin, face outline) of a face contain more low spatial-frequency information and are more tolerant to the perceptual limitations in the periphery. Therefore, it is conceivable that external features might be more informative for face recognition when the task is performed using the peripheral retina, as is the case for patients with central vision loss.

In this study, we evaluated the relative importance of internal and external features of face images for the task of recognizing familiar faces in a group of observers with central vision loss. We first sought to confirm the results of Seiple et al.[19] by determining which parts of face images are used for fixation by these observers for the task of recognizing familiar faces. We then examined how the presence or absence of internal and external features in face images affects face recognition performance in different experiments. To anticipate our results, we found that observers with central vision loss make greater use of external features when recognizing faces compared with normally sighted observers. These results may explain the larger proportion of fixations on external features observed in patients with central vision loss for recognizing familiar faces.

METHODS

Observers

Five observers with central vision loss and four normally sighted (control) observers participated in the study, which comprised a preliminary (familiarity testing) and three main experiments (experiments 1 to 3). Except for experiment 1, all observers participated in experiments 2 and 3. Four of the five observers with central vision loss participated in experiment 1. All observers with central vision loss had a stable PRL, as assessed using an SLO (Rodenstock 101, Munich, Germany) for a fixation task. Table 1 lists the age, sex, diagnosis, best-corrected distance visual acuities, and the location of the PRL for fixation of these observers. The normally sighted observers, aged between 64 and 76 years, all had acuities 20/20 or better in each eye, with no detectable ocular anomalies or disorders. The research followed the tenets of the Declaration of Helsinki and was approved by the Committee for Protection of Human Subjects at the University of California, Berkeley. Observers gave written informed consent before the commencement of data collection.

Stimuli: Face Images

Face images of 292 celebrities were collected from the Internet. These well-known persons included politicians, athletes, actors, actresses, and other performers who became famous during the past 50 years. The orientation of the face in each image was either a frontal or near-frontal view, with both eyes clearly present in the image. Each image was scaled such that the separation between the two eyes and the midpoint of this separation were fixed across all images and that the RMS contrast of the images was equated (see Yu and Chung[25] for more details about the face image stimuli). In this study, all images were presented at their full standardized contrast. Three sets (sets A, B, and C) of these 292 images were created, with each set containing a unique picture of each celebrity. For each celebrity, the three images in the three sets are all different, with different orientations of the face (frontal, near-frontal), different hair styles, or different face expressions (see the top row of Fig. 1 for an example of the set of three face images of the same celebrity). Image set A was used for preliminary familiarity testing, and image sets B and C were used for experiments 1 to 3. The purpose of using two sets of distinct images (B and C) for experiments 1 to 3 was to increase the number of face images that could be presented to each observer. The second row of Fig. 1 shows examples of face images from four celebrities. We also used face image sets B and C to create two other sets that contained only internal features (image sets Bi and Ci) and two other sets with only external features (image sets Be and Ce). Face images with only internal or external features were constructed as follows. For each unaltered face image, a boundary ellipse was defined to separate the external features (shape of the face, ears, hair, neck) from the internal features (eyes, mouth, nose, eyebrows). The dimensions of this ellipse were the same across all images and were chosen such that the ellipse best separated the internal and the external features of all the face images used in this study. Face images

TABLE 1.
Age, sex, diagnosis, visual acuity, and PRL eccentricity of the five observers with central vision loss

Observer	Age, yr	Sex	Diagnosis	Visual acuity (logMAR, Snellen equivalent) OD	Visual acuity (logMAR, Snellen equivalent) OS	PRL eccentricity, degrees
S1	73	Female	AMD	0.66 ($20/100^{+2}$)	0.48 ($20/63^{+1}$)	2.49
S2	83	Female	AMD	0.50 (20/63)	0.52 ($20/63^{-1}$)	3.49
S3	74	Female	AMD	0.54 ($20/63^{-2}$)	1.12 ($20/250^{-1}$)	1.19
S4	57	Male	Stargardt	1.02 ($20/200^{-1}$)	1.04 ($20/200^{-2}$)	11.69
S5	51	Male	Chorioretinitis	0.86 ($20/160^{+2}$)	0.98 ($20/200^{+1}$)	7.80

