UNIVERSITY OF CALIFORNIA, SAN DIEGO

The Fundamentals of Configuration in Face Perception and Discrimination

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requirements for the degree Doctor of Philosophy

in

Psychology

by

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2008

DEDICATION

For his loving nature and strong spirit despite a

weak heart, I dedicate this dissertation to

Marmaduke "Dukey" Pallett.

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ABSTRACT OF THE DISSERTATION

The Fundamentals of Configuration in Face Perception and Discrimination

by

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Face recognition is superior to object recognition, but inversion disproportionately impairs face recognition. This suggests that face perception is fundamentally different from object perception. There are two possible sources of this difference: 1. Faces are perceived as integrated wholes, while objects are processed in a part-based manner. 2. Face recognition relies on the accurate perception of facial feature arrangement, while object recognition relies more on the perception of details. In this dissertation, I examine these claims and explore the extent of the influence of facial feature arrangement on face perception. Chapter 2 assesses our ability to discriminate differences in facial feature

arrangement with the goal of understanding the source of the inversion effect on face recognition. Chapter 3 further investigates our ability to discriminate differences in facial feature arrangement, as well as typicality and gender, to determine the degree to which face perception differs from object perception. In addition, I investigated whether adaptation resulting from extended exposure to a specific face, e.g. a male face or compressed face, affects discrimination. Chapter 4 explores the source of illusory changes in perceived face length resulting from adjustments to the feature arrangement. It also examines how these illusory percepts relate to natural distribution of faces. Chapter 5 then applies the results of Chapter 4 to determine how variations in facial feature arrangement and their relation to the population average affect our perception of attractiveness.

Chapter 1

General Introduction

Faces are intuitively interesting, multifaceted objects of supreme biological importance. A face contains several layers of information, each defined by the same underlying properties: features and their spatial arrangement. Of these, spatial arrangement has received the most attention.

Variations in the spatial organization of a face are fundamental to daily human interaction. A subtle twist of the mouth from an upward to a downward orientation replaces happiness with sadness. In one glance, feature spacings help us to know the identity, gender, attractiveness, and affect of an individual. Efficient face perception is crucial to human survival; therefore the detection of slight variations in spacing within a face and between faces is essential.

The Face Inversion Effect – Impaired Spatial Processing

All objects are recognized best when viewed in an upright orientation, but faces are disproportionately impaired by inversion (Yin, 1969). This fundamental difference between object and face recognition is called the face inversion effect and has sparked decades of high-level vision research focused on discovering what makes faces special.

One possible source of the face inversion effect is a disruption in the ability to process spacing information (Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; for a review, see Rossion & Gauthier, 2002). If true, then this suggests that face recognition depends primarily on the processing of spatial arrangement rather than the details of individual facial features. Tanaka and Sengco (1997) demonstrated that in an upright face, recognition of a facial feature can be modulated by the feature arrangement. Presentation of the feature in a new spatial arrangement or in isolation impaired feature recognition, which strongly indicates that spatial arrangement is a crucial component of a face. However, if the feature is learned in an inverted face, then spatial context does not affect recognition (Tanaka & Sengco, 1997). The disappearance of a spatial context effect with inversion further suggests that spacing information is mandatory for face recognition.

Given that the face inversion effect is taken to represent a fundamental difference between face and object recognition, then the above results imply that spatial information is either not essential for object recognition or not orientation-dependent in object recognition. Faces are very spatially dependent constructs. To be a face, an object must have a set of eyes above a nose above a mouth. Objects, however, are often defined primarily by function rather than appearance. For example, a house generally has four walls and a roof, but the placement of doors and windows or number of stories is irrelevant. So long as it functions as a domicile, it is a house. A direct result of this is that the context effects observed for upright feature recognition do not pertain to features present in objects (Tanaka & Sengco, 1997). Therefore, it seems that face recognition is characterized by high-level skills for extracting orientation-specific spatial relations between the major facial elements such as the eyes, nose, mouth, and external contour (for further review, see Mauer, LeGrand, & Mondloch, 2002).

The Face Inversion Effect – Impaired Holistic Processing

A second possible source of the face inversion effect is a failure to perceive the face as a whole, i.e. form a holistic percept. Holistic processing binds the elements of the face to its external contour to create an integrated face percept. When holistic processing fails, the visual system invokes a part-based analysis of the image. Therefore, when a face is inverted, it is not perceived as an integrated whole and must be perceived in terms of its parts (Sergent, 1984).

The composite-face effect is a classic example of this. The composite-face effect occurs when the top and bottom halves of two different faces are fused to form a new composite face. When asked to compare this new face to one of the original faces, observers find it remarkably difficult to perceive the identical half as such (Young, Hellawell, & Hay, 1987). Holistic processing renders the identical half inseparable from the different half, producing an overall perception of difference. However, when the faces are inverted, observers can easily detect the matching face halves (Goffaux & Rossion, 2006; Hole, George, & Dunsmore, 1999). Here, inversion prevents the formation of a holistic percept, allowing the faces to be examined in terms of their parts.

The context effect observed in upright faces by Tanaka and Sengco (1997) can be similarly understood if the change in feature arrangement alters the holistic percept. In other words, the context effect may not result from the differences in spatial arrangement per se but rather the difference in holistic percept. If the features are inseparable from the spatial arrangement, then any change to the face percept should impair feature recognition. Likewise, the lack of a context effect with inverted faces could reflect a failure to form a holistic percept.

If inversion causes a shift from holistic to part-based processing, then this suggests that face recognition is holistically driven while object recognition is not. If true, then the failure to find a spatial context effect with objects (Tanaka & Sengco, 1997) may reflect an inability to form a holistic percept with objects.

Given these two plausible hypotheses for the face inversion effect, Chapter 2 seeks to determine which theory is correct: the spatial relations hypothesis of the holistic hypothesis.

Averageness in Face Perception

Some faces are typical, others are highly distinctive, but it is the distinctive faces that are most easy to remember (e.g. Courtois & Mueller, 1981). What determines the distinctiveness and memorability of a face is how it compares to the population average (Chang, Levine, & Benson, 2002; Lee, Byatt, & Rhodes, 2000; Leopold, O'Toole, Vetter, & Blanz, 2001; Rhodes, Jeffery, Watson, Clifford, & Nakayama, 2003). This average face is the basis upon which all other faces are defined. If a face is highly distinctive, then it deviates greatly from the average face. Similarly, the average face is perceived as the most typical face (Bruce, Burton, & Dench, 1994).

Most of the support for a face being defined relative to some average representation derives from adaptation research. Adaptation allows investigators to learn how the various elements of face perception are neuronally encoded without using costly or invasive methods. If a dimension of a face, such as configuration, is defined relative to an average, then adapting to an atypical configuration should cause a normal configuration to appear bizarre. For example, adapting to a center-compressed face shifts the perception of the original non-distorted face in the opposite direction, causing the original face to be perceived as more bloated (Rhodes et al., 2003; Webster & MacLin, 1999). Likewise, our subjective ratings of normality also shift with adaptation (Rhodes et al., 2003). Therefore, adapting to center-expanded face will not only cause an unaltered face to appear center-compressed, but it will also cause it to shift from normal to abnormal. This results from a renormalization process that occurs during adaptation. If neurons fire based on differences from an average and that average shifts, then the resulting perceptions will also shift. Similar effects are documented for emotion, gender, and race (Webster, Kaping, Mizokami, & Duhamel, 2004), indicating that each of these dimensions are defined relative to an average.

Therefore it seems that most, if not all, aspects of face perception and recognition are defined by the amount of displacement away from the average face. Chapter 3 explores this idea further by examining how a holistic percept forms and whether it relates to the probability distribution of natural faces.

Elements of Facial Attractiveness

Beauty drives the world. When considering the elements of facial attractiveness, Hollywood stars and cosmetic surgery easily come to mind; however the desire to find a metric for facial beauty ranges as far back as the Ancient Greeks. The Ancient Greeks believed that the beauty of an object was encapsulated by how closely it matched the Golden Ratio, 1:1.618. This proportion is reflected in Greek architecture and sculpture. When Leonardo da Vinci (1452 - 1519) created the Mona Lisa, he used to Golden Ratio to produce a perfectly proportioned work of beauty (Atalay, 2004). Modern cosmetology also uses the Golden Ratio. Cosmetologist Dr. Stephen Marquardt has developed a series of face masks based on the Golden Ratio that he believes describes the ideal face (Marquardt, 2005).

Despite its long history, scientific support for the golden ratio is highly mixed (Green, 1995). Although one recent study found a neuronal preference for the golden ratio when participants viewed different torso to body length ratios in the Greek sculpture Doryphoros by Polykleitos (Dio, Macaluso, & Rizzolatti, 2007), this is the first and only study using neurophysiological methods to find such a preference and this preference was never tested in faces. There is, however, evidence indicating that facial feature arrangement contributes to facial attractiveness. Searcy and Bartlett (1996) and Bartlett and Searcy (1993) demonstrated that increasing the spacing between the eyes and mouth of an otherwise normal face causes the face to appear increasingly grotesque. Notably, this manipulation also changes the eye-mouth-eye angle, which is a dimorphic feature implicated in attractiveness preferences (Danel & Pawlowski, 2007).

Alongside the support for spatial relations contributing to facial attractiveness is research supporting averageness as attractive. In the late 1800s, Sir Francis Galton attempted to explore the diversity of faces and investigate their mental representations by creating composite faces. He created a composite face by overlaying multiple photographic slides of individual faces and shining a light through the slides so that they resulted in the perception of a single face. Galton (1907) observed that by creating a composite face, he in fact produced an average “ideal” face, neutral in expression, and both more attractive and more typical than any component face. This preference for an average face remains strong when tested with modern computer generated average faces and cannot be accounted for by improvements in symmetry (Langlois & Roggman, 1990; Rhodes, 2006; Rhodes et al., 2003; Rhodes, Sumich, & Byatt, 1999; Rubenstein, Langlois, & Roggman, 2002). However, it is unknown whether this attractiveness stems from a preference for average features or an average feature arrangement. Therefore, Chapter 4 of this dissertation examines these hitherto unconnected bodies of literature with the hypothesis that the ideal feature arrangement for an attractive face will match that of an average face.

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Chapter 2

Face Discrimination and Categorization are Resilient to Inversion

Although inversion dramatically reduces our ability to recognize a face, it does not hinder face perception. To investigate this discontinuity between face perception and recognition, we assessed the effect of inversion on the discriminability of differences in facial compression or elongation using geometrically deformed faces. Results clearly showed that face discrimination is not subject to the traditional face inversion effect. Indeed, if anything, inversion improved the efficiency with which subjects made spacing judgments. We conclude that inversion does not affect our ability to perceive spacing information in a face. Instead, it impairs the face-specific processing of information about spatial arrangement.

The face inversion effect occurs when members of a previously learned set of upright faces are better recognized when tested in the same rather than opposite orientation (Yin, 1969). Although inversion mars our ability to recognize a face, there is mixed evidence on whether it also impairs face perception and discrimination.

There are two traditionally accepted possible causes of the face inversion effect on recognition (Maurer, LeGrand & Mondloch, 2002). One is that inversion impairs the perception of spatial relations between facial features (Diamond & Carey, 1986; Rhodes, Brake, & Atkinson, 1993; Searcy & Bartlett, 1996; Leder & Bruce, 1998, 2000). This theory posits explicit representation of spatial information and asserts that this information is crucial for face recognition.

