ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/228088696

EEG responses to facial contrast-chimeras

Article *in* Journal of Integrative Neuroscience · June 2012

DOI: 10.1142/S021963521250015X · Source: PubMed

CITATIONS
4

READS
316

3 authors, including:

Tapan K. Gandhi
Indian Institute of Technology Delhi

145 PUBLICATIONS **1,277** CITATIONS

SEE PROFILE

Pawan Sinha
Massachusetts Institute of Technology

203 PUBLICATIONS **7,292** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Prakash View project

Autism View project

All content following this page was uploaded by Tapan K. Gandhi on 23 May 2014.

The user has requested enhancement of the downloaded file.

Journal of Integrative Neuroscience, Vol. 11, No. 2 (2012) 201–211
© Imperial College Press
DOI: 10.1142/S021963521250015X

Imperial College Press
www.icpress.co.uk

EEG responses to facial contrast-chimeras

Tapan Gandhi*, Nina Suresh† and Pawan Sinha†

*Centre for Biomedical Engineering
Indian Institute of Technology
New Delhi, 110016, India
gandhitk@gmail.com

†Department of Brain and Cognitive Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139, USA

[Received 26 July 2011; Accepted 1 February 2012]

Contrast negation greatly diminishes the identifiability of a facial image. Recent results have shown that much of this performance reduction can be compensated for if contrast relationships in the neighborhood of the eyes are restored. Chimeric faces that contain positive eyes on negative faces are almost as well recognized as fully positive faces. Here we examine the neural correlates of this behavioral finding. Given that positive and chimeric faces lead to similar behavioral performance, do they also elicit similar neural responses? Specifically, we investigate early event-related potential components in response to these two kinds of images. Past studies have shown that the N170 is significantly affected by contrast negation. However, we find that the simple chimeric transformation has a profound effect on this and two other event-related potential components associated with face perception. Consistent with our behavioral results, we find that the N170, P100 and P250 components for positive and chimeric faces are statistically indistinguishable, but differ significantly from those corresponding to the fully negative faces. We discuss the implications of these results regarding the nature of facial representation underlying behavior as well as the event-related potential components.

Keywords: Face recognition; chimeric face; event-related potential.

1. Introduction

It is remarkably hard to recognize people's faces in photographic negatives. Phillips (1972) and Bruce & Langton (1994) found that recognition accuracy for familiar faces registered a 35–40% decrease in going from normal contrast images to their negated counterparts. This effect has been known at least since the invention of photography and has been the subject of much research over the past several decades (Galper, 1970; Galper & Hochberg, 1971; Phillips, 1972; Kemp *et al.*, 1990; Jeffreys, 1993; Bruce & Langton, 1994; White, 2001).

A prominent explanation for this effect maintains that the decrement in performance is caused by the unnatural shading cues in negatives (Johnston *et al.*, 1992; Kemp *et al.*, 1996; Hill & Bruce, 1996; Bruce & Young, 1998). These unusual shading

created with nitro PDF professional
download the free trial online at nitropdf.com/professional

cues are believed to render shape from shading processes (Horn, 1986; Horn & Brooks, 1989; Pentland, 1988; Ramachandran, 1988a,b; Cavanagh & Leclerc, 1989; Johnston & Passmore, 1994a,b) unable to recover correct three-dimensional (3D) facial shape. The resulting lack of veridical 3D facial shape information is assumed to be responsible for causing a decrement in identification performance. Besides suggesting a specific reason for the recognition deficit, this explanation also highlights the fact that photographic negatives are not merely visual curiosities, but rather touch upon fundamental issues of facial representation by the visual system.

While a loss of shape from shading cues is a plausible explanation of the observed phenomenology, it is unclear whether it is a sufficient one. We suggest an alternative explanation that is based not on the recovery of 3D facial shape, but rather on the use of stable contrast relationships within the two dimensional (2D) image. It may appear unlikely that any contrast relationship over an extended distance on a face will be stable; illumination changes dramatically affect absolute and relative image intensities on different face regions. However, in tackling the computational challenge of identifying facial photometric invariants in order to gain tolerance to illumination variations, we have found that polarity of contrast around the eyes is a remarkably stable feature, with the eyes usually being darker than the forehead and the cheeks (Sinha, 1995, 2002). It is interesting that despite marked changes in the absolute magnitude of contrast across different regions of a face under different imaging/lighting conditions, the local polarity relationships between the eye regions and their neighborhood are maintained in all but the most unnatural lighting setups (such as lighting a face from below). Roger Watt has also remarked on the stability of this polarity relationship (Watt, 1994). Ordinal contrast relationships in the eye region have also been shown to be significant for other face perception tasks such as gaze direction estimation (Sinha, 2001).