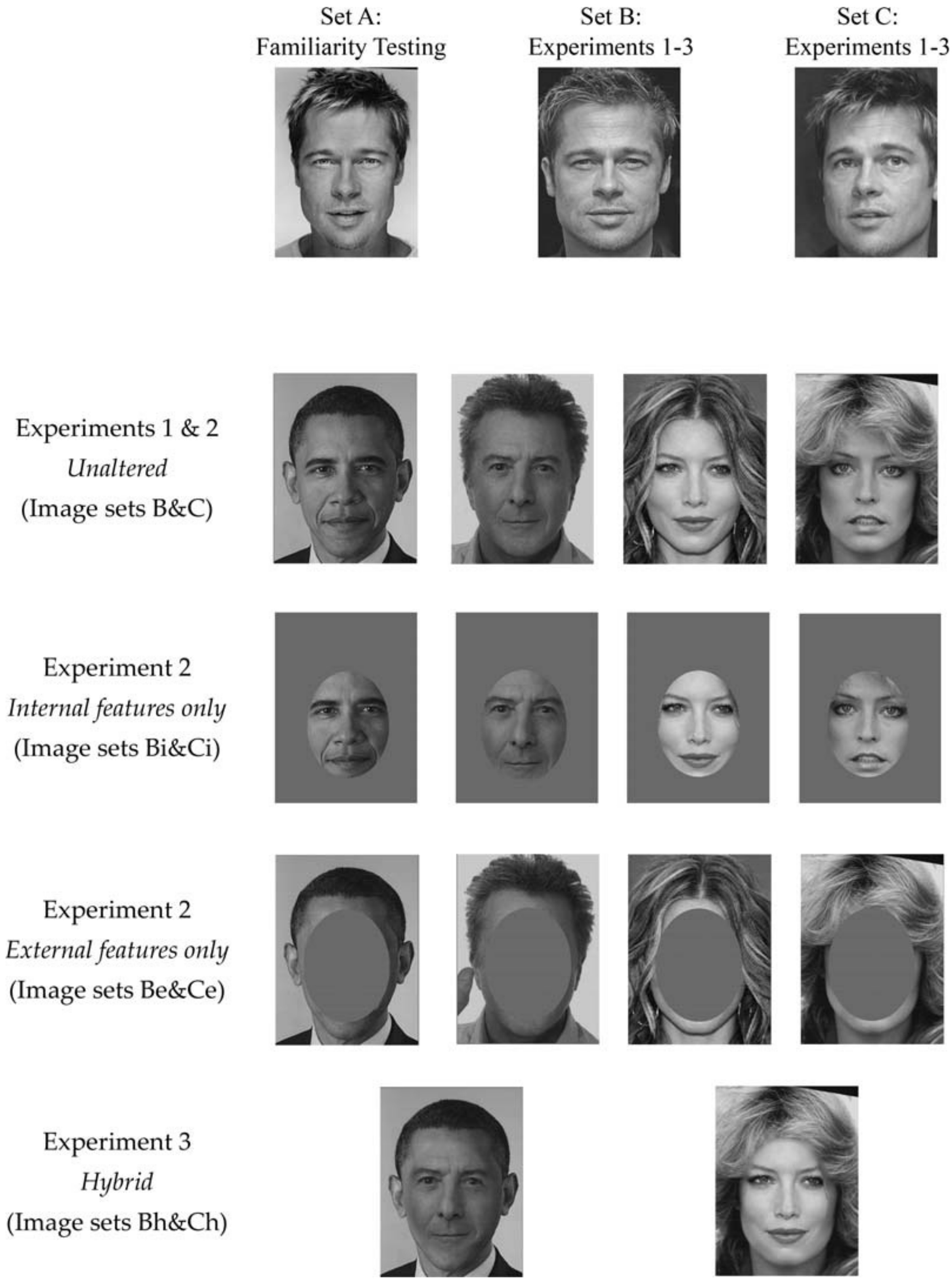

FIGURE 1.

Examples of face images used in the familiarity testing and experiments 1 to 3. The top row shows a set of three faces from sets A, B, and C for the same celebrity to illustrate how different the three images of the same person could be. The next few rows show examples of full unaltered faces (second row), faces with only internal (third row) or only external features (fourth row), and hybrid faces with internal features from one source image and external features from another source image (bottom row).

with internal or external features straddling the ellipse boundary by more than a few pixels were removed from the image sets used for experiments 2 and 3. For image sets Bi and Ci, pixels inside the boundary ellipse were kept unchanged, whereas all pixels outside the boundary ellipse were assigned the mean gray level of the image. For image sets Be and Ce, pixels outside the boundary ellipse were kept unchanged, whereas all pixels inside the boundary ellipse were assigned the mean gray level of the image. The third and fourth rows of Fig. 1 show sample images that contain only the internal or external features defined by the boundary ellipse. Finally, two sets of hybrid face images were created (image sets Bh and Ch, see the bottom row of Fig. 1) based on faces from the internal and external sets (image sets Bi, Ci, Be, and Ce). Each face image of these sets was constructed by combining the internal features of a familiar face image with the external features from another familiar face image. The boundary between both face regions was slightly smoothed with a moving average filter. The celebrity faces for the internal and external features were randomly chosen for both sets Bh and Ch, and the combinations were also independent between sets Bh and Ch. Among all the possible combinations for each observer, we selected 200 hybrid faces for testing. Only hybrid images that were deemed "coherent," meaning that the boundary between the inside and outside of the boundary ellipse was not clearly distinguishable and the resulting face was physically possible, were presented to observers. A specific face image, even when only the internal or the external features were used, was presented no more than five times among the sets Bh and Ch to any given subject. All images from a set (e.g., Bh) had to be presented before images from the other set (e.g., Ch) were presented.

Apparatus

Stimuli presentation and data collection were accomplished using custom-written software developed in MATLAB (version 7.7.0; MathWorks, Natick, MA) using the Psychophysics Toolbox.[26,27] In addition, the Eyelink toolbox[28] was also used for experiment 1. Stimuli were presented on a gamma-corrected SONY color graphic display (model GDM-F500R; refresh rate, 75 Hz; resolution, 1280 × 1024; dimensions, 36.8 × 29.6 cm). For all observers, viewing distance was fixed at 40 cm, a socially acceptable distance for social interaction. At this distance, the width of the face images subtended 13.2 degrees, corresponding to the angular size of faces in real life at a distance of 1 m. Appropriate near corrections were provided to all observers for the testing distance, and testing was binocular.