The second possibility is that inversion produces a qualitative shift in processing strategy: upright faces are perceived in a "holistic" manner and inverted faces involve a part-based or serial approach (Farah, Tanaka, & Drain, 1995; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Rossion, 2008). Although Rock (1974) does not specifically mention holistic and part-based processing, he initially suggested that observers presented with an inverted face cannot mentally rotate the whole face. Instead, one feature is rotated at a time. This implies that the inverted face cannot be perceived holistically.

Support for a shift from holistic to part-based processing with inversion derives primarily from research on the composite-face effect. In the composite-face effect, when two faces with identical top halves are aligned with different bottom halves, these top halves tend to be perceived as different. Yet, if the top and bottom halves of the composite face are misaligned, the identical top halves are now more easily recognized as such (Young, Hellawell & Hay, 1987). Evidently misalignment disrupts holistic processing and allows for the perception of each top half in terms of its parts, making it easy to see that the top halves are the same. But, when the face halves are aligned, holistic processing ensues and the identical top halves become inseparable from the different bottoms. This results in the perception of difference between the identical tops. Like misalignment, inversion also induces part-based analysis and enables observers to correctly perceive the identical top halves as being the same. Moreover, this benefit of inversion persists across contrast-negation (Hole, George & Dunsmore, 1999) and low-pass filtering (Goffaux & Rossion, 2006).

The composite-face effect is one striking case of the influence of inversion on face perception, but not the only example. Inversion can increase the time to detect a face (Lewis & Edmonds, 2003), as well as impair the perception of difference in facial feature spacings (Barton & Deepak, 2003; Barton, Zhao, & Keenan, 2003; Kemp, McManus, & Pigott, 1990; Malcolm, Leung, & Barton, 2004), particularly when the spacings are vertical (Malcolm et al., 2004).

Precise estimation of the spacing of facial features could provide part of the basis for normal face recognition. But alternatively, it might require specific attention to the arrangement of the parts, while recognition of erect faces proceeds ‘holistically’, without such attention and without precise estimation of spatial arrangement. In this view, there is no necessary association between efficient recognition and perception of the spacing of facial features. The inversion effect in face recognition need not be accompanied by an inversion effect in discrimination. In the investigation of Barton and Deepak (2003), directing attention to the relevant spacing information did ameliorate the impairment from inversion. The role of attention was not assessed in the other studies cited.

Schwaninger, Ryf, and Hofer (2003) investigated the ability to accurately perceive the distances between facial features using estimates of these distances in upright and inverted faces. This is a task that demands a critical examination of the feature spacings, therefore employing attention. Results indicated that the precision of such quantitative estimates are robust to inversion. This resilience is particularly relevant because it indicates that the face inversion effect cannot be due to an inability to perceive spacing information. However, the authors suggest that rather than eliminating one possible cause of the face inversion effect, these results instead demonstrated a discontinuity between the use of spacing information in recognition and perception.

Altogether this creates quite a conundrum. Both face perception and face discrimination differ from recognition in that there is no identity matching. Both rely on relatively recent perceptions of the face. Yet several studies showed an effect of inversion on face discrimination, while Schwaninger et al. (2003) reported no effect of inversion on face perception. Therefore, to determine whether the face inversion effect truly results from an inability to accurately perceive spacing information rather than a shift in processing strategy, we need to invoke attention and directly measure the amount of spatial change needed to perceive a difference in spacing. If sensitivity to spacing decreases with inversion, then the face inversion effect could be caused by an inability to accurately perceive spacing information. If sensitivity does not decrease with inversion, this suggests that the face inversion effect results from a failure to perceive the face holistically and a shift to part-based processing.

We assessed participants' abilities to perceive geometrical differences along a single dimension in three experiments, each using either horizontal or vertical compression. In addition, since contrast-negation is known to impair recognition, gender classification (Bruce & Langton, 1994), and the detection of differences in feature spacings (Kemp, McManus & Pigott, 1990), we also chose to examine face discrimination using contrast-negated faces.

Experiment 1

This experiment assessed human ability to discriminate between upright, inverted, and contrast-negated faces varying in center-compression and center-expansion: a manipulation that primarily altered the distance between the eyes. By transversing an array of compressed and expanded faces, participants could select the face perceived as just-noticeably different. If inversion impairs the perception of facial feature arrangement, then we may also expect to observe an inversion effect with discrimination. In addition, this experiment assessed the accuracy of the method of adjustment as a means for measuring thresholds by comparing the resulting distortion thresholds for inverted faces to thresholds obtained via a staircase procedure.

Method

Participants. Participants included three members of the UCSD Vision Laboratory, and six University of California, San Diego graduate students. The graduate students participated in exchange for $10 an hour. Vision in all subjects was normal or corrected to normal.

Stimuli. An average Caucasian male face was created from 32 photographs of Caucasian males using the method described in Levin (2000). Using Matlab 7.1, a photograph of an average Caucasian male was distorted using a procedure similar to that described in Webster and MacLin (1999).

We distorted the average face by horizontally expanding or contracting relative to a midpoint between the eyes (x_m, y_m). The amount of pixel displacement was proportional to the horizontal derivative of a circular Gaussian envelope. This caused the displacement to be maximized at one SD away from the midpoint. Therefore when (x_i, y_i) represents a given pixel,

$$x_i' = x_i - x_m$$

and

$$y_i' = y_i - y_m.$$

In the distorted image, let the shift applied to pixel i be Δx. Then,

Formula 1. $\Delta x = \alpha * x' * \exp(-(x'^2 + y'^2) / 2\sigma^2)$

where the amplitude (α) of the distortion varied from –1 to 1 in steps of .04, and σ = 0.18 times the face width. The maximum displacement when α = 1 occurred at $x_i - x_m = \sigma$ and was 27.3 pixels. This displacement became proportionally smaller for smaller αs. This algorithm could also create partial pixel displacements through luminance interpolation, allowing for fine-tuning of a participant's sensitivity to horizontal displacement.

This differs from the Webster and MacLin (1999) algorithm by including x' and y' as weights when computing displacement. This produces the greatest horizontal displacement between the eyes and less horizontal displacement as the vertical distance from the eyes increased. Figure 1A displays the contour of the displacements in a maximally compressed face. Using Formula 1, we generated

51 distorted faces that systematically varied in expansion or contraction. Figure 1B displays a sample of the resulting faces. These faces were then inverted and contrast-negated to create two additional face sets.

A reference face was presented upper left corner of the display and a comparison face was in the lower right corner. Stimuli were presented in an offset manner to prevent the use of low-level visual cues such as edge matching. Reference stimuli (Figure 1B) in all three conditions included 5 possible amounts of distortion: expanded by 20.7 pixels (high expansion), expanded by 10.9 pixels (moderate expansion), the average, compressed by 10.9 pixels (moderate compression), and compressed by 20.7 pixels (high compression). The initial comparison face was selected to be randomly between four and six distortions away from the reference.

Stimuli were viewed on a 51 cm Iiyama HM204DT A CRT-monitor with a gray background using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Participants were seated at a distance of 90 cm. Images were 640 x 480 pixels and presented at a resolution of 1200 x 1024 pixels. On average, each face encompassed 4.7 x 6.6 degrees visual angle.

Design. Participants made a series of just-noticeably compressed judgments and just-noticeably expanded judgments for upright, inverted, and contrast-negated faces. Judgment direction was counterbalanced and face type was randomized. For example, a participant made judgments for all the upright reference faces followed by all the inverted reference faces, and then all the contrast-negated reference faces. Each reference face was presented in a random order and viewed six times for each judgment direction.

To assess the accuracy of the method of adjustment, inverted faces were also tested using a staircase procedure. Participants responded to whether the comparison face was more compressed or more expanded than the reference following one of two randomly interleaved staircases. Each staircase contained a 4:1 step size that tracked the 20% and 80% more-compressed points. Tracking these percentages, rather than 25% and 75%, maximized the efficiency of the staircase procedure.

Procedure. Each trial commenced with a beep. Participants scrolled through a continuum of faces using a mouse roller ball and selected the just-noticeably compressed or expanded face with a single left click. Selection of a face ended the trial. No feedback was provided. There were 180 total trials.

In the staircase procedure, rather than scrolling through a continuum of faces, the participant pressed the left arrow key to indicate that the comparison face was perceived as more compressed and the right arrow key if the comparison face appeared more expanded. Choice response determined the future comparison face for that reference and terminated the trial. No feedback was provided. There were 250 trials.

Data analysis. For each participant, each face type, and each reference distortion, the number of distortion steps between just-noticeably compressed (JNC) selections and the reference face and the just-noticeably expanded (JNE) selections and the reference face were averaged together. Thus, the threshold amount of distortion is expressed as the necessary shift in distortion steps to perceive a difference regardless of direction. Every four distortion steps roughly equaled one pixel of displacement. Taking the log of the discrimination thresholds normalized the distribution. Log distortion thresholds were tested for significance using a 3 x 5 within-subjects ANOVA with face type and reference distortion as repeated measures variables in SPSS 11.0.1.

Thresholds for the staircase data were determined for each reference distortion by fitting the proportion of compressed and expanded responses for each participant and each reference to a logistic function. Psychometric functions were fitted using `psignifit` version 2.5.6 (see http://bootstrap-software.org/psignifit/), a software package which implements the maximum-likelihood method described by Wichmann and Hill (2001) and runs in Matlab 7.1. These thresholds represented the amount of displacement necessary to perceive a difference regardless of direction. The logs of the staircase thresholds were compared to the logs of the discrimination thresholds using a t-test for each reference distortion in SPSS 11.0.1.

Results

Face inversion did not clearly affect discriminability. The mean threshold in distortion steps was 17 (S.E. = 1.9) for upright faces, 19 (S. E. = 1.7) for inverted faces, and 21 (S. E. = 1.3) for contrast-negated faces. There was a trend for face type to affect discriminability, F (2, 16) = 3.55, p = .053, but this effect primarily resulted from the difference in upright face discrimination and contrast-negated face discrimination. Table 1 contains the mean thresholds and standard deviations for each face type and reference distortion. Figure 2 displays the threshold profiles for the upright, inverted, and contrast-negated faces.

Overall, discrimination was best between the highly expanded faces and decreased roughly linearly as compression increased. This was confirmed by a significant linear trend, F (1, 8) = 16.0, p = .004, and a non-significant quadratic trend. This non-significant quadratic trend indicated no benefit for discrimination between natural faces, and discrimination was worst between the maximally compressed faces. This remained true regardless of the type of face presented, F (8, 64) = 1.55, p = .16.

There was no difference in threshold based on method, all ps > .05, indicating that the method of adjustment produced accurate discrimination thresholds.

Discussion

Contrast-negation slightly decreased the discriminability of the distorted faces, raising the threshold by a factor of about 1.2. Inversion had no detectable effect at all on discrimination.

Why did we find no inversion effect? The type of distortion could be relevant, since there is some evidence that unlike differences in vertical spacings, the perception of shifts in horizontal spacing is resilient to inversion. Specifically, Malcolm et al. (2004) demonstrated that vertical shifts in mouth location within an inverted face were the least detected type of spacing change. This corresponds well with the results reported by Goffaux and Rossion (2007) in which inversion significantly hindered the perception of difference in vertical but not horizontal feature spacings. Goffaux and Rossion proposed that vertical information is more sensitive to inversion than horizontal information because the facial features are organized primarily around the vertical axis.

Another possible explanation for the failure to find an inversion effect results from the unnatural demands of the task. In the natural world, no one makes judgments of eye displacement within a single identity. Real world discrimination occurs between identities, and a single identity cannot vary in this way. Therefore, the extrinsic nature of the task in Experiment 1 may not have invoked the entire set of face processing mechanisms, leading to a null effect of inversion. Experiment 2A sought to replicate the results of Experiment 1 by systematically altering the vertical spacing in faces with different identities.

