Illumination encoding in face recognition: effect of position shift

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Recognition of faces and objects is impaired when illumination direction varies. Three experiments explore whether this impairment can be explained by display changes (Biederman & Bar, 1999), and whether cast shadows help or hinder face recognition. Observers judged whether two sequentially-presented faces, shown with or without cast shadows, were the same person. The faces were illuminated from the same or different directions, and were presented in the same or different positions on the screen. In Experiment 1, performance was illumination-dependent only on same-position trials, same person. The faces were illuminated from the same or different directions, and were presented in the same or different positions on the screen. In Experiment 1, performance was illumination-dependent only on same-position trials, suggesting that observers used display changes. Experiment 2 tested whether this could be explained by peripheral viewing on different-position trials. A fixation cross cued each face's location, such that observers could move their eyes to view each face centrally. Performance was illumination-dependent regardless of whether position changed. In both experiments, shadows did not affect performance, in contrast to earlier findings (Braje, Kersten, Tarr, & Troje, 1998). In Experiment 3, all faces were presented peripherally without shadows. Changing the illumination direction did not affect performance. These results demonstrate that peripheral viewing, rather than display changes, can explain why changes in illumination direction do not affect performance when position changes. The results also suggest that face representations retain illumination information.

Keywords: face recognition, object recognition, illumination, shadows, peripheral vision

Introduction

Humans can effortlessly recognize faces and objects under a wide variety of lighting conditions. However, changing something as simple as the direction of illumination leads to complex changes in the face image, including changes in shading gradients and in the shapes and locations of shadows. How do we recognize faces given these marked image variations? One class of recognition models proposes that the visual system extracts illumination-invariant features, such as edges (e.g., Biederman, 1987; Marr & Nishihara, 1978). According to these models, recognition should not be affected by variations in illumination direction because illumination direction is not encoded in the stimulus representation. Image-based models, on the other hand, propose that illumination direction is encoded in face and object representations, either because it is too difficult to discount or because it provides information useful for computing 3-D shape (Bülthoff, Edelman, & Tarr, 1995; Gauthier & Tarr, 1997; Poggio & Edelman, 1990). These models predict that the encoding of illumination information will result in an impairment of recognition performance when illumination direction varies.

Consistent with image-based models, several studies have demonstrated that recognition of faces and geometric objects is impaired by changes in illumination direction (Braje, Kersten, Tarr, & Troje, 1998; Hill & Bruce, 1996; Tarr, Kersten, & Bülthoff, 1998; Troje & Bülthoff, 1998). These studies employed a matching paradigm, in which two stimuli are presented sequentially and observers determine whether they are the same or different, regardless of changes in lighting. When two identical objects or faces are illuminated from different directions, response time is typically slower than when they are illuminated from the same direction. This increase in response time presumably reflects the longer processing time needed for encoding illumination direction and/or information closely linked to illumination direction, such as shading patterns.

Recently, however, it has been suggested that “display changes” can account for these findings (Biederman & Bar, 1998, 1999; Nederhouser & Mangini, 2001; Nederhouser, Mangini, Biederman, Subramaniam, & Vogels, 2001). According to this view, when two identical stimuli are illuminated from the same direction in a matching task, observers can quickly determine that they are the same because the stimulus display does not change. That is, observers can rely on the absence of any difference between the two stimuli to respond “same” very quickly. However, when two otherwise-identical stimuli are illuminated from different directions, the stimulus display does change (e.g. some previously dark pixels become lighter). Further processing is then required in order to determine whether this display change is due to different stimulus identities or to different illumination directions. According to this interpretation, it is this additional processing that is responsible for the increase in response time for stimuli illuminated from different directions.
Biederman and Bar (1998, 1999) tested whether reliance on display changes could account for findings of viewpoint-dependence in object recognition. They used a matching paradigm in which two objects were shown from the same or different viewpoints. Additionally, they shifted the position of the second object relative to the first, producing a display change for both same- and different-viewpoint trials. Their results showed that there was little if any cost associated with changes in viewpoint for objects differing in non-accidental properties, demonstrating that viewpoint dependence disappears when observers cannot rely on display changes in making same/different judgments.