Relationships that are stable within an object class but distinctive across classes are ideal candidates for encoding the object class. To the extent that this principle applies to neural encoding strategies (Wallis & Bulthoff, 1999; Fiser & Aslin, 2002; Purves & Lotto, 2003), it stands to reason that facial representations will incorporate the kinds of stable contrast polarity relationships we have described above. Mismatches between this internal representation and observed data will then be expected to lead to decrements in recognition. Contrast negation of face images is one way of creating such mismatches.

Inverting image contrast destroys the otherwise highly consistent polarity relations and may be a factor leading to the poor recognizability of negated faces. In our prior work, we have tested this hypothesis by assessing recognition performance with a set of "contrast chimeras". These are novel stimuli comprising faces which are photo-negatives everywhere except in the eye region (thus preserving local contrast polarity in that neighborhood). Since such faces have unnatural shading cues over much of their extents, they present largely the same problems to shape from shading processes as the full negatives do. Hence, from the perspective of a shape from shading based account, these faces would not be much more recognizable than the

created with nitro PDF professional
download the free trial online at nitropdf.com/professional

fully negative faces. The only small increment in recognizability could derive from the intrinsic recognizability of the eyes. If, on the other hand, the primary cause for the poor recognizability of negated faces is the destruction of local polarity relations between the eyes and their neighborhood, then we would expect that performance with contrast chimeras will be significantly better than that with contrast negatives.

Our results, reported earlier (Gilad *et al.*, 2009) are consistent with our hypothesis. The results are shown in Fig. 1. We found that contrast chimeras were recognized at a significantly higher rate than the full negatives and the increase in performance cannot be explained simply by appealing to the recognizability of the eyes when shown either by themselves or when embedded in a head silhouette.

To further validate this behaviorally driven finding, we need to probe the analogous issue with neural markers: Can the inclusion of this relationship in a negated face equalize the neural responses it engenders to those corresponding to a fully positive face? In other words, given that chimeric faces behave similarly to fully positive ones in terms of behavioral performance, will the neural responses the two elicit also exhibit similarities despite their profound low-level differences?

2. Methods

2.1. *Participants*

Nine adults (four females) between the ages of 20 and 30 years (M = 24.8) participated in this experiment. An additional two adults were tested but were excluded from final data analysis due to excessive EEG artifact. All adults had normal or corrected-to-normal vision, and none had a history of neurological abnormalities. The study was approved by the Massachusetts Institute of Technology Institutional review board (MIT IRB) and informed consent was obtained from all participants.