Experiment 2A

Experiment 2A examined the influence of inversion and contrast-negation on the discriminability of faces that varied in eye to mouth spacing. In addition, Experiment 2A strove to improve upon the ecological validity of Experiment 1 by using multiple identities within the distortion continuum.

Method

Participants. 46 undergraduates from the University of California, San Diego with normal or corrected-to-normal vision participated in exchange for course credit.

Stimuli. We aligned the eyes and mouths of 22 grayscale male Caucasian faces with the eyes and mouth of the averaged male Caucasian face used in Experiment 1. Using Matlab 7.3 and the method described in Experiment 1, we then produced 41 levels of distortion for each face ranging in even vertical steps from highly compressed to highly elongated. The algorithm for vertical displacement varied only slightly from the equation for two-dimensional displacement. No horizontal distances were included in the equation, so the distortion affected each pixel's y-coordinate alone:

$$\Delta (y) = \alpha * y * \exp(-(y^2) / 2\sigma^2)$$

where the amplitude (α) of the distortion varied from –1 to 1 in steps of .05 and $\sigma = .20$ of the face length. This resulted in a maximum pixel displacement when $\alpha = 1$ of 42.5 pixels. From these faces, a continuum of 41 differentially distorted faces was created, in which the adjacent levels of distortion originated from different individual faces.

Five reference faces were selected as in Experiment 1.[1] The identity used for the references faces was different from the identities in the distortion continuum. Figure 3 displays the reference faces (top) as well as their distortion continuum matches (bottom).

Each face in the multiple-identity continuum, including each reference face, was contrast-negated with respect to the average pixel intensity of the image, and inverted to create a total of three different face types: upright, inverted, and contrast-negated. All faces were placed into a black oval frame to minimize the effect of different external facial contours and hair.

All stimuli were viewed on a gray background. The images were 320 x 240 pixels displayed at a resolution of 1200 x 1024 pixels using Matlab 7.3.

Design & Procedure. Participants made JNC and just-noticeably elongated (JNL) judgments following the method described in Experiment 1.

Data Analysis. Distortion thresholds were measured in the manner described for Experiment 1. However, since the data were normally distributed, it was unnecessary to take the log of the distortion thresholds. Data were analyzed using a 5 x 3 x 2 mixed-

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[1] The reference faces included shifts of: 27.9 pixels of elongation, 12.7 pixels of elongation, no shift, 12.7 pixels of compression, and 27.9 pixels of compression.

model ANOVA, with reference distortion and face type as the within-subjects factors and judgment order as the between-subjects factor.

Results

The results of Experiment 2A replicated the results of Experiment 1 with no effect of inversion on face discrimination. This was supported by the non-significant effect of face type[2], $p = .53$, and a non-significant Face Type x Judgment Order interaction, $p = .87$. Table 2 contains the threshold means and standard deviations for discrimination, and Figure 4 displays the threshold profiles for each face type. These results suggest that inversion and contrast-negation do not impair the discriminability of spacing differences in faces.

Discriminability varied significantly with the reference distortion, $F\ (2.53, 111) = 56.8$, $p < .001$. Similar to Experiment 1, a non-significant quadratic trend indicated no benefit for natural faces. Rather, discrimination was best around the maximally elongated reference face and became increasingly worse as compression increased following a significant linear trend, $F\ (1, 44) = 106$, $p < .001$. This again suggests that our experience with natural faces does not facilitate discrimination.

There was a small improvement with practice: Prior experience making elongated judgments produced an overall advantage for discrimination, $F\ (1, 44) = 6.68$, $p = .013$,

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[2] Reference Distortion and Reference Distortion x Face Type failed to conform to the assumption of sphericity (*Mauchly's W* = .284, $\chi 2\ (9) = 53.5$, $p < .001$; *Mauchly's W* = .123, $\chi 2\ (35) = 86.1$, $p < .001$). Therefore, these results include Greenhouse-Geisser corrections (Greenhouse & Geisser, 1959).

although interpretation of this effect is complicated by the significant interaction between judgment order and reference distortion, $F\ (2.53, 111) = 2.95$, $p = .044$. Specifically, participants who performed judgments with elongated references first produced better discrimination as compression increased than those who made compressed judgments first. Both the Face Type x Reference Distortion and the Face Type x Reference Distortion x Judgment Order interactions were non-significant, *ps* = .34 and .51.

Discussion

These data clearly show that there is no substantial difference in the perception of feature spacings based on face inversion or contrast-negation. Therefore, Experiment 2A successfully replicated the results from Experiment 1. In addition, Experiment 2A also replicated the trend for discriminability to decrease as compression increased.

These results suggest that differences in the sensitivity of horizontal and vertical information to inversion cannot account for the failed inversion effect in Experiment 1. Instead, humans are capable of selectively attending to spacing information in both face orientations. Thus, the hypothesis that inversion impedes the perception of spacing information is incorrect. Instead, our results support the theory that inversion causes a shift from holistic to part-based processing. This can be understood if the nature of the task leads participants to treat spacing information like a part, in effect, causing each face to be processed like an object. If part-based processing is beneficial to our geometrical face discrimination task, then the upright face discrimination task may induce a voluntary shift from holistic to part-based processing.

However, given the counterintuitive nature of the current results and their failure to conform to previous findings supporting an effect of inversion on face discrimination (Goffaux & Rossion, 2007; Searcy & Bartlett, 1996), replication is necessary. Therefore, Experiment 2B seeks to replicate the results of Experiment 2A in the context of a slightly different task: categorization.

Experiment 2B

Experiment 2B considers the effect of inversion on face categorization. We propose that upright faces are naturally categorized, but inverted faces may not be accommodated by the upright face categories. Accordingly in Experiment 2B, subjects were asked to categorize faces by judging each as elongated or compressed. If inverted or contrast-negated faces are not categorized like upright faces, then sensitivity to compression and elongation at the category boundary should then be high for upright faces and low for inverted and contrast-negated faces.

Method

Participants and Stimuli. These were the same as in Experiment 2A. In addition, a mask was created by randomizing the pixels in the average male Caucasian face to avoid discontinuities in average lightness and contrast and then placing it in a black oval frame.

Design. Each of 22 face identities could be presented in either a compressed or elongated form. For each face presented, subjects categorized the face as elongated or compressed. No identity appeared in two trials in a row. Categorization trials were blocked by face type.

Procedure. Each trial began with a beep, followed by a 500ms mask. Then the mask was removed, and participants viewed the to-be-categorized face. If the face appeared elongated, the participant depressed the left arrow key, and if it appeared compressed, the participant depressed the right arrow key. Choice response terminated the trial. No feedback was provided. There were 123 categorization trials.

Data analysis. Categorization data for each condition were aggregated across participants and assessed using `psignifit` version 2.5.6 (Wichmann & Hill, 2001) in Matlab 7.3. The psychometric fits for each condition produced estimates of the distortion level that was perceived as elongated 50% of the time, as well as the slope and the 95% confidence interval of the slope at the threshold distortion level. This slope represents the pooled sensitivity to differences in vertical configuration. It is the amount of increase in elongation necessary to elicit a perceptible change in elongation. If that sensitivity is high, then the slope should be large, but if the participants were relatively insensitive to small deviations in vertical spacing, then the slope should be small.

Results

Ability to categorize did not vary substantially with face type. The 95% confidence intervals for upright (slope = .015, 95% C. I. = .0013), inverted (slope = .013, 95% C. I. = .0011), and contrast-negated (slope = .015, 95% C. I. = .0014) face categorization all overlapped indicating that sensitivity to variations in elongation did not vary with contrast-negation or inversion. The slopes and 95% confidence intervals for each face type are displayed in Figure 5.

Discussion

Once again, we failed to find an effect of inversion. These categorization results lend additional support to our conclusions from the discrimination data in Experiment 2A, in which we suggested that participants can and do shift from holistic to part-based processing to meet the demands of the task with upright faces. Here selectively attending to the relevant face parts facilitated the categorization of the upright, inverted, and contrast-negated faces.

As mentioned in the introduction, both face perception and face discrimination differ from recognition in that there is no identity matching. Notably, this identity-matching task also involves a memory component. Therefore, an alternative possibility is that the face inversion effect for recognition results from a memory impairment or difficulties accessing the stored information, rather than a perceptual impairment. An overtaxing of the mechanisms involved in mental rotation could inhibit the ability to store spatial relations in long-term memory, causing them to become lost. If true, then the discrimination and categorization tasks employed in Experiments 2A and B would not detect an inversion effect. Therefore, Experiment 3 tests discriminability when the reference and comparison faces are separated by a delay. This manipulation forces participants to consult a stored representation of the reference face.

Experiment 3

Experiment 3 tested whether the face inversion effect originates from memory limitations by presenting participants with sequential reference and comparison faces, separated by delays of 0 s, 250 ms, and 5 s. Participants made judgments of relative compression and elongation between the reference face and the comparison face. This allowed us to assess the time course of the impairment and whether it occurred at the iconic store, short-term store, or long-term store (Baddeley, 1997). In addition, we measured response times (Robertson & Palmer, 1983). These are of interest because if subjects use different processing strategies for inverted and erect faces, this could lead to a difference in response time. In the case of erect faces, global precedence (Navon, 1977) predicts that the global information such as facial feature arrangement will be processed more quickly than its parts. However, Tanaka and Farah (1993) demonstrated that inverted faces cannot be mentally rotated in a holistic fashion; therefore global precedence does not apply. Instead, perception centers on the local information such as facial features rather than the overall facial impression. Indeed this is also supported by observations on word perception. Response times in a lexical decision task for longer words are more affected by large degrees of rotation than shorter words, suggesting that inversion of complex stimuli results in a part-based rather than holistic processing strategy (Koriat & Joel, 1985). Therefore two possibilities arise: 1. If, as we suggest, the geometrical face discrimination task presented in Experiments 1 and 2A benefits from part-based comparisons, then inverted face RTs should be faster than erect face RTs with no differences in accuracy. 2. Contrary to this, Tanaka and Farah (1993) showed that holistic perception facilitates accurate recognition of face parts. However, as discussed previously effects in face recognition do not always apply to perception. If holistic processing does benefit part perception, then it is plausible that subjects choose to give more prolonged scrutiny to the inverted faces to compensate for the benefits of the missing holistic representation, and achieve comparable error rates with inverted faces by sacrificing speed to maintain accuracy. This would produce longer RTs for inverted faces.

Method

Participants. Participants included 20 undergraduates or members of the University of California, San Diego community. Community members participated in exchange for $10 an hour and undergraduates received course credit. Vision in all participants was normal or corrected to normal.

Stimuli. The stimuli were the same as in Experiments 2A and B, except there were no contrast-negated faces. In addition, we subjected the mask from Experiment 2B to a Gaussian blur. This eliminated the presence of lines that could be used as a reference during the delay period.

Design. The reference and comparison faces were separated by a delay of 0 s, 250 ms, or 5 s. There were two sessions for this experiment. In each session, faces were presented in one orientation – either upright or inverted. The order of face orientation was counterbalanced between subjects. Trials were blocked by delay, and the order of the delays and reference faces were randomized. Each session was separated by at least one day.

Procedure. Participants heard a beep, and then viewed a 150 ms fixation, followed by a 1 s reference face. Then the reference face disappeared, and participants viewed a mask for either 0 s (no mask), 250 ms, or 5 s. Following this was a comparison face that remained on display until the participant indicated whether it was more compressed or elongated than the reference face. Participants did this by depressing either the left arrow key or the right arrow key on the computer keyboard. Choice response terminated the trial. There was no feedback.

At the end of each block, participants were offered a break. There were 250 trials per block and 750 trials per session.