Eye Tracking

An EyeLink II Eye Tracker (SR Research) was used to determine the positions of fixations of observers with central vision loss during face recognition trials in experiment 1 at a sampling rate of 500 Hz. Eye movement calibration was performed using the built-in five-dot fixation stimuli paradigm, in which dots located at the center of the screen, left, right, above, and below (close to the edge of the display) the center dot were serially presented in a random order. Observers were asked to fixate the calibration dots as they appeared, and we made the assumption that they used their PRL for fixation. For most of the trials, several successive calibrations were necessary until a calibration defined as a "good trial" by the EyeLink system (gaze location accuracy <1 degree) was obtained. After the calibration, a drift correction was performed with a dot located at the center of the screen. A new calibration was performed after every block of 10 trials. Eye movement analyses were performed offline using the Dataviewer software (SR Research) to determine the fixation locations on the face images. *Fixations* were defined as the intersaccadic intervals, whereas *saccades* were defined based on a velocity threshold of 30 degrees per second. Fixation coordinates were obtained by averaging the coordinate positions of samples between two successive saccades.

Experimental Protocol and Procedures

A familiarity test, similar to that used by Yu and Chung,[25] was first performed on each observer to identify a subset of face images that were familiar to the observer. Only images judged as familiar to a given observer were used as stimuli in subsequent testing for the same observer. During this test (~2 h), observers looked at each of the 292 face images of set A and rated each image as "familiar," "somewhat familiar," or "not familiar." A face image was considered *familiar* if the observer was able to correctly name the celebrity or to clearly describe the person's work or for what the person was famous, for example, observers could name the movie or the TV show in which the celebrity had a role (and what the role was). Because most observers called out the name of a celebrity almost instantaneously if the celebrity was familiar to the observers, we took this (provided that the celebrity was identified correctly) as meaning that the celebrity was familiar to the observer. The average numbers of familiar faces recognized were 57 (range, 34 to 78) and 154 (range, 92 to 189) for observers with central vision loss and control observers, respectively. Although control observers could recognize almost three times more images than observers with central vision loss, to match the average number of face images recognized by observers with central vision loss, we randomly chose 60 of the faces rated as familiar for each of the control observers and used these images for subsequent testing (experiments 2 and 3).

Three experiments were then performed with a similar general protocol. Each trial began with the experimenter pressing a button on a keyboard, displaying a face image at the center of the monitor display. Observers were asked to identify the face image as accurately and as fast as possible. A verbal response from the observer immediately terminated the presentation of the face image. The response and the reaction time were recorded for later analysis. No feedback was given as to whether the responses were correct.

Experiment 1 consisted of one session (~2 h) in which four observers with central vision loss identified face images from image sets B and C (full faces without any internal or external features removed or altered). Using both image sets simply increased the number of images we could use for testing. All images in image set B (presented in a random order) were shown before images in set C were shown (also presented in a random order). Eye movements were recorded during testing. Between 100 and 178 trials were tested for our observers, depending on the number of faces they rated as familiar.

In experiment 2 (one session of ~2 h), observers (five with central vision loss and four controls) were tested with randomly interleaved

TABLE 2.
Individual observer's identification performance and oculomotor characteristics in experiment 1

Observer	No. face images presented	Recognition accuracy (% correct)	Average reaction time (s)	Average no. fixations	Average duration of fixation (ms)	Percentage of fixations on external features	Percentage of fixation durations on external features
S1	128	83	9.75 ± 8.21	33 ± 27	240 ± 40	57 ± 21	57 ± 22
S2	100	88	9.44 ± 9.44	32 ± 32	227 ± 30	48 ± 18	47 ± 17
S3	160	82	8.32 ± 8.75	33 ± 35	214 ± 28	26 ± 14	30 ± 16
S4	178	88	14.81 ± 11.86	36 ± 30	381 ± 77	30 ± 31	29 ± 30

Each variable (except recognition accuracy) was calculated only for trials with correct recognition responses.

blocks (10 faces each) that consisted of face images with only internal features (image sets Bi or Ci), only external features (image sets Be or Ce), or unaltered faces (image sets B and C). Each observer was tested with at least 60 trials for each different condition.

In experiment 3 (one session of ~2 h), we tested observers (five with central vision loss and four controls) with the hybrid face images (image sets Bh and Ch) in blocks of 10. Each observer was shown 200 hybrid faces (100 faces from each image set Bh and Ch). Observers with central vision loss S1 to S4 were not aware that the faces presented were hybrids of two faces. S5 (also an observer with central vision loss) noticed that the images looked odd or peculiar after 110 trials; consequently, the experiment was terminated immediately. On the contrary, control observers noticed that faces presented in this experiment were composed of two different celebrities after only 1 to 12 trials. Thus, we asked the control observers to report both celebrities if they were convinced that a given face image was made up of two different face images. The experimenter never confirmed that the images were hybrid until after experiment 3 was completed.