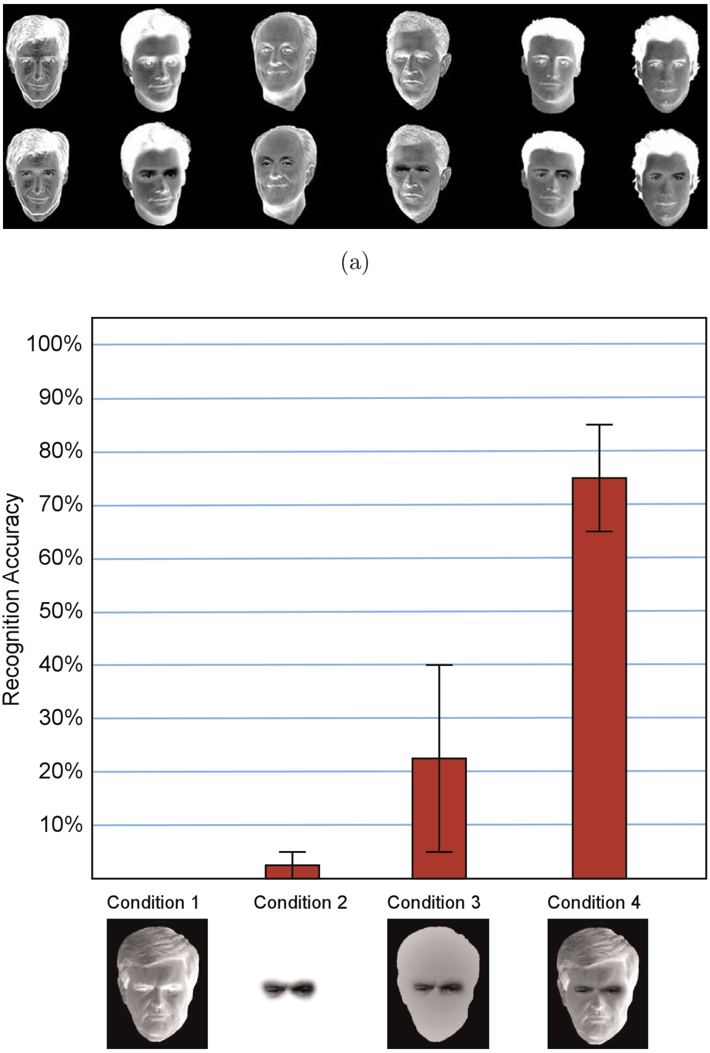
2.2. *Stimuli*

Our stimulus set consisted of 120 images (30 images for each of the four categories: positives, chimeric, eyes on a silhouette and negatives).

2.3. *Procedure*

Participants saw all images in random order. The pictures were presented against a uniform gray background. Each trial consisted of stimulus presentation (500 ms) and a post-stimulus recording period (1000 ms). The inter-trial interval, during which a black fixation cross was presented on a gray background, varied randomly between 1500–2000 ms. During the experiment, a green dot was presented on 10% of randomly selected stimuli. Participants were required to respond by pressing a button on the response box when a green dot appeared but not required to indicate their recognition of images presented. The participants were instructed to make their responses as quickly and accurately as possible, and they had 1500 ms from stimulus onset to do so.

created with nitro PDF professional
download the free trial online at nitropdf.com/professional


(a)

(b)

Fig. 1. (a) A few negative faces (top row) and the corresponding "contrast chimeras" (bottom row). The only difference between these sets of images is that the chimeras are re-negated in the eye regions. They are thus a composite of negative faces and positive eyes. This local transformation significantly restores facial recognizability, as data in (b) show. (b) Recognition results averaged across nine subjects. Data are reported for the faces that were not recognized in the photographic negatives, but were recognized in the original positives. This normalizes data so that performance with the negatives is 0% and with the positives, 100%. Performance with contrast chimeras is much improved relative to the full negative condition. This cannot be explained simply in terms of the intrinsic recognizability of the eyes, as data from conditions 2 and 3 demonstrate (after Gilad *et al.*, 2009).

2.4. *Electrophysiological recording and processing*

While participants were performing the above task, continuous EEG was recorded using a 128-channel Geodesic Sensor Net (Electrical Geodesics, Inc.), referenced online to vertez (Cz). The electrical signal was amplified with 0.1–100 Hz band-pass

created with nitro PDF professional
download the free trial online at nitropdf.com/professional

filtering, digitized at a 500 Hz sampling rate, and stored on a computer disk. Data were analyzed offline using NetStation 4.2 analysis software (Electrical Geodesics, Inc.). The continuous EEG signal was segmented into 700 ms epochs, starting 100 ms prior to stimulus onset. Data were filtered with low-pass finite impulse response (FIR) filter of Kaiser type with passband gain 0.1 dB, stopband gain 40 dB and rolloff 0.3−10 Hz. Baseline-corrected to the mean of the 100 ms period before stimulus onset. NetStation's automated artifact detection tools combed the data for eye blinks, eye movements, and bad channels. Segments were excluded from further analysis if they contained an eye blink (threshold $+/-70\,\mu$V) or eye movement (threshold $+/-\ 50\,\mu$V). In the remaining segments, individual channels were marked bad if the difference between the maximum and minimum amplitudes across the entire segment exceeded $80\,\mu$V. If more than 10% of the 128 channels (i.e., 13 or more channels) were marked bad in a segment, the whole segment was excluded from further analysis. If fewer than 10% of the channels were marked bad in a segment, they were replaced using spherical spline interpolation. Average waveforms for each of the four stimulus categories were calculated for each participant and re-referenced to the average reference configuration.

