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Efficient visual information for unfamiliar face matching despite viewpoint variations: It's not in the eyes!

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ABSTRACT

Faces are encountered in highly diverse angles in real-world settings. Despite this considerable diversity, most individuals are able to easily recognize familiar faces. The vast majority of studies in the field of face recognition have nonetheless focused almost exclusively on frontal views of faces. Indeed, a number of authors have investigated the diagnostic facial features for the recognition of frontal views of faces previously encoded in this same view. However, the nature of the information useful for identity matching when the encoded face and test face differ in viewing angle remains mostly unexplored. The present study addresses this issue using individual differences and bubbles, a method that pinpoints the facial features effectively used in a visual categorization task. Our results indicate that the use of features located in the center of the face, the lower left portion of the nose area and the center of the mouth, are significantly associated with individual efficiency to generalize a face's identity across different viewpoints. However, as faces become more familiar, the reliance on this area decreases, while the diagnosticity of the eye region increases. This suggests that a certain distinction can be made between the visual mechanisms subtending viewpoint invariance and face recognition in the case of unfamiliar face identification. Our results further support the idea that the eye area may only come into play when the face stimulus is particularly familiar to the observer.

1. Introduction

The recognition of familiar faces is a rapid and effortless process for the majority of individuals (Jackson & Raymond, 2006, 2008; see however Barragan-Jason, Lachat, & Barbeau, 2012). Indeed, most can easily identify friends, colleagues and celebrities, regardless of considerable variations in visual conditions such as lighting, pose, age, health and facial expression (Burton & Jenkins, 2011). Our ability to identify faces affected by these changing visual conditions, however, is considerably hindered for unfamiliar or newly learned faces (Bruce et al., 1999; Murphy, Ipser, Gaigg, & Cook, 2015; White, Kemp, Jenkins, Matheson, & Burton, 2014). In an effort to clarify the reasons subtending this discrepancy between familiar and unfamiliar faces, many have investigated how changes in the visual conditions in which we encode new faces influence our accuracy in recognizing these stimuli. Despite a growing interest aimed towards this issue, the way we process faces varying in viewing angle or pose is still poorly understood. In fact, although faces are encountered in highly diverse angles in a real-world setting, the vast majority of studies in the field of face recognition have focused almost exclusively on frontal views of faces.

A number of authors have explored the question of viewpoint variations in face processing using different methodologies, such as behavioral performance measures (Bruce, 1982; Bruce, Valentine, & Baddeley, 1987; Hancock, Bruce, & Burton, 2000; Hill, Schyns, & Akamatsu, 1997; Liu & Chaudhuri, 2002; McKone, 2008; Moses, Ullman, & Edelman, 1996; Stephan & Caine, 2007; Troje & Bülthoff, 1996; Turati, Bulf, & Simion, 2008; Van der Linde & Watson, 2010), eye tracking (Bindemann, Scheepers, & Burton, 2009), event-related potentials (Caharel, Collet, & Rossion, 2015; Caharel, d'Arripe, Ramon, Jacques, & Rossion, 2009; Caharel, Jacques, d'Arripe, Ramon, & Rossion, 2011; see also Ewbank, Smith, Hancock, & Andrews, 2008), and functional imaging (Kowatari et al., 2004; Pourtois, Schwartz, Seghier, Lazeyras, & Vuilleumier, 2005a, 2005b). Generally, these studies show that

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face viewpoint variations are linked, in certain conditions, to changes in the visual, cognitive and neural processes involved in face recognition. Nonetheless, very little is known about the nature of the information useful for face matching when the encoded face and test face differ in viewing angle. Seeing a face in a certain angle highlights some facial cues and occludes others, thus most likely changing the diagnosticity of each facial feature (Stephan & Caine, 2007; see Bindemann et al., 2009 for the impact of face viewpoint variations on eye movements). In the context of frontal face recognition, we know that some features are more diagnostic than others (i.e. the eye area, and particularly the left eye; Schyns, Bonnar, & Gosselin, 2002; Sekuler, Gaspar, Gold, & Bennett, 2004; Vinette, Gosselin, & Schyns, 2004). Our current knowledge of the diagnostic value of each facial region was obtained, however, using tasks where there was no change in viewpoint between the study and test faces. More specifically, observers were asked to memorize a set of full-frontal view faces, and were subsequently tested using these identical stimuli (e.g. Caldara et al., 2005; Gosselin & Schyns, 2001; Schyns et al., 2002).