Data analysis. Response data for each participant were analyzed separately for each combination of variables using Functional Adaptive Sequential Testing (FAST) designed by Vul & MacLeod (in prep). Using the individual subject data as a basis for its simulations, FAST identified the parameters of the logistic psychometric function, in particular the threshold parameter, for which the probability of the data was maximized. The threshold was the inter-quartile range expressed in distortion steps.

To improve the normalcy of the distribution of data, we dealt with the log of the individual discrimination thresholds. These were subjected to a 2 x 3 x 5 within subjects ANOVA with inversion, delay, and reference distortion as repeated measures factors.

Response data were also combined across participants and analyzed using FAST (Vul & MacLeod, in prep). By computing this for each condition and collapsing data across conditions, we obtained probabilities and consensus discrimination thresholds for models in which inversion, delay time, and reference distortion were and were not factors. Combining the data across participants reduced the impact of outlying individuals on the results and produced a model representative of the population. The effects of inversion and delay on the consensus discrimination thresholds were then assessed using t-tests.

Response times were analyzed for each participant to determine the presence of outliers. Any RTs beyond two standard deviations away from the mean of that participant's data were excluded as outliers. The remaining RTs were averaged for each participant to provide values for each combination of inversion, delay, and reference distortion. To improve the normalcy of the distribution of RTs, we analyzed the log of the RT data using a 2 x 3 x 5 repeated measures ANOVA with inversion, delay, and reference distortion as repeated measures factors.

Results

Based on the discrimination thresholds obtained from individual subjects, discriminability was unaffected by face inversion. The effect of inversion and the delay by inversion interaction were both non-significant, $ps > .05$. Delay, reference distortion, and all remaining interactions also failed to produce significant variation in discriminability, $ps > .05$, indicating that the face inversion effect does not result from memory limitations.

The consensus data further supported these results. Although the model of the consensus data that included inversion as a factor was naturally more probable than the model without inversion, inversion did not significantly affect discrimination, t (14) = 0.90, $p = .38$. Delay length also did not affect discriminability, although there was a trend for worse discrimination after a 5 s delay compared to a 250 ms delay, t (9) = 2.13, $p = .051$. Critically, there was no evidence of an interaction between delay and inversion on face discrimination (see Figure 6A). Therefore, the face inversion effect cannot depend on the length of memory storage.

Examination of response times likewise revealed no evidence that inversion affects ability to perceive differences in center-compression or center-expansion, $p = .33$.

This gives no support for the suggestion that subjects preserve accuracy for inverted faces by making a speed/accuracy tradeoff.

Nor was there any superiority in performance for natural faces: Overall, participants responded fastest to the maximally compressed reference faces and significantly *slower* with the midrange reference faces, following a quadratic trend, F (1, 9) = 7.88, p = .011. This is further supported by a significant effect of reference distortion on response time, F (4, 76) = 3.57, p = .01. Participants' response times varied with delay, F (2, 38) = 45.8, p < .001. Bonferroni comparisons indicated that participants took longer to respond after a 5 s delay compared to a 0 s or 250 ms delay, *ps* < .001.

If natural faces are processed more efficiently, we might expect an interaction between inversion and level of reference distortion in reaction time. This interaction was indeed significant, and it is displayed in Figure 6B, F (4, 76) = 2.94, p = .026. But the polarity of the interaction is quite unexpected, in that natural erect faces are the most slowly processed. On this evidence natural faces are processed not more, but less efficiently.

Discussion

Although delay and inversion did not mediate discrimination thresholds, they did affect response time. The longer discrimination times observed with the five-second delay likely reflect the extra time needed to retrieve the memory of the reference face from long-term storage. More importantly, there was no interaction between delay and inversion. If face inversion affected the ability to place spacing information into long-term store, then the response times with a 5 s delay should have been longer for inverted faces compared to upright faces. This was not the case. Therefore, the face inversion effect for recognition cannot result from an inability to store spacing information.

For undistorted or only moderately distorted faces, participants were able to make swifter discriminations when the faces were inverted rather than upright. This reflects greater efficiency for discrimination between inverted faces with natural feature arrangements, a result that is contrary to the traditional face inversion effect.

As mentioned in the introduction, it has been suggested that inversion can induce part-based analysis (Goffaux & Rossion, 2006; Hole et al., 1999). In the discussion of Experiment 2A, it seemed that the geometrical discrimination task induced subjects to shift from holistic processing to part-based processing. The reverse inversion effect observed here supports these suggestions. If inversion causes part-based processing, then participants would not need to force a shift in mental strategy. Upright faces, however, require holistic processing and therefore the participant must voluntarily initiate a shift to part-based processing. The time it takes to make this shift could be a function of how "face-like" the stimulus is, which could explain the longer response times for natural upright faces.

General Discussion

Key results

In three experiments, we demonstrated that the face inversion effect cannot be due to an inability to perceive spatial configuration in inverted faces. Experiment 1 showed that discrimination of differences in horizontal spacing does not vary with face inversion or contrast-negation. Similarly, Experiments 2A and 2B demonstrated that face inversion (and contrast-negation) do not affect the discrimination of differences in vertical spacing.

However, in both Experiments 1 and 2A participants made simultaneous comparisons, whereas the face inversion effect observed in recognition involves comparison to a memory trace. Although Experiment 2B involved comparison to an internal standard, this is not the same as comparing the face to a memory trace. Therefore, Experiment 3 assessed the effect of memory on discrimination. Here again inversion failed to affect the amount of change necessary to perceive a difference in vertical spacing, no matter what the delay.

The lack of an inversion effect was accompanied by an 'inverted inversion effect' in reaction times. In Experiment 3, inversion did alter the speed with which participants made their judgments, but in a surprising direction: discrimination was more efficient between natural faces when the faces were inverted rather than upright. This is the opposite of the traditional face inversion effect.

Dissociation between Discrimination and Recognition

The most straightforward interpretation of the discrimination thresholds is that the process of discrimination is the same, and goes on with similar precision whether applied to an erect or an inverted face. This would pose no theoretical problem by itself, but it creates a problem for the explanation of the inversion effect: how can we account for the dissociation between recognition, which shows an inversion effect, and discrimination, which shows none?

The inversion effect in recognition is hardly surprising in itself, given that face cells in the visual system are strongly activated by erect faces, but are activated relatively poorly by inverted ones (Kanwisher, Tong & Nakayama, 1998; Rossion & Gauthier, 2002). It is a direct consequence of this reduced activation (with the associated reduction in signal to noise ratio) that the neural representations will not distinguish between inverted faces as well as between erect ones.

The lack of an inversion effect in our experiments on the detection and discrimination of distortion can also be easily understood, if these judgments depend on processes distinct from those involved in recognition. Once the corresponding features of two face images are identified, their separations might be compared using processes that are not in any way specific to face perception, and do not depend on any impression of the face as a whole. The neural representation of a face as such need not be implicated in the discrimination of the arrangement of its parts.

But if so, a problem remains: How do the face cells acquire their selectivity, and why is it inversion dependent if sensitivity to the spatial arrangement of the features is not? Clearly face recognition must depend strongly on spatial aspects of the image in a broad sense (as well as on completely non-spatial cues such as eye and hair color), and it is natural to assume that the effect of inversion is due to an impaired representation of the spatial aspects of the face.

Information about spatial arrangement may be processed in quite distinct ways in the service of recognition and discrimination. Discrimination experiments isolate a single dimension of variation, yet faces can be characterized along a huge number of dimensions that may support recognition through complex configuration-dependent computations, a so-called ‘holistic’ mode of processing.

For recognition, precise specification along any individual dimension may be unnecessary—or even undesirable, given the need to accommodate variation in viewpoint. Such configuration-dependent processing, if adapted to the processing of erect faces, would naturally be impaired by inversion. The demands of the discrimination task are very different and much simpler, since the single relevant dimension can in principle be isolated by selective attention.

Attentional selection can enhance the salience of the relevant stimuli (Shepard, 1964) and allow finer discrimination than when selective attention is not deployed (Palmer, 1990). But the fine discriminations made possible when an attribute is effectively isolated by selective attention are not generally available in face recognition tasks, where the potentially relevant dimensions are not known in advance and there is no time to focus attention on them all in turn.

In this view, the lack of the inversion effect in well-defined discrimination tasks creates no paradox: on the contrary, it is expected if selective attention isolates the relevant dimension effectively from its configural context. In recognition tasks, the small differences that can be revealed by selective attention to either erect or inverted faces are not available, and may have little or no relevance for recognition, except in situations like our own where the sole relevant distinction is defined for the observer in advance.

This interpretation requires us to distinguish between different varieties of spatial analysis in the perception of faces: the orientation-dependent pre-attentive processing on which recognition depends, and the focused extraction of well-defined aspects of spatial arrangement. These could be identified with what we previously termed ‘holistic’ and ‘part-based’ processing respectively.

The orientation-dependent processing has been experimentally and theoretically considered within a template framework: upright and inverted face templates differ substantially in the amount of information represented (Sekuler, Gaspar, Gold & Bennett, 2004; Valentine, 1991). One notable finding is that the regions of the face template critical for recognition or identification remain the same for both upright and inverted faces, but the amount of information gleaned from these regions is substantially less with the inverted faces (Sekuler et al., 2004). An upright face template represents all physiognomic features used to encode a face (Valentine, 1991) An inverted face template, on the other hand, contains this same information but in a less precise, sparse representation. This reduced amount of available information could diminish face recognition. Some recent studies have reported equal effects of inversion on features and configuration (Riesenhuber, Jarudi, Gilad & Sinha, 2004; Yovel & Kanwisher, 2004). This supports a quantitative rather than qualitative difference between upright and inverted face perception.

The inverted inversion effect in reaction time

Assuming that upright faces automatically engage holistic processing, the disadvantage in response times observed for upright natural face discrimination may reflect the time needed to make a voluntary shift in processing strategy. If inverted faces were automatically processed in a part-based fashion, then there would be no need to shift strategies and no increase in response time.

This would not be the first report of upright faces being automatically processed in a “face-specific”, i.e. holistic, manner. In the case of prosopagnosic patient L. H. described by Farah (1996), L. H. failed to produce the standard face inversion effect. Instead, inverted face recognition was superior to upright face recognition. Therefore, recognition of upright faces must have involved a damaged “face-specific” region of the brain while inverted face recognition relied on a separate area of the brain that was still intact. Similar to the current results, this implies that the "face-specific" region of the brain was automatically engaged despite the fact that it was maladaptive.

Rock (1974) suggests that erect faces are recognized efficiently through a holistic process that can not be engaged for processing inverted faces. Our RT results take this further by demonstrating that not only does inverted face perception fail to engage holistic processing, but also there is no initial attempt to engage in holistic processing. Therefore, the face inversion effect with recognition results from the brain circumventing holistic processing with the inverted face and delving directly into a part-based approach. This represents a strong qualitative difference in the perception of upright and inverted faces. Given the biological importance of faces, it is beneficial for a high-level task such as face perception to be immune to task demands.

Conclusions

Geometrical face discrimination and categorization are unaffected by inversion. Thus the face inversion effect does not result from a general inability to perceive spacing information in the face. Rather, it must result from an impairment in face-specific processing of information about spatial arrangement, a specific process that is more efficient for erect faces, and automatically evoked by their presentation.

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Table 2.1. Horizontal Discrimination Thresholds in Experiment 1

	Reference face									
	Highly Expanded		Slightly Expanded		Original		Slightly Compressed		Highly Compressed	
Face Type	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Upright	12	3.7	14	4.5	17	7.9	21	9.6	22	8.5
Inverted	15	5.4	15	5.6	18	7.1	22	10	23	6.4
Contrast-Negated	17	4.9	18	6.4	23	8.1	23	9.7	23	12

Note: Thresholds represent the shift in distortion level necessary to perceive a just-noticeable difference in compression or expansion, $n = 9$.