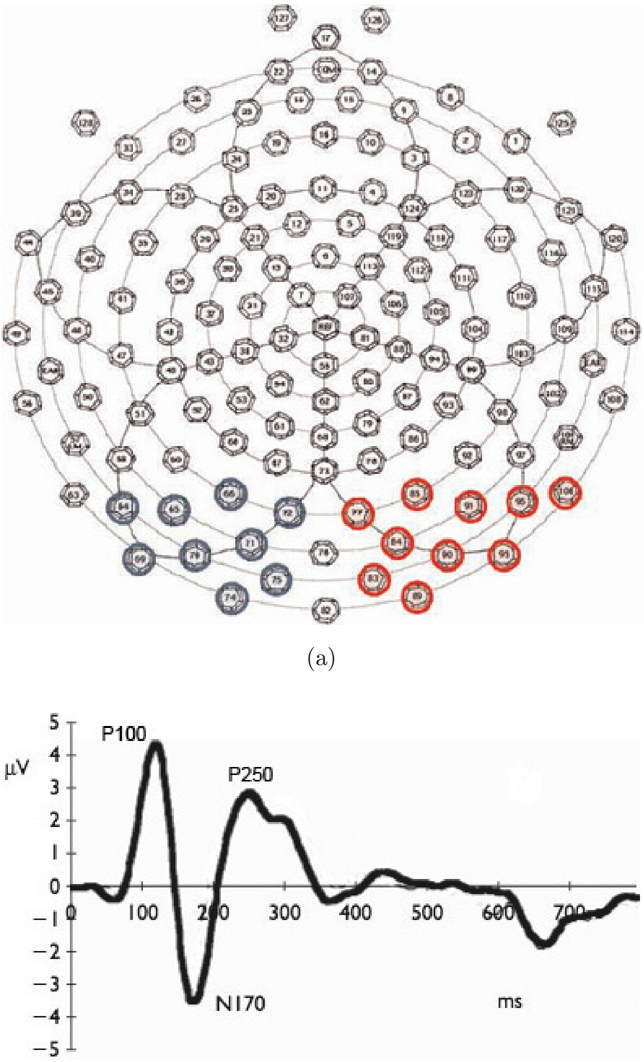
2.5. *Data analysis*

The acquired 128-channel pre-processed data were subjected to discrete wavelet transform (DWT) for denoising purposes. The denoising technique used in this study is the wavelet thresholding method. The EEG signals were decomposed using Coif1 (Gandhi *et al.*, 2011). The idea of thresholding is to set to zero all coefficients that are less than a particular threshold with the expectation that this operation attenuates high-frequency, but low amplitude, noise without substantially affecting the main features of the dataset. These coefficients are then used in an inverse wavelet transformation to reconstruct the data set. This yields the desired denoised signal. In this process, the EEG signals were band limited to 1−40 Hz. By averaging the responses to all of the fully positive faces for each subject, we identified the sensors exhibiting a face-evoked N170 component (Bentin *et al.*, 1996; Anaki *et al.*, 2007; Itier & Taylor, 2002, 2004). This selection process identified sensors in occipito-temporal location in the left and right hemispheres consistent with previous reports (Fig. 2(a)). All subsequent analyses were performed after averaging responses of the selected sensors on the left and, separately, those on the right. The amplitudes and latencies of specific event-related potential (ERP) components were calculated for each subject individually.

3. Results

Although the N170 is the primary electrophysiological correlate of face perception, past work has also implicated two other ERP components in this task: P100 and P250 (Marzia & Viggiano, 2007; Burkhardt *et al.*, 2010). Figure 2(b) shows these three components. In what follows, we describe our results from analyses of all of

created with nitroPDF professional
download the free trial online at nitropdf.com/professional



(b)

Fig. 2. (a) Channel locations in 128 channel Geodesic sensor net that typically exhibited robust N170 response to face images and were used for further analyses to probe the consequences of negation and partial re-inversion (in chimeras) on ERP amplitudes and latencies. (b) A prototypical ERP over occipito-temporal sensors in response to face stimuli. Three components can be identified and are believed to be involved in face perception, the P100, N170 and P250. Of these, the N170 is the component most reliably associated with face perception.

these components' amplitudes and latencies corresponding to the different stimulus conditions we used in our experiment.