To our knowledge, only one study has explored the importance of each facial feature for the generalization of unfamiliar face identity across different viewpoints. Indeed, Stephan and Caine (2007) showed that, when a single feature is revealed (i.e. either the eyes, nose, or mouth), the generalization of a face's identity to a different viewpoint is more accurate in the eye condition compared to both the nose and mouth, which lead to similar levels of correct identity matches. Interestingly, results obtained using faces of celebrities, i.e. faces that have been viewed and encoded in highly diverse visual conditions, are consistent with those of Stephan and Caine (2007). With highly familiar faces, it appears that the eye area is even more diagnostic for accurate face recognition (Butler, Blais, Gosselin, Bub, & Fiset, 2010). However, based on the results from these studies, it is difficult to know if this bias favouring the eye area is a truly effective strategy for the generalization of a face's appearance across different viewpoints or is associated to face identification *per se*. In their paper, Stephan and Caine (2007) specifically asked their participants beforehand to learn the face identities used in the experiment. This allows the possibility that matching performance with two different viewpoints may have been mediated by perceptual strategies associated with face identification, instead of an attempt of the visual system to extract view invariant facial cues. Since the eye area is likely the most informative region for face identification, the fact that this region leads to viewpoint invariance was expected for previously learned faces. However, this strategy may be inefficient in the context of first encounters with faces, i.e. unfamiliar faces.

The main objective of our work was to pinpoint the diagnostic facial features for minimizing sensitivity to viewpoint variance in an unfamiliar face matching task. Although a relatively high number of identities (30) was selected and that our task did not explicitly ask the participants to memorize facial identity, it is likely that face identification strategies were eventually used by the observers in an effort to aid their performance. In order to isolate the process of viewpoint invariance as much as possible, we relied on an individual differences approach in which we verified which visual strategy was linked to a lower sensitivity to viewpoint variance. We hypothesized that the information useful for unfamiliar face matching differs from that of face identification. This point makes a clear prediction, as it suggests that in the context of a task where the same identities are repeated many times (as the one used here), the diagnosticity of facial features used in face identification and those associated with viewpoint invariance should follow a distinct pattern over time. More specifically, it predicts that the diagnosticity of the former will gain in importance, while the diagnosticity of the latter should instead decrease in importance.

In order to pinpoint, in an unbiased manner, the features associated with identification of faces encoded from different viewpoints, we used the *Bubbles* method (Gosselin & Schyns, 2001). The general idea behind *Bubbles* is that by randomly sampling specific visual information on a trial-by-trial basis, we will be able to precisely determine, after many trials, what information is significantly correlated with performance in any given visual categorization task (e.g. Robinson, Blais, Duncan, Forget, & Fiset, 2014; Royer et al., 2016; Smith, Cottrell, Gosselin, & Schyns, 2005; Thurman & Grossman, 2008; Willenbockel et al., 2010a). In our case, the method allowed us to reveal which facial cues are associated with the discrimination of frontal view faces previously seen in either the same or a different viewpoint.

2. Material and methods

2.1. Participants

Fifty Caucasian, right-handed participants aged between 18 and 35 provided informed consent to complete an ABX, match-to-sample Bubbles task for this study. The study was approved by the Université du Québec en Outaouais's Research Ethics Committee and was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). We chose this number of participants to ensure the presence of a wide range of individual differences in sensitivity to viewpoint variations in our sample (see Furl, Garrido, Dolan, Driver, & Duchaine, 2011; Richler, Cheung, & Gauthier, 2011 for similar sample sizes). This number also allowed us to include a sufficient amount of trials in each condition of our bubbles task (see Section 2.3). All participants had normal or corrected-to-normal visual acuity as confirmed by their score on the Snellen Chart and Pelli-Robson Contrast Sensitivity Chart (Pelli, Robson, & Wilkins, 1988). Data from the first two participants were not taken into account in the analyses as an error in the testing procedure forced us to exclude their results. Thus, analyses were conducted on data from forty-eight participants.

2.2. Apparatus

The experiments were conducted on MacPro QuadCore or Mac Mini computers. Stimuli were displayed on a 22-inch 120 Hz Samsung LCD monitor. The monitor's resolution was set to 1680×1050 pixels. Minimum and maximum luminance values were $0.4\ cd/m^2$ and $101.7\ cd/m^2$, respectively. The participants were seated in a dark room and viewing distance was maintained constant at 57 cm using a chinrest.

2.3. Bubbles task

The stimuli presented during this task consisted of 30 caucasian identities from the *Fundação Educacional Inaciana* (FEI) Face Database (15 females; Thomaz & Giraldi, 2010). All chosen identities exhibited a neutral facial expression. The grayscale stimuli were cropped with an elliptical aperture that masked their external facial features. Image resolution was 256×256 pixels, and the face width was 6 degrees of visual angle (Yang, Shafai, & Oruc, 2014). The spatial frequency spectrum was equalized using SHINE (Willenbockel et al., 2010b) and the stimuli from each condition (see below) were spatially aligned on the positions of the main internal facial features (eyes, mouth, and nose) using translation, rotation, and scaling.