More recently, Nederhouser and Mangini (2001) and Nederhouser et al. (2001) examined whether the use of display changes might also explain why changes in illumination direction impair object recognition. They replicated Tarr et al.’s (1998) object-matching experiment, in which the two sequentially-presented objects were illuminated from the same or different directions. On half of the trials, they shifted the position of the second object relative to the first. The results showed that when the position of the two objects differed, changing the illumination direction did not impair recognition. Biederman and Bar’s (1998, 1999) and Nederhouser et al.’s (2001) results suggest that previous findings of viewpoint- and illumination-dependent object recognition could be explained by observers’ use of display changes, rather than by the encoding of viewpoint and illumination information in object representations.

However, other studies have suggested that display changes may not account for viewpoint- and illumination-dependent recognition. For example, in studies that demonstrate viewpoint dependence, performance costs typically increase as the angle of rotation between two objects increases. If display changes were responsible for viewpoint-dependent performance, then performance would not depend on the angle of rotation, since display changes occur with all of the non-zero rotation angles used in these studies.

Moreover, some studies that have incorporated display changes have still obtained viewpoint- and illumination-dependent effects. In an object-matching task, Hayward and Williams (2000) varied the viewpoint and position of the two objects on each trial. The latter manipulation produced display changes regardless of whether viewpoint changed, and yet performance was still viewpoint-dependent. Similarly, in exploring illumination invariance with a face-matching task, Braje et al. (1998) included slight variations in the size and viewpoint of the faces, producing display changes regardless of whether the illumination direction changed. Despite these display changes, performance was impaired by changing the illumination direction.

Finally, studies have demonstrated that changing the illumination direction impairs face- and object-recognition in a naming task, in which observers learned to name stimuli illuminated from one direction and were tested the next day with the same stimuli illuminated from a new direction (Braje et al., 1998; Tarr et al., 1998). The substantial delay between learning and testing makes it unlikely that observers could rely on display changes, and yet performance was still impaired by changes in illumination direction.

The studies described above, however, only partially address the issue of display changes. The variations used by Hayward and Williams (2000) and Braje et al. (1998) were not as large as those used by Biederman and Bar (1998, 1999) or Nederhouser et al. (2001), and therefore may not have been substantial enough to overcome reliance on display changes. Additionally, the results of the naming studies address long-term representations, but not the short-term representations tapped by matching tasks.

The first goal of the present experiments, therefore, was to examine whether display changes can explain why face recognition in matching tasks is impaired when illumination direction changes. Nederhouser et al. has explored this issue with regard to recognizing geometric objects, but face recognition might behave differently. It has been argued that faces are a special class of objects and therefore may not be subject to the same effects that Nederhouser et al. found. For example, unlike the geometric objects used in other studies, faces are fairly similar in their global shape, hue, and texture. Illumination information may therefore be particularly important in the recovery of finer-scale characteristics useful for face recognition. Experiment 1 examines whether face recognition is subject to the same effects found by Nederhouser et al. with objects. Experiments 2 and 3 explore whether peripheral viewing, rather than display changes, can explain why illumination direction does not affect performance when position changes.

The second goal was to explore the impact of cast shadows on recognition, as shadow shapes and locations can change when illumination direction is varied. Shadows can potentially affect recognition in two ways. They might hinder recognition, either by masking informative features or by introducing spurious contours that must be discounted prior to recognition. Alternatively, they could improve recognition by providing information about illumination conditions or 3-D shape. Studies examining the impact of shadows on recognition have yielded inconsistent results. Shadows impair recognition of faces (Braje et al., 1998) and two-tone images of novel objects (Moore & Cavanagh, 1998). However, they improve recognition of geometric objects (Tarr et al., 1998). And, Braje, Legge, and Kersten (2000) found that they had no impact on recognition of familiar natural objects (fruits and vegetables). Experiments 1 and 2 therefore further explore whether shadows help or hinder recognition.
The aim of the first experiment was to determine whether Nederhouser et al.'s object recognition results extend to the domain of faces. Observers viewed two sequentially-presented faces and decided whether they were the same person. The two faces were illuminated from the same or different directions on each trial, and could appear in the same or different positions on the screen (as in Nederhouser et al.'s experiments). If Nederhouser et al.'s findings with geometric objects extend to the domain of faces, then changing the illumination direction should impair performance only when the two faces are presented in the same position.

The presence of shadows was also varied. Previous findings provide no consistent predictions regarding the effect of shadows, particularly when stimulus position changes. However, the results of the most comparable study (Braje et al., 1998) suggest that shadows should impair face recognition.

Methods

Observers

Thirty undergraduate introductory psychology students (ages 18 to 25) at Plattsburgh State University participated for class credit. All had normal or corrected-to-normal visual acuity. The observers were not familiar with the people whose faces were used as stimuli. All research reported here followed the tenets of the World Medical Association Declaration of Helsinki, and informed consent was obtained from all participants after explanation of the nature and possible consequences of the study. The research was approved by the Plattsburgh State University institutional review board.