Table 2.2. Vertical Discrimination Thresholds in Experiment 2A

Elongated Judgments Before Compressed Judgments

	Reference Face									
	Highly Elongated		Slightly Elongated		Original		Slightly Compressed		Highly Compressed	
Face Type	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Upright	10.80	5.52	11.65	5.95	13.61	7.23	16.79	9.15	16.43	11.37
Inverted	11.23	5.81	12.54	5.81	12.26	8.26	14.60	8.09	19.84	9.44
Contrast-Negated	10.72	6.14	12.45	5.58	13.51	7.08	15.87	8.08	18.97	10.98

Compressed Judgments Before Elongated Judgments

	Reference face									
	Highly Elongated		Slightly Elongated		Original		Slightly Compressed		Highly Compressed	
Face Type	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Upright	12.88	7.80	16.00	8.62	20.09	10.67	22.34	12.63	25.58	11.83
Inverted	15.74	10.02	17.46	10.92	19.47	12.03	22.07	10.50	24.98	14.23
Contrast-Negated	14.50	8.45	17.17	8.50	20.58	9.95	23.50	10.49	27.05	12.11

Note: Thresholds represent the number of distortion levels between just-noticeably elongated and just-noticeably compressed faces, $n = 46$.

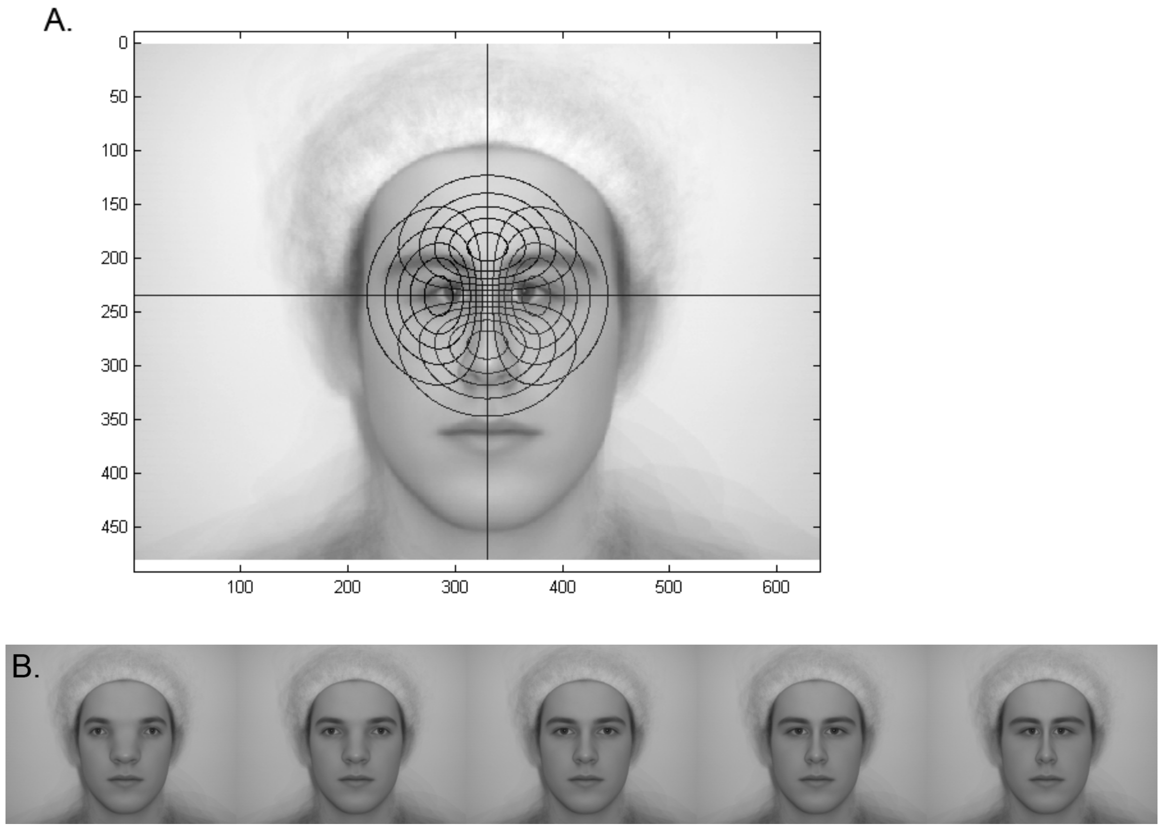


Figure 2.1. A. The contour of displacement followed by the morphing algorithm. B. Reference faces produced by the morphing algorithm described in Experiment 1.

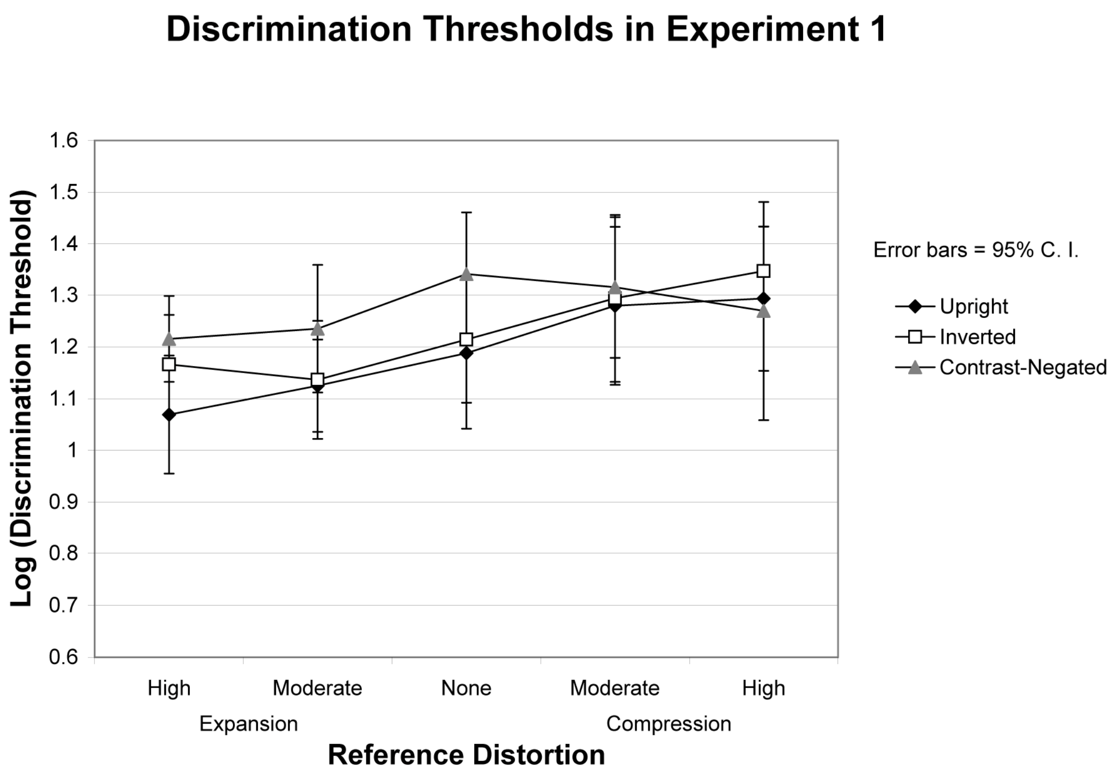


Figure 2.2. Log discrimination thresholds in Experiment 1. Smaller thresholds indicate better discrimination of horizontal spacing change. Error bars represent the 95% confidence interval, $n = 9$. Upright face discrimination (diamonds), inverted face discrimination (squares), and contrast-negated face discrimination (triangles).

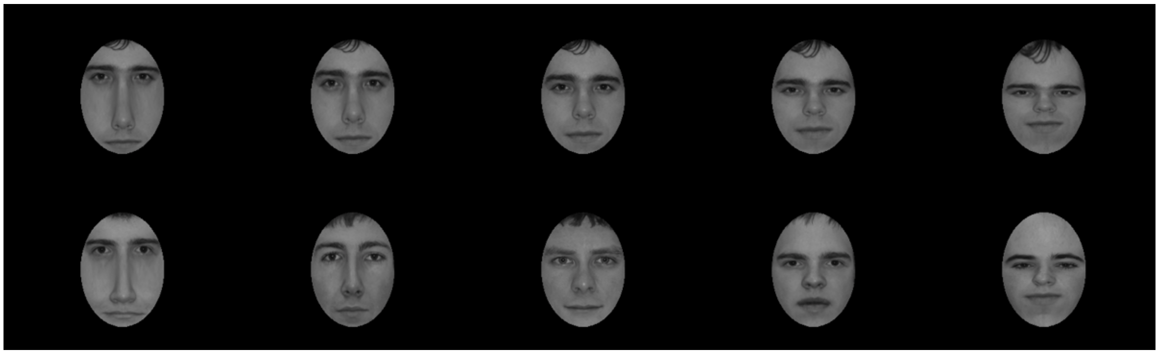


Figure 2.3. Upright reference faces (top) and distortion continuum matches (bottom) in Experiment 2A.

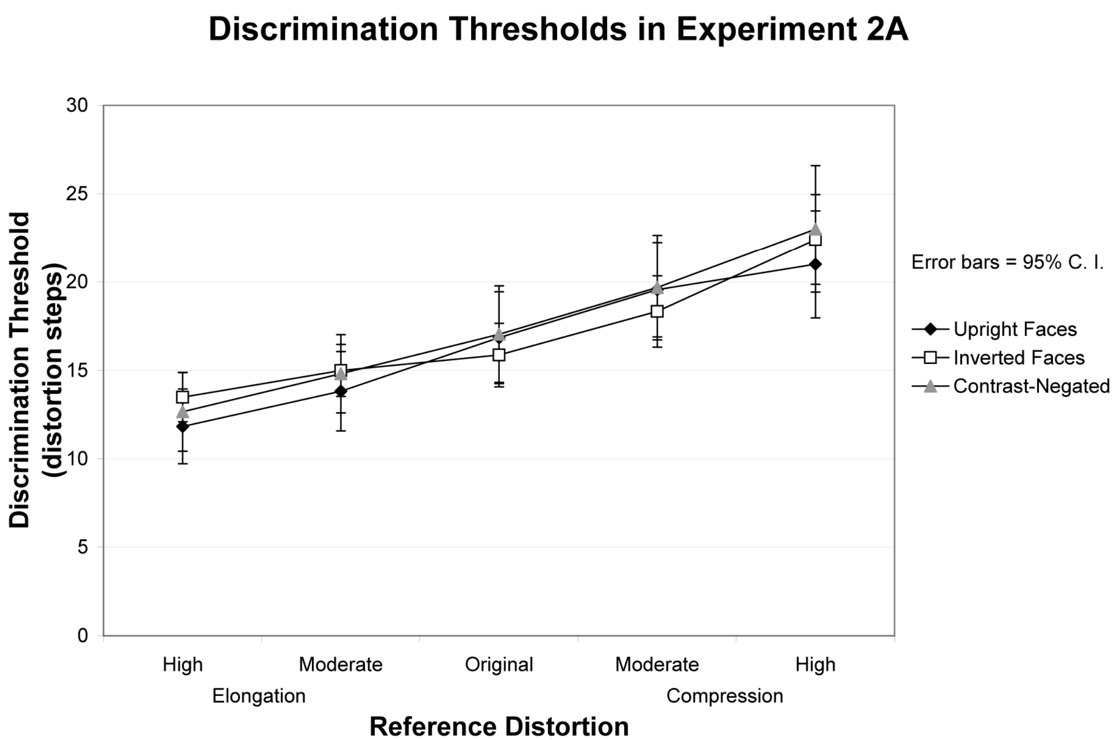


Figure 2.4. Discrimination results for Experiment 2A. Smaller thresholds indicate better discrimination of vertical spacing change. Error bars represent the 95% confidence interval, *n* = 46. Upright face discrimination (diamonds), inverted face discrimination (squares), and contrast-negated face discrimination (triangles).