To create a *bubblized* stimulus, a face (Fig. 1A) was first decomposed into five different spatial frequency (SF) bands (Fig. 1B; 106-53, 53-26, 26-13, 13-6, and 6-3 cycles per face, the

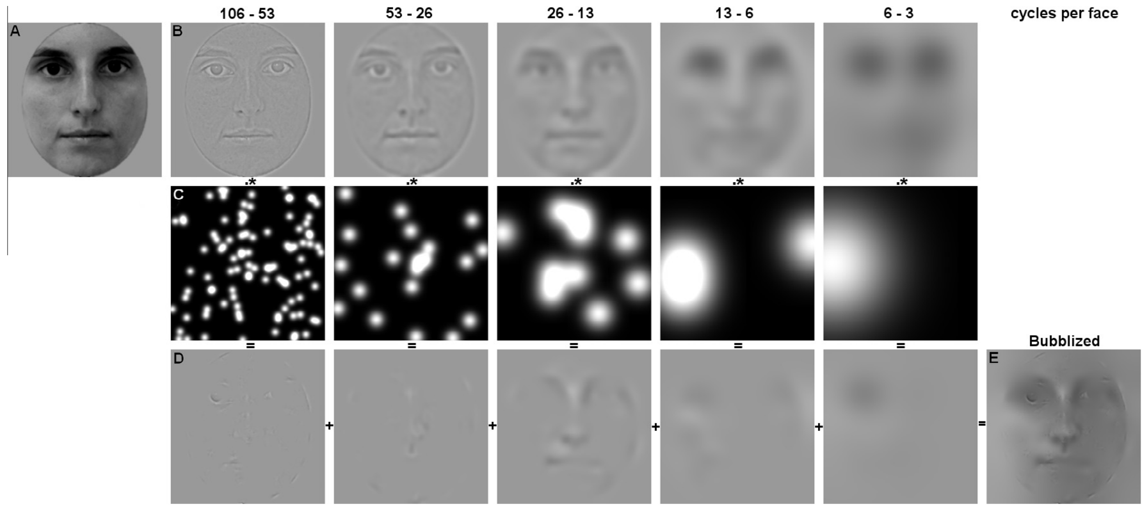

Fig. 1. Creation of the bubblized stimulus using an exemplar from the FEI Face Database (Thomaz & Giraldi, 2010). The original stimulus (A) is filtered into the five spatial frequency bands in B. In each band, a number of randomly positioned Gaussian apertures puncture a homogeneous black field (C). Applying the punctured masks to the filtered stimulus reveals the information in each band (D). This spatially filtered information is then summed, producing a bubblized stimulus (E).

remaining low-frequency band serving as a constant background) using the Laplacian pyramid transform implemented in the pyramid toolbox for Matlab (Simoncelli, 1999). Each SF band was then independently and randomly sampled with Gaussian apertures (i.e. bubbles) of different standard deviations. More specifically, the size of the bubbles was adjusted in accordance with frequency band to only reveal three cycles (Fig. 1C). Since the size of the bubbles is much larger for lower SF bands, the number of bubbles was adjusted at each scale to maintain the probability of a given pixel being revealed constant across SF bandwidths. This ensures that the same amount of information is presented in each SF band. A point-wise multiplication was then performed between the bubbles' masks and the filtered images to obtain one bubblized face for each SF band (Fig. 1D). Finally, these five randomly sampled images plus the constant background were summed to produce the bubblized stimulus, i.e. what is shown to the participant on a given trial (Fig. 1E).

A 500 ms fixation point initiated each trial, which only served to warn the participant of the impending presentation of the study face. Then, one of the 30 possible identities (i.e. the study face) was presented for the same duration (i.e. 500 ms). The study face's pose was randomly chosen to either be a full frontal view or a 3/4 view facing either towards the left or the right of the subject. A 100 ms white noise mask immediately followed the study face. Finally, two bubblized frontal view faces (i.e. the test faces) were presented side-by-side and kept on screen until the subject indicated which of the two stimuli was the same identity as the study face; one of the test faces was the previously viewed face and the other, one of the randomly chosen 14 other possible faces of the same gender (see Fig. 2 for an illustrated outline of a given trial). The same pattern of Bubbles was applied to the target and distractor faces. Each participant completed 15 blocks of 120 trials each for a total of 1800 trials. The number of bubbles was adjusted independently for each pose condition using QUEST (Watson & Pelli, 1983) to maintain an accuracy rate of 75%. Since accuracy is strictly controlled in tasks using Bubbles, individual performance can be assessed with the number of bubbles (i.e. the amount of information) required by each participant to reach the accuracy criterion (Royer, Blais, Gosselin, Duncan, & Fiset, 2015). A single adjustment procedure was used for all spatial scales; the amount of information revealed in each scale was manipulated so that, on average, the same number of pixels was revealed across SF bandwidths.

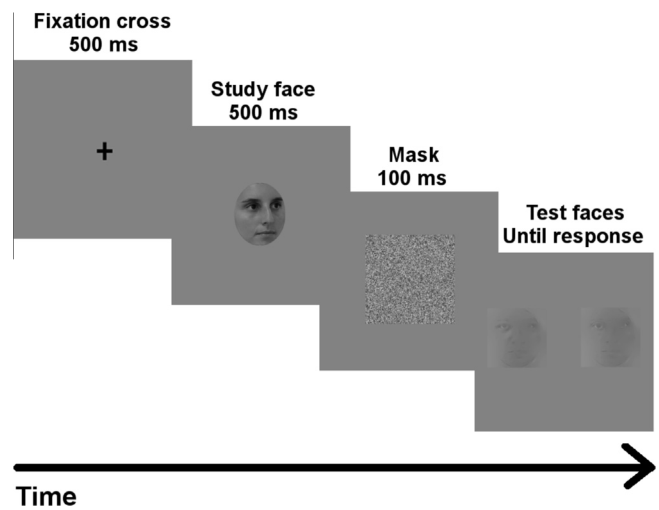

Fig. 2. Course of a trial in our Bubbles task (stimulus exemplars from the FEI Face Database, see Thomaz & Giraldi, 2010). See Section 2.3 for details.