Stimuli and Apparatus

The stimuli were full-color faces obtained from 3-D models of 80 real human heads (Troje & Bülthoff, 1996). They were the same faces used by Braje et al. (1998). The stimuli were obtained from an early version of the face database provided by the Max-Planck Institute for Biological Cybernetics in Tübingen, Germany. The faces measured about 150 pixels from ear to ear and 215 pixels from the neck to the top of the forehead. They were rendered from two viewpoints (7° and 11° with respect to the frontal view), and in two sizes (7.9° × 9.5° and 8.5° × 10.3°), for reasons discussed in the Procedure. The faces were illuminated from 45° above and 45° to the right or left of the viewing axis, and they were rendered with and without cast shadows (the faces always contained attached shadows). Figure 1 shows examples of the faces in these different rendering conditions. A 256 × 256-pixel (14.6° × 14.6°) collage of face features—eyes, noses, mouths, and ears—was used as a mask. The face features were taken from the different renderings of the 80 faces.

The experiment was run on an Apple iMac using RSVP software (Williams & Tarr, 1999). The faces were presented on a black background on a 640 × 480-pixel (36.5° × 27.4°) Apple 15-inch color monitor. They were viewed from a distance of 45 cm.

Figure 1. One face rendered from a 7° viewpoint with left/right illumination and with/without cast shadows.

The faces were each presented at one of nine screen positions, arranged in a 3 × 3 matrix. The nine positions were equally spaced, separated by 160 pixels (9.1°) horizontally and 120 pixels (6.8°) vertically.

Procedure

A sequential matching paradigm was used (see Figure 2). On each trial, a fixation cross was presented in the center of the screen for 500 msec. One face was then presented in one of the nine positions for 200 msec, followed by the mask for 750 msec, a second face for 100 msec, and finally the mask for 500 msec. This is the same timing sequence used by Braje et al. (1998), Nederhouser et al. (2001), and Tarr et al. (1998). The two faces could be illuminated from the same or different directions, and could appear in the same or different positions on the screen. The mask was always presented in the same position as the face preceding it. The observer’s task was to decide whether the two faces were the same person or not, regardless of changes in illumination or position, and to respond by pressing one of two keys on a keyboard. Feedback was not provided. Responses occurring before the onset of the second face were excluded from the data analysis.2
Results and Discussion

The results are presented in Figure 3. For same-face trials, changing the illumination direction slowed median response time; however, this occurred only when the two faces were displayed in the same position (F(1,24)=4.46, p<.05 for the face x illumination x position interaction; Tukey HSD α=.01). In this condition, response time was 29 msec slower when the illumination direction changed. Thus, Nederhouser et al.’s object recognition results do appear to extend to the domain of face recognition. The results are consistent with the suggestion that, when deciding whether two stimuli are the same or different, observers rely on display changes, rather than on illumination-dependent representations. Experiments 2 and 3 explore this interpretation further.

Figure 2. Matching paradigm showing a same-face same-illumination different-position trial. Movie 1 demonstrates this presentation sequence.

Movie 1. Presentation sequence from Experiment 1.

Each observer completed a 10-trial practice block, followed by four blocks of 128 experimental trials. In each block, there were an equal number of same- and different-illumination trials, an equal number of same- and different-face trials, and an equal number of same- and different-position trials, all presented in random order. Cast shadows were present for 13 observers and absent for 17 observers.

For each presentation of each image, the viewpoint and size were randomly chosen from among those described in the Stimuli section. This prevented observers from simply matching images for size, silhouette, or local image features.

Response time was measured as the time between the onset of the second face and the observer’s key-press. Observers were allowed up to 5 seconds to respond. Only correct responses were included in the overall calculation of response times.

Sensitivity (d') was calculated using the z-scores for the correct responses on same-face trials (hits) and the incorrect responses on different-face trials (false alarms): d' = zfa - zhit. Hit rates of 1.0 and false-alarm rates of 0.0 were modified by half a trial, resetting them respectively to .984 and .016 (Macmillan & Creelman, 1991).

Sensitivity and median response time were analyzed using an ANOVA. The factors were block, illumination (same/different), position (same/different), and cast shadows (present/absent); additionally, face (same/different) was a factor in the analysis of response times. Significant effects were further analyzed using Tukey’s HSD test.