The electrodes selection criterion was a liberal one: all sensors in the right occipital region (the area conventionally studied in past reports on face responses) that exhibited the characteristic positive-negative-positive ERP waveform (corresponding to the P100, N170 and P250), and where the negative peak was within 125 to 190 ms post-stimulus onset were included in our analyses. The three waves are typically

created with nitroPDF professional
download the free trial online at nitropdf.com/professional

studied as components of a common underlying waveform, hence our usage of the same sensors for all three analysis sets. Furthermore, anchoring the selection to the existence of an N170 (the primary marker for face perception) appropriately constrains the inclusion criterion to face-sensitive sensors.

3.1. *N170 response to positive, chimeric, isolated eye and negative stimuli*

Based on its selectivity for facial patterns, the N170 component has been the most strongly implicated in face processing (Bentin *et al.*, 1996; Anaki *et al.*, 2007; Itier & Taylor, 2002, 2004). To assess the pattern of N170 response for all four categories of stimuli in occipito-temporal region, we performed two-way ANOVA with repeated measures. We treated hemisphere and stimulus categories as repeated measures and amplitude or latency as the dependent measure. Analysis of the N170 amplitude revealed a significant difference between right and left hemispheres $[\mathrm{F}(1,8) = 6.944, \mathrm{p} < 0.05]$. The amplitude on the right side of the brain was greater than that on the left for all four types of stimuli. Considering the effects of stimulus type, we found that the amplitude of the N170 component elicited in response to the positive faces and chimeras was significantly different from that corresponding to fully negative faces $[\mathrm{F}(1,8) = 12.115, \mathrm{p} < 0.001]$ and the eyes $[\mathrm{F}(1,8) = 10.12, \mathrm{p} < 0.05]$ alone. Furthermore, N170 amplitudes corresponding to the positive faces and chimeras were statistically indistinguishable $(\mathrm{p} = 0.31)$.

Latency analyses revealed a similar picture. The N170 latency for positive faces was significantly different from both negative $[\mathrm{F}(1,8) = 2.3, \mathrm{p} < 0.05]$ and eye on face silhouette $[\mathrm{F}(1,8) = 3.1, \mathrm{p} < 0.05]$ conditions, whereas there was no significant difference between the latencies corresponding to fully positive and chimeric faces. The same trend holds in the left hemisphere. Figure 3 summarizes the results.

Overall, both the amplitude and latency of the N170 response indicates an equivalence between fully positive and chimeric faces, consistent with the behavioral finding that recognition rates obtained with these two kinds of stimuli are comparable. The decrement in performance with negative faces is reflected in the significantly reduced N170 amplitude to such faces.

3.2. *P100 and P250 responses to positive, chimeric, eye and negative stimuli*

Results with the P100 and the P250 further attest to the equivalence of positive and chimeric faces. As before, a two way ANOVA with repeated measures was conducted; hemisphere (left/right) and stimulus category (positive, chimera, eye and negative) were treated as repeated measures and amplitude or latency were the dependent measures. The results are summarized in Fig. 4. Both the P100 and the P250 show an effect of hemisphere on response amplitudes, with responses in the right being stronger than those in the left across all stimulus types (for the P100, $[\mathrm{F}(1,8) = 6.52, \mathrm{p} < 0.05]$ and for the P250, $[\mathrm{F}(1,8) = 2.3, p < 0.05]$). For both the P100 and P250, in right

created with nitro PDF professional
download the free trial online at nitropdf.com/professional

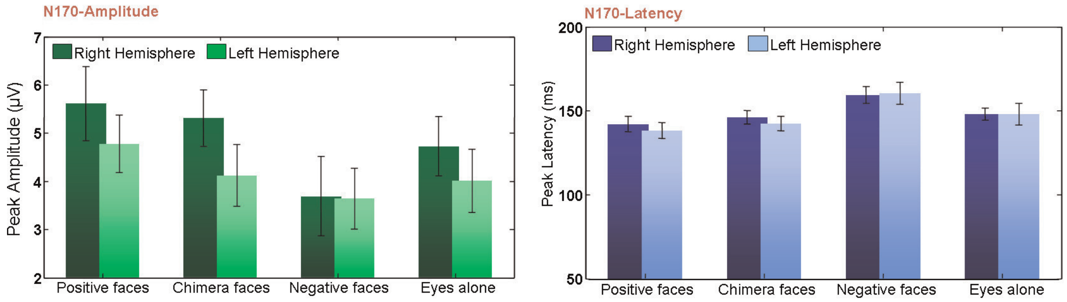


Fig. 3. N170 amplitude and latency results in the left and right hemispheres for each of the four stimulus conditions. For both of these dimensions, positive faces elicit responses that are significantly different from those corresponding to negative faces as well as the eyes alone, but are statistically indistinguishable from chimeric faces.