3. Results

3.1. Analysis of Bubbles Data

We computed a least-square multiple linear regression on the location of the bubbles and the subject's response for each trial to uncover the features that the observers used during the task. The plane of regression coefficients yielded by this operation is called a classification image (CI): It reveals which regions of the face image are systematically associated with recognition performance. This procedure was completed independently for the five SF bands. The individual CIs in each SF band were smoothed using a Gaussian filter corresponding to a bubble in the adequate spatial scale. We grouped all observers' smoothed CIs by summing them and dividing the result by the square root of the number of observers (i.e. 48). To determine what visual information was significantly correlated with accuracy, we applied the Pixel test ($p < 0.05$; $Z_{crit} = 4.125$; 3.760; 3.366; 2.948; 2.536). The statistical threshold provided by this test corrects for multiple comparisons (for details, see Chauvin, Worsley, Schyns, Arguin, & Gosselin, 2005).

Since we were also interested in verifying the location of the most useful visual information in this task independently of SF information, we computed a distinct analysis where the planes for the SF bands were summed before smoothing. The resulting classification planes were divided by the square root of five (i.e. for the five SF bands) for normalization. We then smoothed the individual CIs with a Gaussian filter corresponding to a bubble in the third SF band. Thus, two distinct analyses were computed: one for the data obtained in each SF band, and one combining the SF results. We grouped all observers' smoothed CIs by summing them and dividing the result by the square root of the number of observers (i.e. 48). To determine what visual information was significantly correlated with accuracy, we applied the Pixel test to these group CIs ($p < 0.001$; $Z_{crit} = 4.43$).

3.2. Information used by all observers

Before specifically exploring the data with an individual differences approach, it is interesting to look at the more general trends in the visual strategies used by the observers. These results show us whether the features revealed as diagnostic in the present experiment are generally consistent with those uncovered in previous studies on face identification that did not include viewpoint variations in their design. Thus, we first identified the features that were significantly correlated with recognition accuracy in all three encoding condition, on average. These diagnostic regions correspond to the areas in Fig. 3, which shows the information that was significantly correlated with performance for all 48 observers (i.e. the statistically thresholded CIs). The data decomposed across spatial scales (A) and when all SF bands were combined (B) are both presented in Fig. 3. The top row shows the areas that reached statistical significance when considering all three conditions, while the bottom row illustrates which facial areas were significantly correlated with performance when only considering the trials for the left and right conditions, i.e. the conditions where a purely image-based processing strategy could not be used to successfully complete the trial.

Our results reveal a considerably greater use (i.e. higher *Z*-scores) of the facial regions located in the center of the face stimulus (i.e. nose and mouth) relative to the eyes, regardless of the inclusion of our image-based condition. This qualitative observation contrasts with previous results obtained with Bubbles in face recognition tasks where variation in face viewpoint were not included in the experimental design (Butler et al., 2010; Caldara et al., 2005; Gosselin & Schyns, 2001; Schyns et al., 2002). Indeed, these previous accounts of the diagnostic features in face recognition usually demonstrate a greater use of the eyes compared to the nose and mouth, while our results show the opposite trend. A possible explanation for these results is the central location of these features, rendering them particularly informative in the context of face viewpoint variations, as they remain most visible relative to other facial features across changes in viewing angle. Conversely, more lateralized features such as the eyes are more easily occluded following viewpoint changes. This indicates that observers adapted their use of facial information to the constraints in the extraction of facial information imposed by changes in the study face's angle. On a given trial, the participants could not predict whether the study face's viewpoint would require them to generalize the face's identity to a different angle. Thus, the demands of our identity matching task seem to have influenced our subjects' recognition strategy leading them to extract the visual information that maximized their efficiency, regardless of viewing condition.

Another explanation may be that the present results only apply to face matching. If we had explicitly asked the observers to memorize the identities, it is possible that the eye area would have been revealed as the most diagnostic region. This proposition can be directly tested using an individual differences approach. We indeed know that important individual differences in the nature and efficiency of face recognition strategies exist in the general population (e.g. Fig. 3 in Caldara et al., 2005; Royer et al., 2015). These differences can be of great use to reveal which visual strategies are optimal for the task at hand. However, this potentially informative diversity is hidden by simply summing all of our observers' CIs without consideration of their individual efficiency in completing the task or its particularly relevant components. With this in mind, we conducted a second analysis where individual sensitivity to variations in viewpoint during our bubbles task was taken into account in the construction of the group CIs. This analysis allowed us to pinpoint the features that were specifically associated with an optimal generalization of identity information across viewpoints.