RESULTS

Experiment 1

The specific goal of experiment 1 was to confirm the finding of Seiple et al.[19] who showed that patients with central vision loss

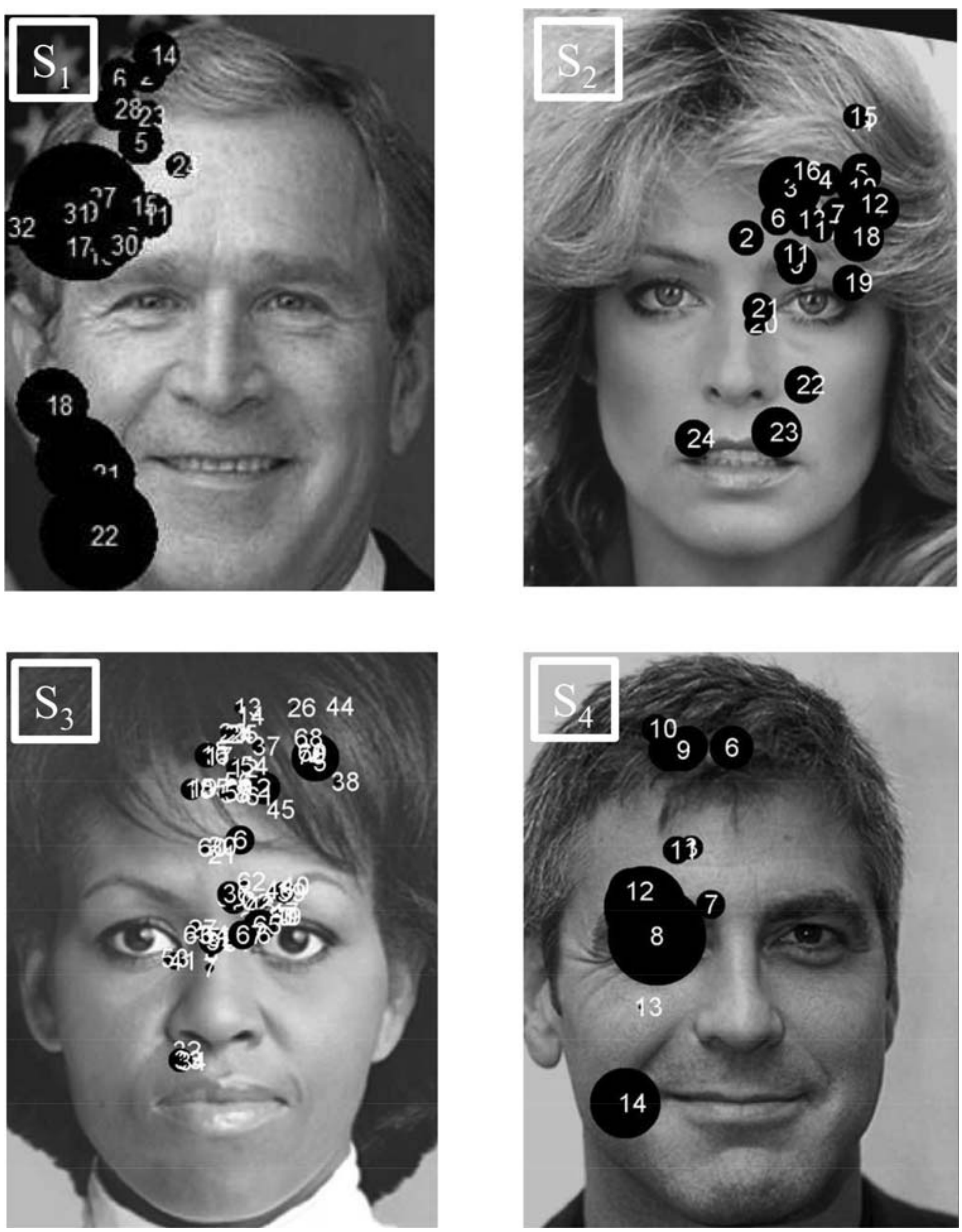

FIGURE 2.

Examples of fixation patterns on a face image of one trial are shown for each of observers S1 to S4. Each black circle represents a fixation, centered on the averaged coordinates of eye positions between two saccades. The size of each circle is proportional to the duration of the fixation, with the same scaling factor for all panels. The number on each circle represents the successive fixation number within a trial. For instance, for observer S4, fixation 14 was centered next to the mouth of George Clooney's face, and the duration was 294 ms.