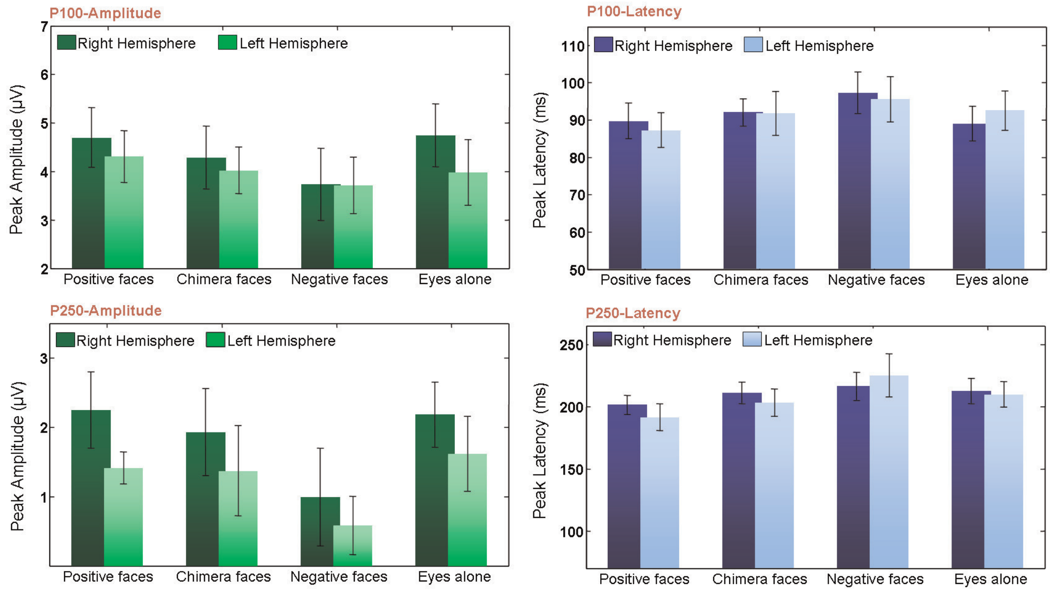


Fig. 4. P100 and P250 amplitude and latency results in the left and right hemispheres for each of the four stimulus conditions. Like the N170, these components too are equivalent for positive and chimeric faces and different for fully negative faces.

hemisphere there was no significant difference in amplitudes corresponding to positive, chimeric and eyes, but response to fully negative faces was significantly different at $p < 0.05$. There were no significant latency differences across the conditions in the right hemisphere. The left hemisphere showed no statistically significant differences in P100 or P250 amplitude or latency were seen across the four conditions.

4. Discussion

One of the primary objectives for identifying neural correlates of face perception is to address the larger challenge of determining the key attributes needed to render a

created with nitroPDF professional
download the free trial online at nitropdf.com/professional

pattern be an effective face. Systematically varying stimulus information and observing its effects on the putative neural correlate is a potentially powerful approach for identifying important facial attributes. With this general motivation, we have explored here the significance of a particular photometric relationship in facial images. Our past psychophysical studies (Gilad *et al.*, 2009) had shown that contrast polarity in the neighborhood of eyes is an important determinant of facial recognizability. More specifically, we found that the mere inclusion of this relationship in a contrast negated facial image brings it in approximate equivalence to fully positive facial images. To further validate this behaviorally driven finding, here we probed the analogous issue with neural markers to examine whether the inclusion of this relationship in a negated face could equalize the neural responses it engenders to those corresponding to a fully positive face.

General consensus in the domain of the cognitive neuroscience of face perception has converged around two neural markers: activity in a small locus of the fusiform gyrus as discerned via fMRI (Kanwisher *et al.*, 1997), and the N170, as detected via EEG (Bentin *et al.*, 1996; Anaki *et al.*, 2007; Itier & Taylor, 2002, 2004). We have previously reported (Gilad *et al.*, 2009) that the fusiform face area (FFA) activity changes exactly in the manner predicted: Contrast negated face images elicit a significantly lower level of FFA activation relative to positive faces. However, with the restoration of contrast polarity around the eyes in a chimeric face, FFA activation is statistically indistinguishable from that for fully positive faces.