3.3. Information linked to viewpoint invariance

In order to uncover the features associated with successful identity matching in the context of face viewpoint variations, we first computed a measure of viewpoint sensitivity for each individual observer. These individual scores were calculated using the number of bubbles required in the different conditions of our task. Indeed, this metric has recently been demonstrated as an adequate indicator of individual face recognition ability (Royer et al., 2015) as shown by its strong correlation with performance on other face recognition tests such as the Cambridge Face Recognition Test (Duchaine & Nakayama, 2006; Russell, Duchaine, & Nakayama, 2009), the Cambridge Face Perception Test (Duchaine, Germine,

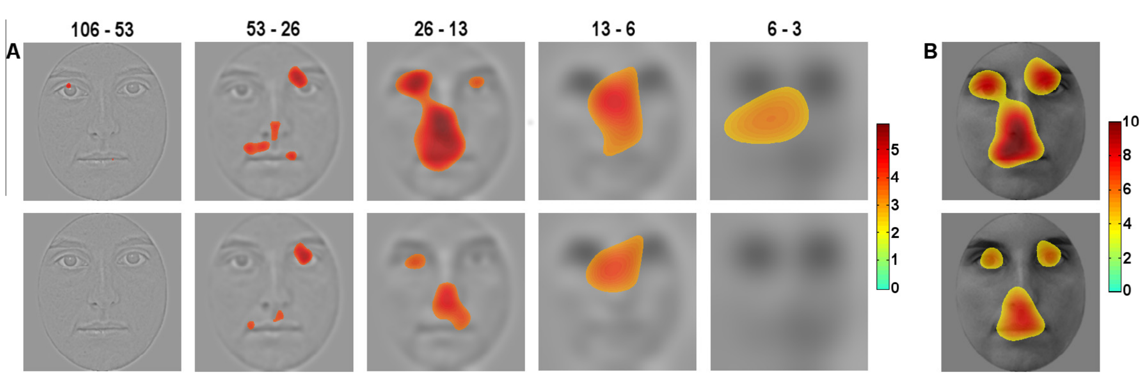

Fig. 3. Visual information significantly linked to accuracy decomposed by SF band (A; units in cycles per face) and combined across all bands (B) in all three conditions (top) and for the non image-based conditions (bottom). The significant portions of the CIs (depicted as heat maps of *Z*-scores) are superimposed on one of the faces used in the study.

& Nakayama, 2007) and the Glasgow Face Matching Test (Burton, White, & McNeill, 2010). To obtain our viewpoint sensitivity scores, we first considered the number of bubbles each observer required, on average, in both non image-based conditions. We then subtracted from this number the amount of bubbles each subject required in the front view condition (i.e. when the study and target images were identical). We supposed that if an individual's performance is considerably hindered by changes in viewpoint from the study to the test face, we could consider their encoding of the study face as more viewpoint dependant than other observers whose performance was not as affected by these changes. Afterwards, we factored out the average number of bubbles required overall by each participant from the difference score described above by using the residuals of the regression between both measures. Thus, low scores indicated little sensitivity to changes in viewpoint between the study and test phases, while higher scores meant that the participant's performance was negatively affected by these changes. This allowed us to see how detrimental changes in viewpoint between the study and test faces were to each individual's performance, while also taking into account their ability to complete the task overall. It was indeed necessary to factor out each individual's overall face recognition ability from our viewpoint sensitivity measure, since an equal difference in performance between our conditions does not necessarily signify an equivalent sensitivity to viewpoint variations. For instance, a difference of 15 bubbles does not mean that changes in viewpoint impacted performance comparably for an observer who required, on average, 100 bubbles versus another, who required 30 bubbles.

We determined the validity of this score by verifying that the observers least sensitive to variations in viewpoint at the performance level also tended to be more constant in their face recognition strategies across the two most distant encoding conditions in terms of viewing angle. To do so, we first correlated, for each observer, the CIs obtained in the two most distant encoding conditions in terms of viewing angle (i.e. the two non image-based conditions, the left and right conditions). Only the portion of the CIs covered by the face was considered to compute this correlation. We then verified the link between the correlation obtained in this first step with the individual viewpoint sensitivity scores. Interestingly, the level of similarity between the non image-based CIs was significantly, though modestly, correlated with individual viewpoint sensitivity ($r = -0.343$; $p = 0.017$). Thus, this suggests that this viewpoint sensitivity score is a valid measure of the extent to which the participants' visual strategy was modulated by the viewpoint in which the face was encoded.

We then used these individual viewpoint sensitivity scores to weigh each participant's CI for the three conditions altogether, and for the non image-based conditions only. In order to reveal which features were the most correlated with low viewpoint sensitivity, we first ranked our subjects' from most sensitive (ranked first) to least sensitive (ranked last) to face viewpoint changes. We then converted these ranks to *Z*-scores. Thus, the observers that were the least sensitive to viewpoint variations were attributed positive scores, and those most sensitive to these variations were attributed negative scores. Each observer's CI was multiplied by his or her respective *Z*-scored rank. Afterwards, all weighed individual CIs were summed to create a group classification image. The values of each pixel in this group CI were converted to *Z*-scores using the mean and standard deviation of the portion of the CI corresponding to the face image's gray background.