fixated more on external face features compared with normally sighted subjects. Table 2 summarizes the recognition accuracies of familiar face images while eye movements were monitored for observers with central vision loss (S1 to S4). Data shown are averages across trials for each observer. Reaction time (duration between the onset of presentation of a face image till the time the observer gave a verbal response), the number and duration of fixations, and the percentage of fixations that were centered on an external feature of face images, determined only for trials with correct recognition responses, are also given in Table 2. First, recognition accuracies were high for all observers (mean ± standard deviation [SD], 85.4 ± 3.3%), confirming that, in general, our observers were familiar with the face images rated by them as "familiar." Second, our observers made more fixations (mean ± SD, 33.7 ± 1.8 fixations) to recognize familiar faces compared with the reported values in the literature of fewer than 13 for normally sighted observers, even for older observers.[1,7,8,29,30] Third, the mean duration of fixation, averaged across the four observers, was 265.6 ± 78.0 ms (SD), with a range of 214 to 381 ms. The mean fixation duration was highly similar for the three observers with age-related macular degeneration (AMD) (S1 to S3), which was in the ballpark of the mean fixation duration reported for a group of young normally sighted subjects (275 ms),[31] despite the age differences. Observer S4 had Stargardt disease and was younger than S1, S2, and S3, yet his mean fixation duration was also the longest, suggesting that age alone may not be a good predictor of fixation duration. Histograms of the fixation durations of the four observers are given in Appendix 1 (available at http://links.lww.com/OPX/A232). Fourth, our observers with central vision loss required a considerable amount of time before they made a verbal response (mean ± SD, 10.6 ± 2.9 s). However, the most important finding is that, contrary to the reported behavior of normally sighted individuals whose fixations are centered predominantly on internal features of face images for the task of face recognition,[1,19,32] on average, 40.0 ± 14.6% (SD) of the fixations exhibited by our observers with central vision loss were centered on external features of face images. This finding confirms the result of Seiple et al.[19] who reported that 38% of fixations made by patients with central vision loss were on the external features of the Mona Lisa painting, and that this number was higher than that of normally sighted subjects (only 13% of their fixations were on external features). However, it remains possible that, although observers made approximately 40% of their fixations on external features, they spent a lot more *time* fixating on internal features. To rule out this possibility, we calculated the percentage of fixation duration when the fixations were centered on external face features. The results are highly similar whether we consider the percentage of fixation on external features (40.0 ± 14.6%) or the percentage of fixation duration on external features (40.7 ± 13.8%). Fig. 2 shows examples of the fixation patterns on a face image of our observers. Each figure was based on one trial, with fixations represented by the black circles with consecutive numbers. The size of each circle is proportional to the duration of the fixation, and the center of the circle represents the averaged coordinate of eye positions between two successive saccades. The different patterns of PRL fixation locations across observers suggest different eye movement strategies used by the observers, as has been reported for normally sighted individuals.[33–35] In addition, some of the different eye movement strategies could be caused by their visual acuities, the size and the position of their scotoma, or other factors. For each observer and each trial, we calculated the percentage of fixations that occurred inside and outside the internal/external boundary ellipse (fixation exactly on the ellipse was considered as inside the ellipse).

Experiment 2

In experiment 1, our finding suggests that observers with central vision loss fixated on external features of face images more often than expected for normally sighted individuals. However, we did not know whether our observers relied on information from the external features of face images for recognizing faces or that the fixation behavior was simply a consequence of our observers placing their PRLs on an external feature so that the internal features fell on other retinal locations that were better suited to extract information from the face images or that it was the consequence of an abnormal oculomotor behavior as suggested by Seiple et al.[19] In this experiment, we removed either the internal or the external features from face images so that observers were forced to extract information only from the remaining features. Fig. 3 and Table 3 compare the recognition accuracy for full-face images, face images with only internal features, and face images with only external features for both groups of observers (central vision loss, S1 to S5; control observers, C1 to C4). We shall first present the results for observers with central vision loss. For these observers, the recognition accuracies for full-face images were comparable with those in experiment 1 (mean ± SD, 82.7 ± 6.8% [experiment 2] vs. 85.4 ± 3.3% [experiment 1]; two-tailed paired t-test: $t_4 = 1.03$, p = 0.38) for the four observers (S1 to S4) who participated in both experiments. When considering the results for faces with only internal or external features, we found that, for all observers with central vision loss, the recognition accuracy was significantly higher for face images that contained only external features than for those that contained only internal features (66.8 ± 3.3% [external] vs. 35.8 ± 15.0% [internal]; two-tailed paired t-test: $t_4 = 4.06$, p = 0.015). The higher recognition accuracy for face images containing only external features is not because of a time accuracy trade-off, as the reaction

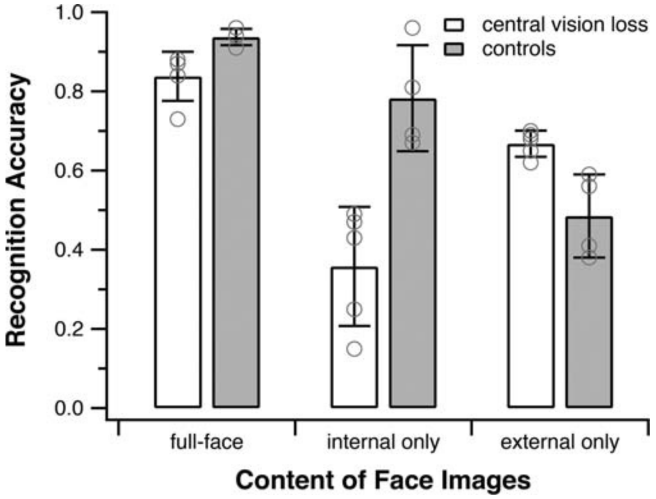

FIGURE 3.
Accuracy for recognizing the full-face images or face images containing only the internal or external features for observers with central vision loss (white bars) and control observers (gray bars). The bars plot the group average data, with the error bars representing ±1 SD. Data of individual observers are represented by the small gray circles.