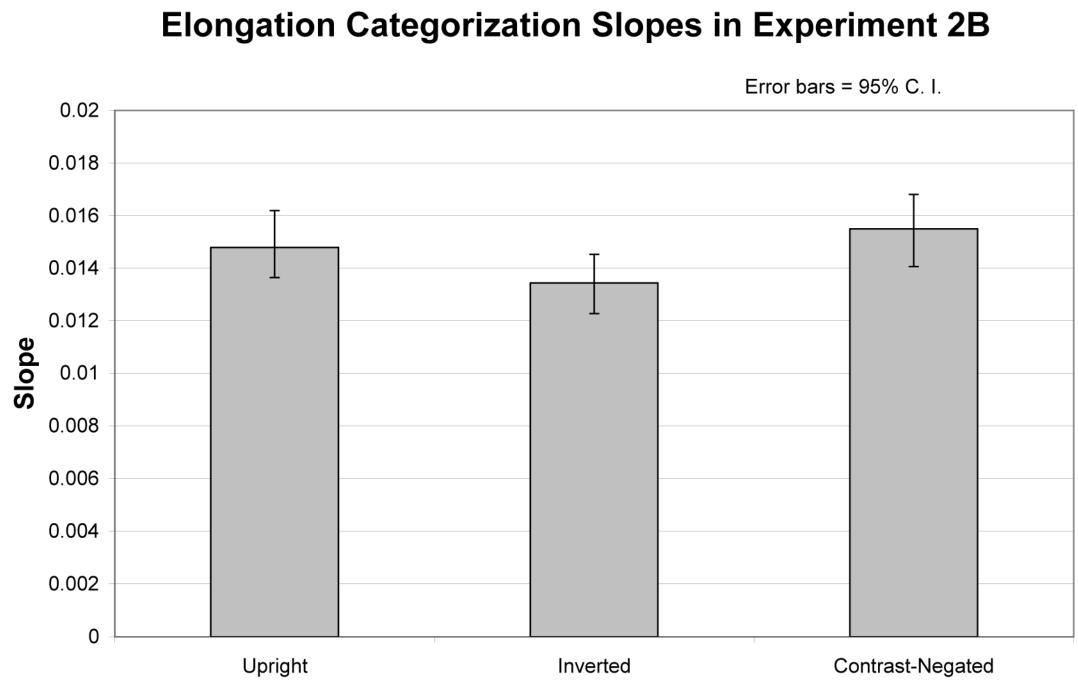
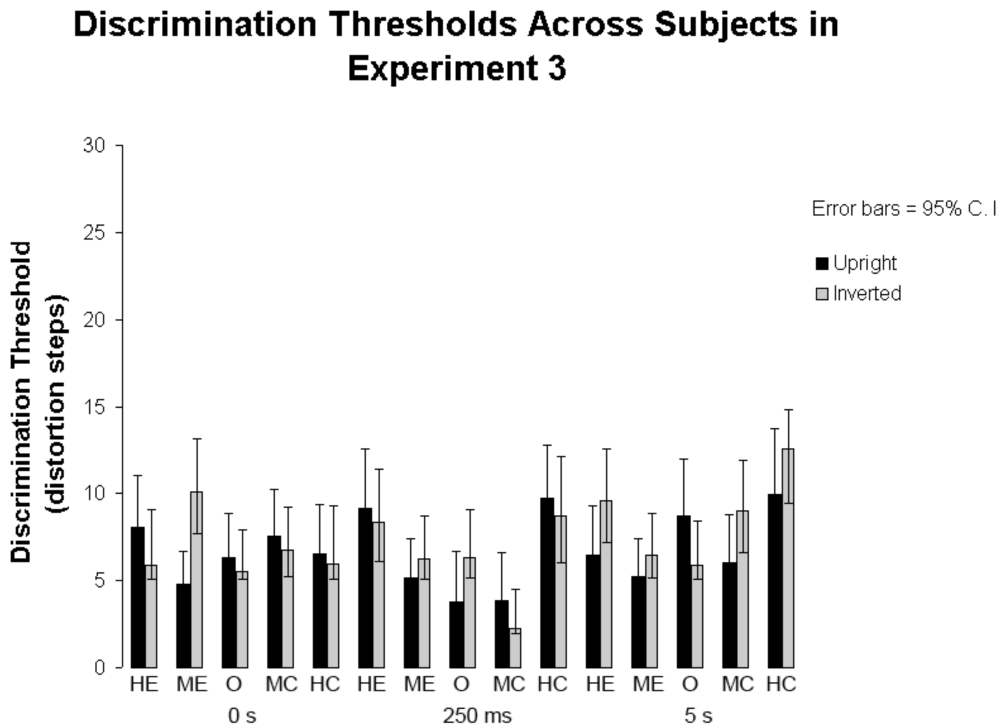


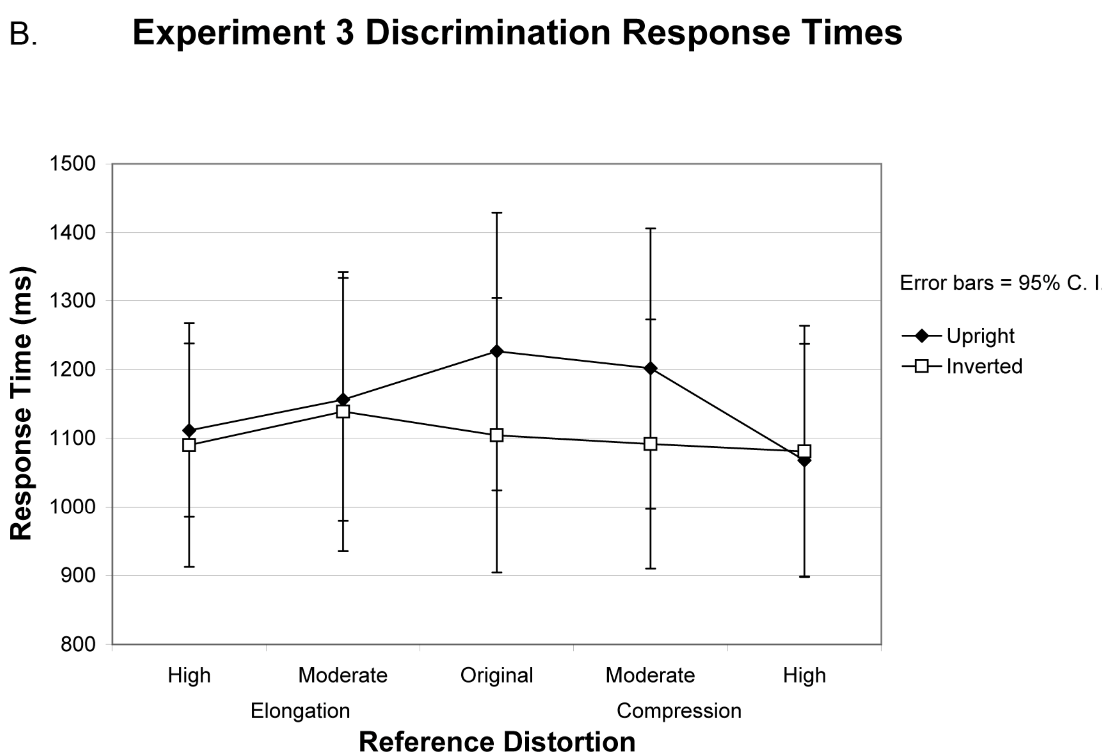
Figure 2.5. Slopes and 95% confidence interval for categorization in Experiment 2B, n = 46. Steep slopes represent strong discriminability.

Figure 2.6. Experiment 3 discrimination results, *n* = 20. HE = highly elongated reference, ME = moderately elongated reference, O = original undistorted reference, MC = moderately compressed reference, and HC = highly compressed reference. A. Discrimination thresholds determined by FAST for the pooled subject data. B. Average response times when discriminating between geometrically distorted upright and inverted faces. Upright face discrimination (diamonds), inverted face discrimination (squares).

A.


Discrimination Thresholds Across Subjects in Experiment 3
Discrimination Threshold (distortion steps)
30
25
20
15
10
5
0
Error bars = 95% C. I.
Upright
Inverted
HE ME O MC HC HE ME O MC HC HE ME O MC HC
0 s
250 ms
5 s

B.


Experiment 3 Discrimination Response Times
Response Time (ms)
1500
1400
1300
1200
1100
1000
900
800
Error bars = 95% C. I.
Upright
Inverted
High
Moderate
Original
Moderate
High
Elongation
Compression
Reference Distortion

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Chapter 3

When do Face Discrimination and Adaptation Involve Face-Specific Processes?

Face recognition is distinct from object recognition both behaviorally and neuronally, with a clear benefit for face recognition. It is uncertain whether this difference reflects a special preference for representing faces or if it results from years of experience with faces. Here we examine this question by assessing whether there is a benefit for natural versus unnatural face discrimination. In addition, we investigated how discrimination is influenced by adaptation to a distorted face. Experiments 1 and 2 investigated whether the discrimination of differences in intraocular distance, a non-face-specific property, displays a benefit for natural faces. This was assessed both with and without adaptation to a center-compressed face. Experiment 3 used these same distortions to measure the effect of adaptation on discrimination of differences in a face-specific property: typicality. Experiments 4 and 5 determined whether there is a benefit to discriminating around natural male and female faces and examined how adapting to a male face affects discrimination. Results suggest that discrimination is best for natural faces when the discrimination task focuses on a face-specific property, whereas the discrimination of non-face-specific properties conforms to Weber's Law. Similarly, adaptation affects discrimination only when it involves a face-specific property.

Recognition of erect faces is better than that of erect objects, yet inversion disproportionately impairs the recognition of faces compared to objects (Yin, 1969). This effect represents a fundamental difference between the processing of faces and objects. The primary source of this difference lies in the use of spatial information. With faces, the availability of spatial information with regard to feature placement is absolutely critical for recognition (Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; for a review, see Rossion & Gauthier, 2002). The same is not true with objects (e.g. Tanaka & Sengco, 1997).

The differences between object and face recognition are also supported by differences observed in brain lesion patients. Patients suffering from prosopagnosia have a selective inability to recognize faces, whereas patients with object agnosia are selectively incapable of recognizing objects (Whiteley & Warrington, 1977). This suggests a dissociation between the neurons dedicated to faces and objects. Moreover, evidence from a case study of prosopagnosic patient, L. H., demonstrated that inverted face recognition uses the intact object-specific areas of the brain, while upright face recognition relies upon the damaged "face-specific" region of the brain (Farah, 1996)

Neurophysiological studies with fMRI have since isolated a face-selective region of the brain called the fusiform face area. This is in contrast to the parahippocampal gyrus, which responds selectively to objects (Kanwisher, Tong, & Nakayama, 1998; Rossion & Gauthier, 2002). When responses to inverted faces are investigated in these areas, however, the picture becomes somewhat marred. Unlike the results from patient L. H., inverted faces do not selectively trigger a response in the object area of the brain. Rather, both face and object regions respond to inverted faces. In the FFA, activation is stronger for upright faces than inverted faces, but activation for inverted faces is also stronger than the activation for objects (Kanwisher et al., 1998; Rossion & Gauthier, 2002). Similarly the PG responds more strongly to objects than upright faces, but it also shows preferential activation for inverted faces compared to upright faces, although at no time was the response to inverted faces as strong as the response to objects (Rossion & Gauthier, 2002). Therefore, the dissociation between object and face recognition observed between prosopagnosic and object agnosic patients is not clear-cut.