The portion of the *Z*-scored CI that reached statistical significance for all three conditions is shown in Fig. 4. This image reveals the information significantly correlated with low viewpoint sensitivity (in gray) as determined by a two-tailed Pixel test ($p < 0.025$, $Z_{crit} = \pm 3.58$; Chauvin et al., 2005; no information was significantly correlated with high viewpoint sensitivity). The data for each SF band is not presented here, as no pixel reached statistical significance in these CIs. The fact that the facial region outlined in Fig. 4 only reached significance when combining all SFs indicates that these features were diagnostic regardless of the SF band in which they were presented. Another possible explanation is the presence of an important inter-observer variability in the use of SF information, but not in the diagnosticity of the features that reached statistical significance. The regions bordered in white show the facial information that reached significance when only considering the non image-based conditions.

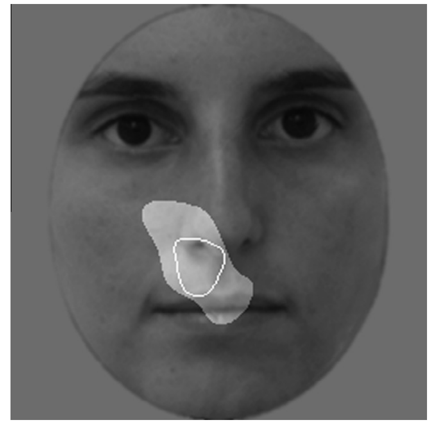

Fig. 4. Visual information significantly linked to accuracy when weighing the individual classification images by sensitivity to face viewpoint variations in all three conditions of our face matching task (in gray). The white line indicates which regions of the face image were significantly correlated with accuracy when weighing the individual classification images in only the two non image-based conditions (i.e. left and right conditions).

The results presented in Fig. 4 indicate that the use of the center of the face stimulus is significantly associated with individual sensitivity to variations in face viewpoint. In other words, the subjects that were the least affected by changes in viewpoint relied specifically on the left portion of the nose as well as the center of the mouth to accurately match identities across different viewing angles. These results further suggest that the use of features located in the center of the face is associated with a most efficient generalization of facial identity across viewing angles. Our observation that the eye area loses its significance in our individual differences analysis can be reconciled with Stephen & Caine's (2007) findings. Indeed, this suggests that the eyes are of high importance when it is possible for the subjects to rely on a strategy based on face identification. As revealed here, this strategy does not seem to be as helpful in the case of unfamiliar faces.

In order to determine that this effect was not merely driven by a few participants, we verified the distribution of *Z*-scores in the region of the individual CIs corresponding to the statistically significant portion of the weighted CI (i.e. center of the face, see Fig. 4), and its link with the viewpoint sensitivity scores. We obtain a significant correlation between the average *Z*-score in this region of the individual CIs and the viewpoint sensitivity rankings used to produce Fig. 4 ($r_{Spearman} = 0.4417$; $p = 0.0017$). This demonstrates a general quantitative trend across our participants in which lower viewpoint sensitivity is associated to a greater reliance on the center of the face (see Fig. 5).

3.4. Changes in feature utilization with task progression

The present study was conducted using unfamiliar faces and the Bubbles method. This technique requires the completion of a considerable amount of trials in order to yield informative results on the task at hand. Although this characteristic of the method is often

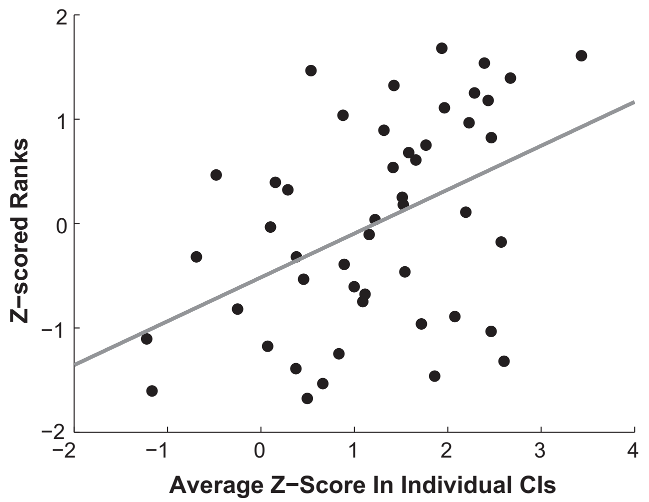

Fig. 5. Correlation between the *Z*-scored ranks used to compute Fig. 4 (i.e. the CI weighted with individual viewpoint sensitivity) and the average *Z*-score in the statistically significant portion of Fig. 4 in each observer's CI ($r_{Spearman} = 0.4417$; $p = 0.0017$). Note that the rankings are computed so that the observer least sensitive to viewpoint changes is ranked the highest.