TABLE 3.

Recognition accuracy for recognizing full-face images and face images containing only internal or external features (experiment 2) for observers with central vision loss (S1 to S5) and control observers (C1 to C4)

Observer	No. face images presented	Recognition accuracy		
		Full face	Internal features only	External features only
S1	180	0.87	0.49	0.62
S2	180	0.84	0.25	0.70
S3	189	0.73	0.15	0.68
S4	186	0.87	0.47	0.69
S5	180	0.88	0.43	0.65
C1	180	0.94	0.69	0.59
C2	180	0.94	0.81	0.38
C3	180	0.91	0.67	0.41
C4	180	0.96	0.96	0.56

times for either type of stimuli were similar (11.3 ± 6.2 s [external] vs. 15.9 ± 7.7 s [internal]; two-tailed paired t-test: t_4 = 0.88, p = 0.215). This result suggests that people with central vision loss rely more on external than internal features of face images for recognizing familiar faces. Although our observers could achieve pretty high accuracy in recognizing face images that contained only external features, these recognition accuracies are still lower than those for recognizing full-face images (66.8 ± 3.5% [external] vs. 83.9 ± 6.4% [full]; two-tailed paired t-test: t_4 = 4.77, p = 0.009), suggesting that the internal features definitely also contributed to the recognition of familiar face images. For control observers, their recognition accuracy for full-face images was also very high (range, 91 to 96%). The most interesting finding is that control observers showed higher recognition accuracies for faces with only internal features compared with faces with only external features (78.3 ± 13.4% [internal] vs. 48.5 ± 10.5% [external]; two-tailed paired t-test: t_3 = 3.94, p = 0.029), a result that was opposite to that of observers with central vision loss but one that is consistent with previous reports.[2–8] This result confirms numerous previous reports that normally sighted control observers who can use their central vision rely more on the internal than the external features of face images for face recognition.

Experiment 3

In experiment 3, we examined the interaction between the presence of internal and external features on face recognition. Table 4 shows the proportions of trials for which observers' responses to the hybrid face images were based on the celebrities who supplied the internal or the external features of the face images or neither of the two celebrities (also see Fig. 4). Because none of the observers with central vision loss realized that each face image presented in this experiment was a composite of two different source images (the experiment was terminated immediately when S5 realized that the images were hybrid, and thus he never gave two responses for a given trial), their responses to a given trial would fall into one of the three response categories. As such, for observers with central vision loss, the sum of the proportion of responses in each category was 1. Clearly, these observers' responses were much more influenced by the external, rather than the internal, features of face images.

TABLE 4.

Summary of recognition responses for experiment 3

Observer	No. face images presented	Proportion of responses matching the source image supplying the internal features	Proportion of responses matching the source image supplying the external features	Proportion of responses not matching either source image supplying the internal and external features
S1	200	0.08	0.36	0.56
S2	200	0.09	0.47	0.44
S3	200	0.04	0.75	0.21
S4	200	0.08	0.62	0.30
S5	110	0.17	0.33	0.50
C1	190	0.73	0.75	0.09
C2	200	0.79	0.02	0.19
C3	194	0.72	0.51	0.15
C4	196	0.95	0.82	0

None of the observers with central vision loss (S1 to S5) realized that the hybrid images were combinations of two different source images, thus their proportion responses for the three categories summed to 1. Control observers (C1 to C4) all realized that the hybrid images were hybrids and thus were allowed to give two answers, thus the sum of their responses exceeded 1.

Averaged across observers with central vision loss, the percentage of trials when observers correctly identified the celebrities who supplied the external features of the face images was 50.4 ± 17.8%, approximately a factor of 5.4 higher than the percentage of trials when observers correctly identified the celebrities who supplied the internal features of the face images (9.3 ± 4.9%; two-tailed paired t-test: $t_4 = 4.28$, p = 0.013). Note that the time taken for the observers to give their responses was not different between the two types of responses (13.3 ± 6.9 s [external] vs. 19.5 ± 5.9 s [internal]; two-tailed paired t-test: $t_4 = 1.50$, p = 0.104), although this might change if more observers were tested. This result suggests that people with central vision loss use the internal features of face images only moderately when attempting to recognize familiar faces; instead, they seem to rely more on the information conveyed by the external features of face images. However, there was still, on average, 40.4 ± 14.4% of trials when these observers gave a response that did not match either of the two celebrities who supplied the internal or the external features of the face image (not different from the percentage of trials for which the responses matched the celebrities who supplied the external features: two-tailed paired t-test: $t_4 = 0.73$, p = 0.51). The high percentage of the "neither" responses could be attributed to some conflicting information introduced when we combined face features from two different sources (celebrities). For example, the combination of the internal and external features from two different celebrities may render the resulting image look similar to a third celebrity or an unfamiliar face.