Sensitivity was not affected by changes in illumination direction, with d'=0.94 for different-illumination trials and d'=1.01 for same-illumination trials. Observers tended to perform better on same-illumination trials, but the difference was not statistically significant (F(1,24)=1.73, p>.10).
Sensitivity was lower for different-position trials ($d' = 0.83$) than for same-position trials ($d' = 1.12$) ($F(1,24) = 22.41, p < .01$). The lower sensitivity in the different-position condition may indicate that the data were simply too noisy to reveal any differences between same- and different-illumination response times. If sensitivity were higher in the different-position condition, an effect of illumination may become evident. This possibility was examined by analyzing (with an ANOVA) the response times for the different-position condition, but using only the response times from the conditions that yielded a $d'$ at least as high as the average $d'$ for the same-position condition (i.e. $d' \geq 1.12$). The results of this analysis showed that there was still no difference between same- and different-illumination response times ($F(21,1) = 1.66, p > .10$); therefore, even when sensitivities are equated, the same-illumination advantage is seen only for same-position trials.

Finally, the presence of shadows did not affect response time or sensitivity, even when the faces were in the same position. This finding stands in contrast to Braje et al.’s (1998) results (Experiment 1), in which the presence of shadows increased response time by 127 msec. The present experiments differed from Braje et al. (1998) only in the addition of a possible position shift between the two faces, and it therefore appears that processing of shadows is affected by this added positional uncertainty. This issue is considered in the General Discussion.

### Experiment 2

The results of Experiment 1 are consistent with the suggestion that display changes, rather than illumination encoding, were responsible for slower performance on different-illumination trials. However, Experiment 1, as well as Nederhouser et al. (2001), employed a procedure that required observers to move their eyes to the second stimulus when it was presented in a different position from the first stimulus. Moving the eyes to a known position requires about 250 msec (Rayner, 1978). Given that the second face appeared for only 100 msec, and that the observers did not know where it would appear, it is likely that the second face was seen primarily with peripheral vision on the different-position trials. On the other hand, on the same-position trials, observers did not need to move their eyes to the second face, and therefore could view it using central vision. Viewing stimuli peripherally is problematic because faces, like many other stimuli, are not processed as efficiently in peripheral vision as in central vision (Hübner, Rentschler, & Encke, 1985; Levy et al., 2001; Mäkelä, Näsänen, Rovamo, & Melmoth, 2001; Melmoth, Kukkonen, Mäkelä, & Rovamo, 2000). The ability to process important information, such as high spatial frequencies, detailed shading gradients, and spatial phase declines in the periphery, and faces must typically be scaled in size and/or contrast in order to equate central and peripheral performance. Without any such scaling, information that is useful for recognizing faces and processing illumination direction is degraded in peripheral vision. It is therefore not surprising that the pattern of results differed in the same- and different-position conditions.

Experiment 2 eliminated the problem of peripheral presentation by cueing each face’s location with a 500-msec fixation cross. This procedure maintains the presence of a display change, but allows observers time to move their eyes to the new stimulus position. Both the first and second faces were therefore viewed using central vision. If peripheral viewing is responsible for the illumination-invariant performance in the different-position condition of Experiment 1, then changing the illumination direction should impair performance on both same- and different-position trials in Experiment 2.

### Methods

#### Observers

Thirty-six undergraduate introductory psychology students (ages 18 to 20) at Plattsburgh State University participated for class credit. None had participated in Experiment 1. All had normal or corrected-to-normal visual acuity. The observers were not familiar with the people whose faces were used as stimuli.

#### Stimuli, Apparatus, and Procedure

The stimuli and apparatus were identical to those used in Experiment 1. The procedure differed only in that two fixation crosses were presented, one before each face. Each fixation cross was displayed for 500 msec and was shown in the same position as the center of the subsequent face. Movie 2 demonstrates this presentation sequence for a same-face same-illumination different-position trial. Shadows were present for 20 observers and absent for 16 observers. All other procedures were identical to those used in Experiment 1.

![Experiment 2 Presentation Sequence](image)

Movie 2. Presentation sequence from Experiment 2.

### Results and Discussion

The results are presented in Figure 4. For same-face trials, changing the illumination direction slowed median response time by 22 msec ($F(1,30) = 8.05, p < .01$). Unlike the results of Experiment 1, however, this illumination impairment occurred for both same- and different-position
trials (F(1,30)=0.15, p>.10 for the illumination × position interaction).