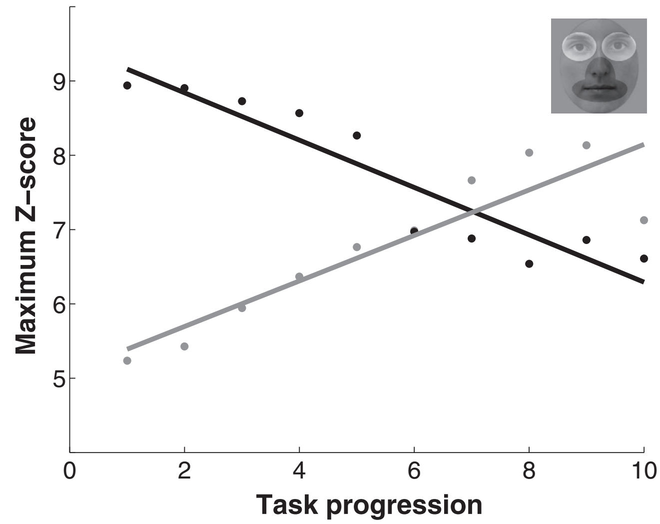

Fig. 6. Changes in feature utilization with task progression. The gray dots and line indicate the maximum *Z*-scores in the eye region, while the black dots and line refer to the nose and mouth area.

considered one of its limitations, it can also inform us on the way visual strategies evolve as the observers become increasingly familiar with the stimuli. Interestingly, Butler et al. (2010) observed an important diagnosticity of the eye regions for the recognition of highly familiar faces (i.e. celebrities). Seeing as these familiar faces have most likely been encoded in diverse viewing angles, we verified if a similar pattern of results could be obtained in the evolution of our participants' visual strategy over time. We indeed hypothesized that as observers became increasingly familiar with the face stimuli and the varying angles in which they were presented, their use of facial features particularly associated with familiar face recognition (i.e. the eyes) should also increase. Conversely, this higher reliance on the eye area should be accompanied by a reduction in the utilization of face cues that are not associated with efficient face identification, namely the nose and mouth.

In order to verify this proposition, we grouped the 1800 trials completed by our participants in 10 overlapping groups of 900 trials (e.g. trials 1–900, trials 101–1000, etc.). Each of the 10 groups shared 800 common trials with its preceding and following group. Then, a CI was computed for each of these groups of trials. Altogether, these CIs illustrated the evolution of the participants' visual strategy with the progression of the task. The eye and nose/mouth areas of each of the 10 CIs were independently sampled using predefined, non-overlapping regions of interest (ROIs; see Fig. 6). The maximum *Z*-scores in each of the two ROIs in the 10 CIs were then fit to a linear regression. As illustrated in Fig. 6, we see that the slopes for the two ROIs show strikingly opposite trends: while the use of the eye region tends to increase with the progression of the task (Fig. 6, gray), the diagnosticity of the nose and mouth area instead steadily decreases (Fig. 6, black). We used a bootstrap to verify if the difference between both slopes was statistically significant. More specifically, we first computed 1000 random permutations of the order of the 10 CIs (with replacement). Then, we fitted a linear regression model to the maximum *Z*-scores obtained for the eye and nose/mouth areas, and compared the slopes of the bootstrapped curves. The difference between the slopes of the bootstrapped curves was equal or greater than the difference obtained in our actual data in less than 1% of cases, allowing us to conclude that the difference in the use of both facial areas over time was statistically significant ($p < 0.01$).

4. Discussion

The present paper investigates the relatively unexplored issue of the diagnostic facial features for the generalization of facial appearance across different viewing angles. Although previous evidence suggested that the eye area may be particularly useful for this task (Butler et al., 2010; Stephan & Caine, 2007), as well as for face recognition in general (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Caldara et al., 2005; Gosselin & Schyns, 2001; Itier, Alain, Sedore, & McIntosh, 2007; Schyns, Jentzsch, Johnson, Schweinberger, & Gosselin, 2003; Schyns et al., 2002; Sekuler et al., 2004; Xivry, Ramon, Lefevre, & Rossion, 2008), our results indicate that center of the face, i.e. the nose and center of the mouth, is crucial for minimizing the negative impact of viewpoint changes in unfamiliar face matching. Thus, despite the overwhelming evidence highlighting the importance of the eye area for accurate face recognition, it appears that the information associated with efficient face matching across different viewpoints is, surprisingly, not in the eyes. Interestingly, as the faces become increasingly familiar, the pattern of feature utilization progressively resembles what we obtain with faces encoded and recognized in a single view. Indeed, in the context of viewpoint variations, although the center of the face remains important for the task, the eye area steadily gains in diagnosticity, while the nose and mouth regions decrease in importance.

In contrast to our results, previous evidence suggested that the eye area was in fact associated to a reduced dependency to face viewpoint (Stephan & Caine, 2007). This is not particularly surprising in a context where the observers were required to learn the identity of the faces used in the task. An important difference between Stephan and Caine's (2007) work and our own is our calculation of a measure of individual viewpoint sensitivity that freed this variable of the influence of mechanisms associated with face identification. As shown in our first analysis where all observers are equally represented in the group CI (Fig. 3), the eye area is indeed, on average, useful for identity matching across viewpoints. Moreover, although not shown in our results section, this facial region is also revealed when the individual CIs are weighted using a measure of viewpoint sensitivity that does not take into account overall face recognition ability (i.e. using only the absolute difference between the number of bubbles required in the non-image-based and image-based conditions to weigh the individual CIs). Thus, our results are in fact consistent with previous accounts of the features diagnostic for an identity matching task requiring a generalization of identity information across different viewpoints.