This dissociation becomes still more muddled with the recognition of objects of expertise. Objects of expertise may exhibit several of the hallmarks of face perception and recognition including an inversion effect, although these characteristics are often muted (Diamond & Carey, 1986; Gauthier & Tarr, 1997, 2002). Objects of expertise may also trigger greater activation in face-selective regions of the brain compared to object-selective regions (Gauthier, Skudlarski, Gore, & Anderson, 2000; Gauthier & Tarr, 2002), though activation is greatest for faces in the face-selective regions (for a review see, McKone & Kanwisher, 2005). Therefore, it seems that the amount of neuronal response in each location depends upon the degree to which the object relies upon facial processing mechanisms, although no conclusion is yet agreed upon (Gauthier & Bukach, 2007; McKone & Robbins, 2007; Robbins & McKone, 2007).

Although the special nature of face processing has been intensively investigated using brain imaging, few behavioral studies examine whether basic visual principles apply to face perception, and those that do focus mostly on adaptation. Adaptation is a psychophysical method designed to elucidate the neuronal coding underlying human behavior. In objects, adaptation to a blurred image causes the original image to appear sharper, and the same occurs with faces (Webster, Werner, & Field, 2005). Similarly, adaptation to a face with the green and blue channels removed (i.e. red only) causes a full-spectrum face to appear more green. Moreover, the transfer of an aftereffect from adaptation to a face-specific property are weakly selective for the size, contrast, and color of the image, and strongly selective for contrast polarity and spatial frequency (Yamashita, Hardy, De Valois, & Webster, 2005). These results suggest that there are elements of face perception common to object perception and that face perception is not completely divorced from basic visual principles.

Adaptation studies also provide insight into the brain's representation of face-specific properties such as race or gender. For example, adapting to a compressed face causes an undistorted face to appear bloated. Likewise, adapting to a bloated face causes an undistorted face to appear compressed (Rhodes, Jeffery, Watson, Clifford, & Nakayama, 2003; Webster & MacLin, 1999). Moreover, Rhodes et al. (2003) demonstrated that the perception of normality will also shift with adaptation to a distorted face. These results suggest that face configuration is encoded relative to standard, and that standard is likely represented by the population average. When adaptation occurs, the face representations are normalized around a new average – one that is influenced by the adapting distortion. Therefore, the adapting distortion appears undistorted or normal, i.e. average.

Similar effects are documented for emotion, gender, race (Webster, Kaping, Mizokami, & Duhamel, 2004),and identity (Leopold, O'Toole, Vetter, & Blanz, 2001), indicating that each of these dimensions are defined relative to an average face representation. In the case of identity, adapting to Donald renormalizes the representations of identity around Donald. Therefore, the average face is perceived as the perceptual opposite of Donald or anti-Donald (Leopold et al., 2001). This shift in perception suggests that the neurons coding for face identity do so in an opponent-based manner. However, such encoding is not unique to faces - color also relies on opponent-based processing. Therefore we ask, to what extent are faces special?

Here we aim to determine whether faces are special by assessing participants' abilities to discriminate differences in faces. These results are then evaluated for compliance with Weber's law. Following this, we also examine whether adaptation affects discrimination. Given that adaptation serves a functional purpose to maintain a constant environment, it is worthwhile to investigate whether it also maintains a constant level of discrimination. In other words, can adaptation to a particular form of distortion improve our capacity to discriminate among faces that are more or less similarly distorted, just as our capacity to discriminate differences from white shifts with our post-red adaptation perception of white? Except here, instead of using colors, we test this hypothesis with the discrimination differences in faces.

Experiment 1

Here we measured performance in a geometrical discrimination task: detecting differences in intraocular[1] distance within natural and unnatural faces. Observers panned through a set of center-compressed to center-expanded comparison faces, a manipulation that primarily altered the intraocular distance, and selected the face that appeared just

[1] Intraocular distance is defined as the distance between the centers of each pupil.

noticeably more-compressed (JNC) or just noticeably more-expanded (JNE) than a given test face.

According to Weber's Law, just noticeable differences in distance are a constant fraction of the judged distance, rather than constant in absolute terms. A corollary of this is that when the distances between facial landmarks are equal, sensitivity to spacing change should be minimized. This is similar to a bisection task involving the estimation of distance between three linearly placed dots (Westheimer, Crist, Gorski, & Gilbert, 2001), but in the case of faces there are four reference points: the left external contour, the left eye, the right eye, and the right external contour. When the middle dot of a bisection task is equidistant from the two external dots, it lies in a perceptually ambiguous location. Without a nearby reference, estimation of the difference in distance between the external contour and each eye is difficult.

Therefore, if natural faces are privy to a special process that promotes accurate face perception, then discrimination should be better between natural faces and worse between the highly distorted faces. If, however, face perception follows Weber's Law, then the geometrical discrimination task should produce similar results to a bisection with the lowest thresholds for detecting differences when either the eyes are close together or when the eyes approach the external contour. In natural faces the distances between the eyes and external contour are less than the interocular distance. In the following experiment, the center-compressed faces approximate the equal-distance configuration. Therefore, if face perception draws only on general spatial localization mechanisms to which Weber's Law applies, thresholds should be highest for detecting differences between these center-compressed faces.

Method

Participants. Participants included 5 members from the UCSD Vision Laboratory and 6 undergraduate students from University of California, San Diego. The undergraduate students participated in exchange for course credit. Vision in all participants was normal or corrected to normal.

Stimuli. Using the procedure described in (Pallett & MacLeod, submitted), we distorted a photograph of a Caucasian male in Matlab 7.1 by horizontally expanding or contracting relative to a midpoint between the eyes. The amount of pixel displacement was proportional to the horizontal derivative of a circular Gaussian. Therefore, this displacement was maximized at one SD away from the midpoint or 60 pixels. The maximum amount of displacement was approximately 36 pixels. The algorithm also created partial pixel displacements, which allowed fine-tuning of the participant's thresholds.

Using this procedure, we generated 51 faces to form a continuum of 'reference faces' that systematically varied in center-expansion and contraction. Test faces included 5 possible amounts of distortion: expanded by 27.7 pixels (high expansion), expanded by 14.6 pixels (moderate expansion), the original undistorted face, compressed by 14.6 pixels (moderate compression), and compressed by 27.7 pixels (high compression). The initial reference face was selected randomly from faces four and six distortions away from the test face.

In each trial, a test face was presented in the upper left corner of the display and a reference face was in the lower right corner. Stimuli were presented in an offset manner to prevent the use of low-level visual cues such as edge matching.

Stimuli were viewed on a 51 cm Iiyama HM204DT A CRT-monitor with a gray background. Participants were seated at a distance of 90 cm. Images were 600 x 700 pixels and presented at a resolution of 1200 x 1024 pixels. Each face encompassed 8 x 11.5 degrees visual angle.

Design & Procedure. Participants made a series of JNC and JNE judgments, with the order of each counter-balanced by subject. Each test face was viewed six times for each judgment direction. The presentation of test faces was randomized.

There were 60 trials in the experiment. Each trial commenced with a beep. Participants used a mouse roller ball to adjust the level of distortion in the reference face by panning through an array of center-compressed to center-expanded faces. Participants selected the JNC or JNE face with a single left click. This action ended the trial, and the next trial began automatically. No feedback was provided.

Data analysis. For each participant, we computed the average number of distortions between each test face and its corresponding JNC and JNE selections. This represented the threshold amount of change needed to perceive a difference regardless of direction. We applied a log transformation to the discrimination thresholds and analyzed them using a general linear model with reference distortion as a repeated measure using SPSS 11.0.1.

Results and Discussion

Despite the benefit of faces over objects in a recognition task (e.g. Yin, 1969), natural faces provided no benefit for face discrimination. Instead, discrimination was best between the highly center-expanded faces and became linearly worse with increasing compression, $F(1, 10) = 18$, $p = .002$, as predicted by Weber's Law. This linear trend is represented in Figure 1. There was no significant quadratic trend, $p > .05$, implying that there is no premium in sensitivity for natural faces, and thus that face discrimination and object discrimination use overlapping neural circuitry.

As predicted by Weber's Law, geometrical discrimination should be worst between faces with relatively equal distances between the facial landmarks. In our experiment, the moderately center-compressed and highly center-compressed test faces both approximated this configuration. Therefore, these faces were the most perceptually ambiguous in geometric configuration. Accordingly, they showed the poorest sensitivity to differences in distortion. This is further supported by the substantial effect of test distortion on face discrimination, $F\ (4, 40) = 7.9$, $p < .001$, in which Bonferroni comparisons indicated no significant difference between the discrimination of highly center-compressed and moderately center-compressed faces, $p > .05$.

Experiment 2

Here we explored the effect of adaptation on geometrical face discrimination by comparing discrimination thresholds under undistorted face adaptation with thresholds under center-compressed face adaptation. Experiment 1 showed that discrimination is most difficult when the intraocular distance equals the distance between each eye and the local external contour. This occurred with the center-compressed test faces. Given that adaptation causes a shift in perceived normality toward the adapting distortion (Rhodes et al., 2003), Experiment 2 determines whether this effect extends to a shift in discriminability. Specifically, we tested whether adaptation to a center-compressed face improves discrimination between center-compressed faces.

Method

Participants. Participants included 6 members of the laboratory, 10 University of California, San Diego graduate students, and 6 undergraduates for a total of 22 observers. The graduate students participated in exchange for $10 an hour, undergraduates chose between $10/hr and course credit, and lab members received no compensation. Vision in all but one subject was normal or corrected to normal. The remaining subject was red-green colorblind. Since the stimuli in this experiment were in grayscale, this deficit did not affect the experiment results.

Stimuli. Stimuli were the same as in Experiment 1. The adapting distortions contained either 0 pixels of displacement or 21.8 pixels of center-compression. The test face contained 18.2 pixels of center-compression. Reference faces were determined by one of two interleaved staircases and started matching the test face. Each staircase contained a 4:1 step size that tracked the 20% and 80% more-compressed points. Tracking these percentages, rather than 25% and 75%, maximized the efficiency of the staircase procedure. Multiple key presses indicated a greater perceived difference in compression or expansion and multiplied the number of steps taken in the staircase.

All else was the same as in Experiment 1.

Design. Participants indicated which of two faces was more compressed or more expanded: the test face or the reference face. Responses determined the distortion level of the future reference face on the next trial. Each adapting distortion was blocked, with the order of presentation counter-balanced across participants.

Procedure. Each trial commenced with a beep and a 400ms reference face followed by the 400ms test face. These short presentation intervals reduced the likelihood of undesired adaptation. Then a second beep sounded and the adaptation face appeared. While adapting, participants indicated whether the reference face was more center-compressed or more center-expanded than the test face by depressing either the left or right arrow keys. Each key press corresponded with a beep. There was no other feedback. Subjects viewed the adaptation face for at least 4s or until a response was made. After the first block of adaptation, subjects received a break and initiated the second block by depressing the spacebar.