In this study, we have considered the other prominent neural correlate of face perception, the N170. Consistent with past reports (Itier & Taylor, 2002) our results show that both the amplitude and latency of the N170 are significantly different for positive and contrast negated faces. Crucially, however, with the restoration of eye-neighborhood contrast polarity in chimeric faces, the N170 amplitude and latency become indistinguishable from those corresponding to the fully positive face condition. Furthermore, this change cannot be attributed merely to the presence of positive eyes (Eimer, 1998) since positive eyes on a head silhouette are unable to elicit responses equivalent to those for the positive face. Two other ERP components, P100 and P250, believed to be related to face perception, also behave in an analogous manner. They are different for positive and negative faces, but the same for positive and chimeric faces. The overall pattern of results that emerges attests to the significance of eye-neighborhood contrast polarity. The inclusion of this relationship in a negated face equalizes the neural responses it engenders to those corresponding to a fully positive face. However, as discussed above, we have considered only nine subjects for the analysis. The question may arise about the firm statistical conclusion due to small population size. If the only result we had found was a negative one, i.e., the lack of a difference between the amplitude/latency of an ERP component across the original and chimeric face conditions, then the issue of lack of statistical power would be a genuine concern. However, since we also find systematic and statistically significant differences across conditions, i.e., a positive result along with a negative one, we respectfully submit that the observed

created with nitro PDF professional
download the free trial online at nitropdf.com/professional

equivalence between the positive and chimeric conditions is not simply attributable to lack of power.

These results lend credence to the suggestion that a key component of facial representation is the polarity of contrast relationships in the neighborhood of the eyes. On the one hand, this helps explain why contrast negation (as in photographic negatives) is so detrimental to face recognition performance, and on the other hand, it points to the perceptual validity of a basic representational strategy which uses ordinal contrast relationships across large image regions. Computationally, this strategy has proven to be a very robust one for handling appearance variations across faces and even other object classes (Oren *et al.*, 1997; Sinha, 2002; Balas & Sinha, 2006). The present study suggests that a similar strategy might be at work in the human visual system as well.

REFERENCES

Anaki, D., Zon-Golumbic, E. & Bentin, S. (2007) Electrophysiological neural mechanisms for detection, configural analysis and recognition of faces. *Neuroimage*, **37**, 1407–1416.

Balas, B.J. & Sinha, P. (2006) Region-based representations for face recognition. *ACM Trans. App. Perception*, **3**, 354–375.

Bentin, S., Allison, T., Puce, A., Perez, E. & McCarthy, G. (1996) Electrophysiological studies of face perception in humans. *J. Cog. Neuroscin*, **8**, 551–565.

Bruce, V. & Langton, S. (1994) The use of pigmentation and shading information in recognising the sex and identities of faces. *Perception*, **23**, 803–822.

Bruce, V. & Young, A. (1998) *In the Eye of the Beholder — The Science of Face Perception.* Oxford University Press.

Burkhardt, A., Blaha, L. M., Jurs, B. S., Rhodes, G., Jeffery, L., Wyatte, D., DeLong, J. & Busey, T. (2010) Adaptation modulates the electrophysiological substrates of perceived facial distortion: Support for opponent coding. *Neuropsychologia*, **48**, 3743–3756.

Cavanagh, P. & Leclerc, Y.G. (1989) Shape from shadows. *J. Exp. Psychol. Hum. Percept. Perform.*, **15**, 3–27.

Eimer, M. (1998) Does the face-specific N170 component reflect the activity of a specialized eye processor? *Neuroreport*, **9**, 2945–2948.

Fiser, J. & Aslin, R.N. (2002) Statistical learning of new visual feature combinations by infants. *Procs. Natl. Acad. Sci. U. S. A.*, **99**, 15822–15826.

Galper R.E. (1970) Recognition of faces in photographic negative. *Psychonomic Science*, **19**, 207–208.

Galper, R.E. & Hochberg, J. (1971) Recognition memory for photographs of faces. *Am. J. Psychol.*, **84**, 351–354.