For the control observers, their results cannot be directly compared with the results of observers with central vision loss because most of the control observers gave two responses to each hybrid face image—one for the celebrity who contributed to the internal features and one for the celebrity who contributed to the external features of the image. Hence, the sum of their responses to the three response categories may exceed 1. Nevertheless, clearly, even in the presence of conflicting information coming from another face image source, control observers were able to correctly recognize the celebrities who contributed to the internal features of the hybrid images at a higher accuracy (79.8 ± 10.6%) than to correctly recognize the celebrities who contributed to the external features of the images (52.5 ± 36.2%), although this difference in performance is not statistically significant (two-tailed paired t-test: $t_3 = 1.58$, p = 0.21) likely because of the high variability in recognition accuracy for the external features (C2 practically could not correctly identify the celebrities who contributed to the external features).

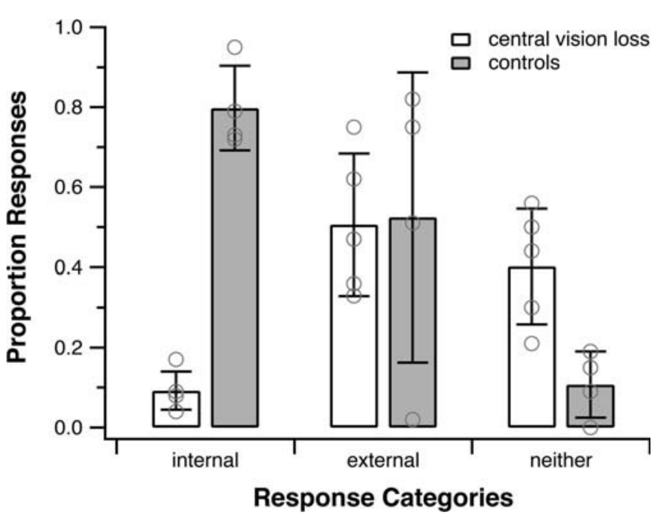

FIGURE 4.

Proportion of responses for each of the three response categories in experiment 3 where hybrid face images were presented. In each trial, responses were scored depending on whether they matched the celebrity who contributed to the internal or external features or neither of the two celebrities. The bars plot the group average data (white for observers with central vision loss and gray for control observers), with the error bars representing ±1 SD. Data of individual observers are represented by the small gray circles.

DISCUSSION

The goal of this study was to evaluate the relative importance of internal (eyebrows, eyes, mouth, nose) and external (hair, chin, face outline) features of face images for the task of recognizing familiar faces for people with central vision loss. In experiment 1, we tracked the eye movements during the task of recognizing familiar faces in a group of observers with central vision loss to determine the locations of fixations, from which we derived the percentage of fixations and the percentage of fixation durations that their fixations were centered on an internal or external feature of face images. First, contrary to the reported findings for people with normal vision who require fewer than 13 fixations to recognize familiar faces, even for older participants,[1,7,8,29,30] our observers required, on average, approximately 34 fixations to recognize familiar faces at a relatively high level of accuracy (~85.4%). Second, when we compared the number of fixations or the percentage of fixation durations on internal versus external features, we found that, on average, our observers spent approximately 40% of the fixations or 40% of the fixation durations on external features. Although this result implies that our observers still spent a fair amount of time fixating on internal face features, the fact that approximately one-half of the fixations was spent on external face features is in stark contrast to the reported finding of people with normal vision who almost exclusively rely only on internal face features.[1] The finding, however, is consistent with the report of Seiple et al.[19] who showed that people with central vision loss exhibited significantly more fixations on external face features when asked to look at the famous painting of Mona Lisa (38% of total fixation) than normal controls (13% of total fixation) and significantly fewer fixations on the internal features (62%) than normal controls (87%). The important question is why do people with central vision loss make more fixations on external features of face images when recognizing faces? One explanation is that external features of face images carry information that is useful for people with central vision loss. An alternative explanation is that the result is an artifact of the fixation (oculomotor) behavior as a consequence of central vision loss.

As previously stated, people with central vision loss eventually develop, and rely on the PRL, an extrafoveal retinal location for seeing. The measurement of the PRL location during a visual task often assumes that the observer/patient extracts information of the visual target from the PRL location. However, it is plausible that an individual may strategically place his/her PRL on a certain location so that useful information from locations away from the PRL can be extracted. It is also possible that patients have difficulties keeping their PRLs on the specific region of a target from which they extract information. To rule out these possibilities, in experiment 2, we manipulated the content of the face images by removing either the internal or the external features to determine how face recognition performance depends solely on the internal or the external features of face images. By removing the internal or external features, even if an observer strategically or accidentally places his/her PRL on a certain location and extracts useful information from some other locations away from the PRL, the features from which information can be extracted are still limited to either all-internal or all-external features. The main finding of experiment 2 is that, on average, observers with central vision loss recognized twice as many faces with only external features than faces with only internal features. This result clearly shows that external features of face images, by themselves, could support high accuracy of face recognition. Interestingly, normally sighted control observers did not show the same performance in recognizing familiar faces based only on external features. On average, they recognized 49% of face images with only external features. In contrast, they recognized 78% of face images with only internal features. These results confirm our original hypothesis that patients with central vision loss rely more heavily on external than internal face features when recognizing familiar faces, whereas normally sighted individuals rely more on internal features.