Sensitivity was also reduced by changing the illumination direction, with \( d' = 1.94 \) for different-illumination trials and \( d' = 2.09 \) for same-illumination trials (F(1,30)=2.86, p<.05). As with response time, this impairment occurred for both same- and different-position trials (F(1,30)=1.03, p>.10 for the illumination × position interaction).

Experiment 3

The results of Experiment 2 suggest that the position-dependent illumination effects found in Experiment 1 were the result of peripheral viewing, rather than display changes. Although the results are consistent with this interpretation, Experiment 2 did not directly test whether peripheral viewing eliminates illumination effects, since all faces were (presumably) seen with central vision. Experiment 3 therefore examined the effect of peripheral viewing on face recognition. The procedure was identical to that used in Experiment 2 except that all faces were presented in the periphery. If central viewing is necessary in order for illumination dependence to occur, then changing the illumination direction should not affect performance in this experiment.

Methods

Observers

Three experienced psychophysical observers participated. None had participated in Experiments 1 or 2, and all had normal or corrected-to-normal visual acuity. The observers were not familiar with the people whose faces were used as stimuli, although one observer (the author) was familiar with the stimulus set in general.

Stimuli, Apparatus, and Procedure

The stimuli, apparatus, and procedure were identical to those used in Experiment 2 except for the following: 1) A central fixation cross was presented at the beginning of each trial 500 msec before the fixation cross that cued the first face. The central fixation cross remained on the screen throughout the trial. Observers were instructed to maintain central fixation at all times. 2) Only eight of the nine possible stimulus positions were used; faces were never presented in the center of the screen. The inner edge of each face (i.e., the edge closest to the center of the screen) was presented at least 2° from the central fixation cross. 3) On any given trial, the two faces were always presented in the same position, as this provides the most direct test of whether display changes were being used. 4) All stimuli were presented without cast shadows. Movie 3 demonstrates the presentation sequence for a same-face same-illumination trial.

These findings demonstrate that the use of display changes does not account for the illumination effects found in Experiment 1. When observers are given time to shift their eyes to the second face so that it can be viewed centrally, changing the illumination direction impairs performance regardless of changes in stimulus position. The presence of shadows did not affect response time or sensitivity, as in Experiment 1. This finding is considered further in the General Discussion.
Results and Discussion

For same-face trials, changing the illumination direction had no significant effect on median response time (F(1,2) = 0.03, p > .10) for the face × illumination interaction, with response times differing by only 6 msec. Sensitivity was also unaffected by changing the illumination direction, with d' = 1.03 for different-illumination trials and d' = 1.16 for same-illumination trials (F(1,2) = 4.69, p > .10). These results demonstrate that peripheral viewing, rather than display changes, can explain why illumination dependence is eliminated by changing the stimulus position. Provided that stimuli are viewed with central vision, it appears that illumination direction is encoded in face representations.

Why is illumination direction not encoded in representations of peripherally-presented faces? One possibility is that such representations are noisier than are the representations of centrally-presented faces. It may be too difficult to obtain reliable estimates of illumination direction, or of information that varies with illumination direction, from a peripherally-presented face. An alternative explanation is that peripheral presentation degrades high spatial-frequency information needed for recognizing faces (Fiorentini, Maffei, & Sandini, 1983). The information that is lost may include information closely linked to illumination direction. For example, changing the illumination direction will have an impact on shading gradients that are useful for recovering the finer-scale shapes and features of a face. This detailed information would be particularly important for face recognition, as faces may be coded using a more precise, metric mechanism than other objects (Cooper & Wojan, 2000; Diamond & Carey, 1986). If illumination-dependent high-frequency information is eliminated as a result of peripheral presentation, then it can no longer be encoded by the observer. Illumination direction would therefore have little or no effect on recognition, as was found in the present experiment.

General Discussion

The first main finding in the present studies is that face recognition was found to be sensitive to changes in illumination direction. When observers were able to view both of the faces using central vision (Experiment 2), changing the illumination direction impaired performance even when display changes were presumably eliminated by presenting the faces in different positions. Experiment 3 further demonstrated that peripheral viewing was likely responsible for the position-dependent illumination effects found in Experiment 1, and it may also explain Nederhouser et al.’s (2001) object recognition findings. The results suggest that display changes may not account for previous findings of illumination dependence in object- and face-recognition, and that illumination information is preserved in face representations. The results are consistent with the findings of Braje et al. (1998) for faces and Tarr et al. (1998) for geometric objects, and they lend further support to image-based models of recognition.