Gandhi, T.K., Panigrahi, B.K. & Anand, S. (2011) A comparative study of wavelet families for EEG signal classification. *J. Neurocomput.*, **74**, 3051–3057.

Gilad, S., Meng, M. & Sinha, P. (2009) Role of ordinal contrast relationships in face encoding. *Proc. Natl. Acad. Sci. U. S. A.*, **106**, 5353–5358.

Hill, H. & Bruce, V. (1996) Effects of lighting on the perception of facial surfaces. *J. Exp. Psychol. Hum. Percept. Perform.*, **22**, 986–1004.

Horn, B.K.H. (1986) *Robot Vision.* Cambridge, MA: MIT Press.

created with nitro^PDF professional
download the free trial online at nitropdf.com/professional

Horn, B.K.P. & Brooks, M.J. (1989) *Shape From Shading*. Cambridge, MA: MIT Press.

Itier, R.J. & Taylor, M.J. (2002) Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *Neuroimage*, **15**, 353−372.

Itier, R.J. & Taylor, M.J. (2004) N170 or N1? Spatiotemporal differences between object and face processing using ERPs. *Cereb. Cortex*, **14**, 132−142.

Jeffreys, D.A. (1993) The influence of stimulus orientation on the vertex positive scalp potential evoked by faces. *Exp. Brain Res.*, **96**, 163−172.

Johnston, A., Hill, H. & Carman, N. (1992) Recognising faces: Effects of lighting direction, inversion, and brightness reversal. *Perception*, **21**, 365−375.

Johnston, A. & Passmore, P.J. (1994a) Shape from shading I: Surface curvature and orientation. *Perception*, **23**, 169−189.

Johnston, A. & Passmore, P.J. (1994b) Shape from shading II: Geodesic bisection and alignment. *Perception*, **23**, 191−200.

Kanwisher, N., McDermott, J. & Chun, M.M. (1997) The fusiform face area: A module in human extrastriate cortex specialized for face perception. *J. Neurosci.*, **17**, 4302−4311.

Kemp, R., McManus, C. & Pigott, T. (1990) Sensitivity to the displacement of facial features in negative and inverted images. *Perception*, **19**, 531−543.

Kemp, R., Pike, G., White, P. & Musselman, A. (1996) Perception and recognition of normal and negative faces: The role of shape from shading and pigmentation cues. *Perception*, **25**, 37−52.

Marzia, T. & Viggiano, M.P. (2007) Interplay between familiarity and orientation in face processing: An ERP study. *Int. J. Psychophysiol.*, **65**, 182−192.

Oren, M., Papageorgiou, C., Sinha, P., Osuna, E. & Poggio, T. (1997) Pedestrian detection using wavelet templates. *Procs IEEE Conference on Computer Vision and Pattern Recognition*.

Pentland, A. (1988) Shape information from shading: A theory about human perception. *Proc. Int. Conference on Computer Vision*, 404−413.

Phillips, R.J. (1972) Why are faces hard to recognize in photographic negative. *Perception and Psychophysics*, **12**, 425−426.

Purves, D. & Lotto, R.B. (2003) *Why We See what We do: An Empirical Theory of Vision*. Sinauer Associates: MA.

Ramachandran, V.S. (1988a) Perception of shape from shading. *Nature*, **331**, 133−136.

Ramachandran, V.S. (1988b) Perceiving shape from shading. *Scientific American*, **259**, 58−65.

Sinha, P. (1995) *Perceiving and Recognizing Three-dimensional Forms*. Doctoral dissertation, Department of Electrical Engineering and Computer Science, MIT.

Sinha, P. (2001) Here's looking at you kid: The perception of gaze direction. *Perception*, **29**, 1005−1008.

Sinha, P. (2002) Qualitative representations for recognition. In: C. Wallraven and H.H. Buelthoff, eds. *Lecture Notes in Computer Science*. Springer-Verlag Publishers.

Wallis, G.M. & Bülthoff, H.H. (1999) Learning to recognize objects. *Trends Cogn. Sci.*, **3**, 22−31.

Watt. R. (1994) A computational examination of image segmentation and the initial stages of human vision. *Perception*, **23**, 383−398.

White M (2001) Effect of photographic negation on matching the expressions and identities of faces. *Perception*, **30**, 969−981.

created with nitro PDF professional
download the free trial online at nitropdf.com/professional

View publication stats