The above finding for observers with central vision loss by no means implies that internal features of face images are not useful for the recognition of familiar faces—quite the contrary. When face images contained only internal features, observers with central vision loss could still recognize approximately one-third of the faces accurately. More importantly, in experiment 2, these observers recognized full-face images at a significantly higher accuracy than images with only external features, suggesting that these observers did take into account the information extracted from the internal features to supplement the information extracted from external features. The interaction between internal and external features is demonstrated more clearly in experiment 3 when hybrid face images were used to assess face recognition performance. On average, 9.3% of the responses of observers with central vision loss matched the celebrities who supplied the internal features of face images, whereas 50.4% of the responses matched the celebrities who supplied the external features of face images. However, a considerable percentage of responses (40.4%) did not match the celebrities who supplied the internal or the external features, implying that observers with central vision loss did not base their responses exclusively on one source of information (only internal or external features). More likely, observers took into account all sources of information available when analyzing a face image, but when the sources of information were in conflict, an incorrect answer might be the solution to the conflict. On the contrary, the conflicts created by combining the internal and external features from two face images of different sources (celebrities) do not seem to affect our control observers. Averaged across the four control observers, there were only approximately 11% of trials when the responses did not match either of the two celebrities who contributed to a given face image. For the rest of the trials, control observers responded correctly 80% of the times to the celebrities who contributed to the internal features of the hybrid images and 53% of the times to the celebrities who contributed to the external features of the hybrid images, implying that control observers were able to separately identify the two source images even when they were combined to form a new image.

Our series of three experiments clearly demonstrates that the higher proportion of fixations made on external features of face images by people with central vision loss is not an artifact of the fixation (oculomotor) behavior as a consequence of central vision loss but, most likely, represents a genuine increased reliance on the external features of face images. Presumably, external features of face images carry information that is useful to people with central vision loss for the task of face recognition but not as useful to people who have a normal fovea. One possibility relates to the perceptual limitations in the periphery that include the fall-off of acuity with retinal eccentricity and the more prominent crowding effect. Internal features such as eyes, eyebrows, nose, and mouth contain more high spatial-frequency information. As such, this information is more prone to the degrading effect of acuity fall-off and crowding in the periphery and may not be useful to observers with central vision loss who must use their peripheral retina. On the contrary, external features such as the shape of the face or hairline and hairstyle are less detail oriented (or contain more low spatial-frequency information) and are expected to be more resistant to the poor spatial resolution and crowding effects in the periphery.[12,14] In contrast, people with normal vision rely heavily on the internal face features for recognizing faces; therefore, when presented with only the external face features, our control observers were likely to be less adept than observers with central vision loss in using the low spatial-frequency information for identifying faces.

A couple of caveats should be kept in mind while evaluating the interpretations of our findings. Because our findings are based on a small group of observers with central vision loss and a small group of normally sighted observers, some of the results that lack a statistical significance, for example, the similar reaction times to face image with only internal features or external features in experiment 2, may change if there are more participants. Whether or not this is true remains to be tested in future studies. In addition, although it is very clear from the different experiments that observers with central vision loss rely more on external than internal face features for the task of face recognition, there are substantial individual differences among the observers. For instance, in experiment 1, the percentage of fixations (also for fixation durations) on external features for the four observers with central vision loss ranged from 26 to 57%, representing a difference of a factor of 2 (Table 2). In experiment 2, the recognition accuracy for identifying face images with only internal features ranged from 15 to 49% for the five observers with central vision loss (Table 3), a difference of more than a factor of 3. We speculate that the individual differences are likely to be caused by different eye movement strategies used by the observers. Walker-Smith et al.[33] recorded eye movements for three normally sighted observers during a face-matching task (matching a test face with a previously viewed target face). Despite the fact that all three observers fixated only on the internal face features (left and right eyes, nose, and mouth), the relative proportion of fixations on each internal face feature and the scanpaths (the sequences of face features on which the observers fixated) are vastly different among the three observers. More recently, Peterson and Eckstein[34] reported that the individual differences in eye movement strategies while identifying faces across observers persisted across time and were mainly caused by the idiosyncrasy in the observers' choice of where they chose to move their eyes. Chuk et al.[35] further showed that individual differences in eye movement strategies could also be caused by whether the observer adopts a more holistic or analytic feature-based approach. All these cited studies show that even normally sighted observers demonstrate substantial individual differences in their eye movement strategies when identifying faces. This may also account for the individual differences demonstrated by our normally sighted control observers (most notably results in experiment 3). For our observers with central vision loss, in addition to the expected individual differences as demonstrated in normally sighted observers, some of the observed differences could be caused by additional oculomotor deficits such as the higher variability of the characteristics of their fixational eye movements[18] or the potential use of more than one PRL.[20–22] Also, given that our observers had different acuities, sizes of scotomas, or placements of PRL relative to the scotoma, it is not surprising that our observers with central vision loss show a range of performance among themselves. Notwithstanding the individual differences, all observers demonstrated a higher reliance on external than internal face features for the task of identifying familiar faces. However, future studies involving a larger number of participants may be needed to confirm that the findings of this study are generalizable to other patients with central vision loss.

ACKNOWLEDGMENTS

Supported by research grant R01-EY012810 from the National Institutes of Health.

Received January 30, 2015; accepted October 5, 2015.

APPENDIX

The Appendix, histograms of fixation durations for the four observers in experiment 1, is available at http://links.lww.com/OPX/A232.

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