The results also demonstrate that, at least under the current experimental conditions, face recognition behaves in a manner similar to object recognition, i.e. both are sensitive to changes in illumination. It is often argued that faces are a “special” category of stimuli, and that they are processed by a specialized face-recognition system. Supporting this view are neuroimaging studies suggesting the existence of neural regions that respond selectively to faces (e.g. Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allision, 1997; Puce, Allison, Gore, & McCarthy, 1995; Sergent, Ohta, & McDonald, 1992). Others have argued that faces are recognized in the same manner as other complex objects, by a more general recognition system (e.g. de Gelder & Rouw, 2001; Gauthier et al., 2000; Gauthier, Behrmann, & Tarr, 1999; Gauthier, Skudlarski, Gore, & Anderson, 2000). The present results are consistent with the latter view, demonstrating one situation in which image information is processed in the same way for faces as for other objects.

The second main result in these experiments is that cast shadows did not affect recognition. Even when the two faces were presented in the same position, shadows had no impact. It is possible that shadows are not particularly helpful for recognizing faces because faces are a familiar class of stimuli. This is consistent with the finding that shadows do not affect recognition of familiar natural objects (Braje et al., 2000). However, it is inconsistent with Braje et al.’s (1998) finding that shadows impaired face recognition in a matching paradigm that was nearly identical to the present experiments in stimuli and procedures. The only difference here is that the position of the stimuli was varied.

Why might shadow processing be influenced by position changes? It is possible that added positional uncertainty increased the task difficulty in the present experiments – response time was longer and sensitivity lower than in Braje et al. (1998). This increased difficulty could influence shadow processing in at least two ways. First, it has been suggested that identification of shadows requires extra time and is not a primary process involved in recognition (Moore & Engel, 2001; Rock, Shallo, & Schwartz, 1978; Rock et al., 1982). If a task is not overly demanding, observers may devote resources to identifying shadows in the image, either to discount them or to extract and make use of them. This process would be reflected in longer response times for images containing shadows (as found by Braje et al., 1998). However, when task difficulty increases, observers might allocate resources to processes other than shadow identification. Shadows would then have a reduced impact on performance, as was found in the present experiments. A second possibility is that shadows normally hinder performance
by masking informative features. When task difficulty is increased by including position changes, however, observers may be forced to rely on different stimulus information, or a reduced amount of information. Shadows would then have little impact because they mask information that is no longer being used. Further research is necessary in order to determine why positional uncertainty affects shadow processing.

Conclusions

In summary, the results demonstrate that face recognition is sensitive to changes in illumination, even when position varies. The findings suggest that illumination information is encoded in face representations, and they provide further support for image-based models of recognition. The results also demonstrate that cast shadows do not affect face recognition when position varies. The role of shadows in recognition is still poorly understood, and the present findings underscore the need for further exploration of this issue.

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Footnotes

1 The term “shadows” will be used to refer to “cast shadows” throughout the paper.
2 Four observers’ data were excluded from the analysis in Experiment 1: three observers responded before the onset of the second face more than 35% of the time, and one observer achieved 0% accuracy in one condition. Three of these observers were in the shadow condition and one was in the no-shadow condition. The exclusion of these data did not alter the nature of the results or conclusions.
3 Several other significant effects were found in the three experiments. In Experiments 1 and 2, the main effect of block was significant (p<.01), with observers becoming faster and more sensitive over blocks. This effect was significant for response time but not sensitivity in Experiment 3. There was a main effect of position on sensitivity and response time in Experiment 2 (p<.05), with better performance on same-position trials. The block x face interaction was significant (p<.05) for response time in Experiment 1; observers were faster on same-face trials only in the first block. Finally, in Experiment 2, the face x illumination interaction was significant (p<.01), with illumination changes impairing performance only for same-face trials.
4 I thank an anonymous reviewer for raising this possibility.
5 A similar argument may be made in the case of attention. Shifting attention from one object to another requires at least 150 msec (Ward, 2001), and so the second face likely received less attention on the different-position trials. However, since lighting direction has been shown to be processed preattentively (Enns & Rensink, 1990), this is not likely to be an issue here.
6 Four observers’ data were excluded from the analysis in Experiment 2 because they responded before the onset of the second face more than 24% of the time. Three of these observers were in the shadow condition and one was in the no-shadow condition. The exclusion of these data did not alter nature of the results or conclusions.
7 Including a central position made it too difficult to maintain fixation because centrally-presented faces covered the central fixation cross.

References