Nonetheless, we considered necessary to factor out individual face recognition ability from our viewpoint sensitivity measure because these variables are most likely correlated, but do not necessarily reflect the same perceptual/cognitive mechanisms. Our data shows that it is possible to pinpoint the facial features associated with a strong decrease in viewpoint variance independently of face recognition ability, suggesting that a certain distinction can be made between these two processes, at least for unfamiliar faces. Indeed, when the visual strategies used by the individual observers were combined in a way to portray sensitivity to viewpoint variations while also factoring out face recognition ability (Fig. 4), only the nose and the center of the mouth were significantly correlated with our measure of viewpoint invariance. In other words, although observers do use the eye area to perform the task, this visual strategy does not specifically subtend a viewpoint invariant performance in unfamiliar face matching. When considering the configuration of the face stimulus, we can understand why the most efficient individuals in the context of our task would rely to a greater extent on these more central facial features. As opposed to more lateralized facial cues such as the eyes, the nose and mouth are less prone to occlusion by other portions of the face following changes in viewpoint (see Stephan & Caine, 2007 for a similar proposal). Another possible reason for the role of these central features in our task is that the nose and the mouth convey visually simpler information than the eyes. This simpler information may be less diagnostic in regards to facial identity, but may facilitate the transfer of the features' appearance to a different viewpoint. Although these possibilities remain speculative, our data clearly demonstrates that the use of these central features is linked to an increased efficiency in transferring identity information across varying viewpoints.

Two of our experimental choices may limit the generalization of out result, namely the cropping of the stimuli and the use of unfamiliar faces. In the context of face identification, it seems that the diagnostic features revealed with cropped faces (see Fig. 3) mostly correspond to uncropped stimuli (see Butler et al., 2010; Gosselin & Schyns, 2001). Furthermore, Estudillo and Bindemann (2014) recently demonstrated that face-view generalization is unaffected when only the internal facial features are shown (i.e. when the faces are cropped to an ellipse, as in the present study). Further studies are nonetheless required to directly test this proposition in the context of facial feature utilization with viewpoint variation.

Furthermore, our results may not necessarily generalize to familiar faces. Viewpoint invariance and face recognition *per se* are most likely intertwined in the case of highly familiar faces, while not necessarily being the case for unfamiliar faces, as shown in the present work. Relatedly, this close relation between recognition and viewpoint invariance is likely linked to the choice to use unfamiliar objects made by authors interested in viewpoint invariance in object recognition (e.g. Blais, Arguin, & Marleau, 2009; Hayward & Williams, 2000; Tjan & Legge, 1998). Since familiar faces are encoded from multiple viewpoints through repeated expositions to the stimulus, it is possible that viewpoint invariance is inherent to the identification of a familiar face, while not being the case for unfamiliar faces. This proposition is supported by functional neuroimaging data showing that long-term, viewpoint invariant representations of familiar faces seem to be processed in more anterior regions of the face processing network (e.g. the anterior temporal lobe face area or ATL-FA), while more posterior regions do not show the same level of viewpoint invariance (Axelrod & Yovel, 2012; Yang, Susilo, & Duchaine, 2014; see Duchaine & Yovel, 2015 for a review). In this framework, the important diagnosticity of the eye region for the recognition of familiar faces demonstrated by Butler et al. (2010) may be accounted for by a long-term representation of these faces acquired through the observer's exposition to diverse viewpoints. The results presented in Section 3.4 directly support the idea that the eye area may gain in diagnosticity only when a face becomes more familiar. Thus, it seems that the center of the face stimulus may play an important role in earlier encoding stages of unfamiliar faces, when a viewpoint invariant representation of the stimulus has not yet been acquired. In fact, this may partially explain why the recognition of unfamiliar faces is particularly difficult in the context of facial expression changes, as these features (especially the mouth) are considerably altered in these conditions (Blais, Roy, Fiset, Arguin, & Gosselin, 2012). The importance of these features, however, appears to markedly decrease as a face becomes more familiar, and the facial representations become increasingly flexible or adaptable in response to changes in viewpoint.

5. Conclusion

In summary, the present work establishes which features are useful to maximize efficiency in matching unfamiliar faces across different viewpoints, i.e. the nose and center of the mouth. The novelty of our results stems from the identification of the features linked specifically to viewpoint invariance, independently of individual face identification performance. We show that the visual strategies associated with viewpoint invariance and those linked to face recognition are partially based on qualitatively different information. This suggests that a certain distinction can be made between these two processes in the case of unfamiliar faces, as shown by the distinct pattern followed by central facial features and the eye area in terms of diagnosticity as faces become more familiar to the observers. Thus, as the facial representations become increasingly flexible to visual changes of faces (in this case, viewing angle), features repeatedly demonstrated as crucial to face identification, and even more so to familiar face recognition, markedly gain in importance.

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