Data analysis. Thresholds for the staircase data were determined for each adapting distortion by fitting the proportion of compressed and expanded responses for each participant to a logistic function. Psychometric functions were fitted using `psignifit` version 2.5.6 (see http://bootstrap-software.org/psignifit/), a software package which implements the maximum-likelihood method described by Wichmann and Hill (2001) and runs in Matlab 7.1. These thresholds represented the amount of displacement necessary to perceive a difference in the configuration of the test face. Threshold estimates underwent a log transformation and were compared a paired sample t-test.

Results and Discussion. Adaptation had no effect on the ability to discriminate differences in center-compression or center-expansion, t (10) = 1.30, $p > .05$. The mean log threshold under undistorted face adaptation was 1.29, S.E. = .04, and the mean log threshold under center-compressed face adaptation was 1.23, S.E. = .06. Therefore, although adaptation causes a center-compressed face to appear more normal, benefits in improved discrimination do not follow. However, it is unknown whether all forms of visual discrimination are immune to adaptation. Although face recognition relies on spatial information, the geometrical discrimination task does not rely on the perception of face-specific properties (Pallett & MacLeod, submitted). Rather, it relies on the physical elements of the stimuli. Therefore, discriminating differences in psychological representations that support recognition may be sensitive to adaptation even though discriminating physical differences is not.

Experiment 3

Experiment 3 tests whether adaptation impacts the discrimination of psychological differences. Typicality is one such difference. Therefore, we examined the effect of adaptation on the discrimination of differences in typicality. First, we obtained the subjective midpoint between a center-expanded face and an average face under normal viewing conditions and again after adaptation to a center-compressed face. Then, we assessed sensitivity to typicality around each midpoint, with and without adaptation.

Method

Participants. Ten undergraduates from the University of California, San Diego participated in exchange for course credit. All participants had normal or corrected to normal vision.

Stimuli. Distinctiveness is defined by the amount of deviation away from an average face (Valentine, 1991). Therefore, we applied the distortions from Experiment 1 to an average Caucasian male face[2] to produce twenty-six center-expanded test faces. The maximum displacement lay 45 pixels away from the midpoint and was approximately

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[2] The average Caucasian male face was created from 32 photographs of Caucasian males using the method described in Levin (2000)

27.3 pixels. The adaptation face contained 27.3 pixels of center compression. In the discrimination tasks, reference faces were determined using the staircase described in Experiment 2.

Depending on the task, faces were either centrally displayed, or a test face was presented in the upper left of the display and a reference face was displayed in the lower right.

Stimuli were displayed on a 51 cm Iiyama HM204DT A CRT-monitor with a gray background. Participants were seated at a distance of 90 cm. Images were 640 x 480 pixels and presented at a resolution of 1200 x 1024 pixels. Each face encompassed 4.7 x 6.6 degrees visual angle.

Design and Procedure. First participants judged the 26 faces as typical or distinctive. Each face was judged four times to improve the accuracy of our 50% typical distortion estimates. This occurred once with adaptation and once without. Adaptation lasted 4 s and occurred before each categorization judgment. Adaptation order was counter-balanced between subjects, and the amount of center-expansion was randomized. Participants indicated their responses by depressing the left or right arrow keys. This action terminated the trial. There were 208 total categorization trials. This resulted in two 50% typical distortion estimates; each served as a test face in the discrimination tasks.

In the no-adapt discrimination task, participants judged which of two simultaneously presented faces was more typical: the test face or reference face. Depressing the left or right arrow key indicated a response and terminated the trial.

The design of the adapt discrimination task was very similar to Experiment 2 with the following exceptions: Participants first adapted for 30 s, and then the trials began. A 200 ms mask appeared between the reference and test faces.

In both discrimination tasks, reference faces were determined using the staircase procedure described in Experiment 2. There were 160 total discrimination trials.

Data analysis. Thresholds were determined using the method described in Experiment 2. We applied a natural log transformation to the data and assessed the effect of adaptation using t-tests.

Results

Adaptation produced the expected shift in perceived typicality with a significant shift in category boundary, t (9) = 3.35, $p < .01$. The mean unadapted category boundary contained 12.8 pixels of center-expansion, S.E. = .82, and the mean adapted category boundary contained 9.3 pixels of center-expansion, S.E. = .82. Adaptation also produced a substantial increase in sensitivity around the adapted category boundary, t (9) = -5.71, $p < .001$, but not the unadapted category boundary, $p > .05$. Discrimination thresholds for the adapted 50% typical distortion decreased by 1.19 log distortion units, S.E. = .21, with adaptation. Whereas the unadapted 50% typical distortion threshold decreased by .30 log distortion units, S.E. = .31. Figure 2 displays this considerable difference in the effect of adaptation on discrimination.

Discussion

Adaptation altered both the perception of typicality and the ability to discriminate differences in typicality. This is in stark contrast to the geometrical discrimination task in

Experiment 2 where adaptation had no effect on discrimination, even though the faces in both experiments contained the same type of horizontal distortion. These results clearly demonstrate that not all visual discrimination tasks are immune to adaptation. Rather, when the task involves a mental comparison the psychological tuning function shifts with adaptation.

Experiment 4

Experiment 1 demonstrated that geometrical face discrimination conforms to Weber's Law. Yet Experiment 3 showed an effect of adaptation on discrimination of psychological differences while Experiment 2 demonstrated no such effect with geometrical discrimination. This suggests dissociation between the discrimination of psychological constructs and physical constructs. Therefore, the discrimination of differences in mental representations may exhibit a benefit for natural faces.

Here we examine whether discrimination of differences in gender is better around natural male and female faces or if it is better around a gender neutral (i.e. 50% male) face. Given the categorical nature of gender perception, only slight changes to a gender neutral face should cause it to appear male or female (Bruce et al., 1993; Campanella, Chrysochoos, & Bruyer, 2001; Wild et al., 2000). If true, discrimination should be best around this face.

Method

Participants. 18 members of the University of California, San Diego community participated in exchange for $10. Vision in all subjects was normal or corrected to normal.

Stimuli. A continuum of 100 gender morph faces were created from one grayscale Caucasian male face and one grayscale Caucasian female face using Abrosoft FantaMorph. Face 1 was 100% female (0% male), and face 100 was 100% male (0% female). Each step along the continuum represented approximately a 1% increase in being male. Therefore, face 25 was approximately 25% male, face 50 was approximately 50% male, and so on. Based on this, the 25%, 40%, 50%, 60%, and 75% male faces were selected as test faces.

Each test face was centered in the left half of the display, and a reference face was centered in the right. All else was the same as in Experiment 3.

Design, Procedure, & Data analysis. Participants selected just noticeably more male and just noticeably more female faces using the method of adjustment described in Experiment 1. The remaining details followed the methods described in Experiment 1 except the discrimination thresholds did not undergo a log transformation.

Results

There was a strong difference in discrimination thresholds depending on the gender of the face displayed, F (1, 17) = 18.46, $p < .001$. The 'just noticeably more female' differences were smaller when the test faces were female and greatest when the test faces were male. This is displayed in Figure 3. The mean percent change necessary to perceive a face as just noticeably more female was 15.06 for the 25% male face, S.E. = 1.54, and 22.94 for the 40% male, S.E. = 1.4, 27.43. Whereas this change was 28.94 for the 60% male face, S.E. = 3.49, and 35.13 for the 75% male face, S.E. = 4.19. The mean necessary change to perceive a difference in the gender neutral face (50% male) was 27.45, S.E. = 2.78.

Similarly, sensitivity to increments in “maleness” was greatest for the more male faces and worse around the more female faces, F (4, 68) = 24.15, $p < .001$. The mean shift in % male needed to perceive a face as just noticeably more male was 14.88 for the 60% male face, S.E. = 2.21, and 11.21 for the 75% male face, S.E. = 1.61. While in the 25% and 40% male faces, this changes was 27.68, S.E. = 4.26, and 20.72, S.E. = 3.56, respectively. For the 50% male face, the mean shift in % male for one JND was 16.20, S.E. = 2.99.

Discussion

Sensitivity was greatest around the natural male and female faces, so long as the desired judgment matched the gender of the test face. Participants could easily detect differences in “femaleness” for the female test faces and differences in “maleness” for the male test faces. There are two possible interpretations of this outcome, but neither fit the data in a clear-cut way.

The first interpretation of this interaction is that it questions the categorical nature of gender perception, but rather suggests some use of a gender continuum. It has been suggested that categorical gender perception is only active in familiar faces (Bülthoff & Newell, 2004). Since the faces used in this experiment started as unfamiliar, this could account for the present results.

The second possible interpretation is that the interaction does support the categorical nature of gender perception. Participants needed to make a female face greater than 50% male before detecting an increase in “maleness” and vice versa for the male faces. In other words, participants needed to cross the category boundary. If gender perception follows a smooth continuum, decreases in femininity should also be perceived as increases in masculinity and vice versa. This was not the case.

Experiment 5

Experiment 5 seeks to replicate the results of Experiment 3 and 4 by assessing the affect of adaptation on gender discrimination. Since this discrimination task involves comparisons along a psychological construct, adaptation should alter discrimination. Here we test the effect of adaptation on gender discrimination. Adaptation to a male face causes a gender neutral face to appear female. If discrimination follows the perceptual shift from adaptation, this should enhance discrimination of “femaleness” in a male face and detract from the discrimination of “maleness”.

Method

Participants. Participants included nine University of California, San Diego undergraduates, 2 male, who completed the experiment in exchange for course credit. Vision in all subjects was normal or corrected to normal, except for one male participant who was red-green colorblind.

Stimuli. From the gender continuum created in Experiment 4, faces were selected in increments of 5% beginning with the 5% male face and ending with the 95% male face to serve as reference faces. Participants made male and female judgments between a 60% male face and a reference face while adapting to either a 75% male face or the 50% male face. Reference faces were determined by the staircase procedure described in Experiment 2.

Design. Adaptation was blocked into 190 trials, and the order of adaptation was counter-balanced across participants. Participants responded to the question “Is the first face more male or more female than the second face?" by depressing either the left or right arrow keys.

Procedure. Each block began with 3 minutes of adaptation, and then the trials began. Each trial commenced with a beep and a 1 s reference face followed by a 1 s test face. Then a second beep sounded and a black screen appeared until the observer indicated whether the reference face was more-male or more-female than the test face. Each response corresponded with a beep, followed by 5 s of top-up adaptation. There was no feedback. Observers received a break before starting the second block of trials.

Data analysis. Thresholds for perceiving a difference in gender were determined using the method described in Experiment 2.

Results

Adaptation affected the discrimination of gender differences. As predicted, adapting to a male face decreased the threshold for a just-noticeable increase in "femaleness", t (8) = 3.00, $p < .05$, and increased the threshold for a just-noticeable increase in "maleness", t (8) = -2.44, $p < .05$. This effect is demonstrated in Figure 4. When adapted to a gender neutral face, participants needed to decrease the male contribution to the reference face by 11.43%, S.E. = 2.19, to perceive it as just noticeably more female. But when participants adapted to the 75% male face, only a 5.91% change was required, S.E. = 1.51. Similarly, when adapted to the gender neutral face, participants needed to increase the male contribution to the reference face by 5.04%, S.E. = 0.66, to perceive it as just noticeably more male. Adaptation to the 75% male face increased the difficulty of this task by decreasing sensitivity to increases in the male contribution to the reference. The threshold shift necessary to perceive a just noticeably more male face when adapted to the 75% male face was 8.10%, S.E. = 1.26.

Discussion

Here we demonstrated a clear effect of adaptation on discrimination. Although gender is determined by physical characteristics, our perception of gender is based upon a psychological construct. As shown in Experiment 3, adaptation affects the discrimination of differences within a psychological construct. Therefore, the observed affects of adaptation on discrimination here are expected. Moreover, the nature of the effect is in keeping with the results for gender discrimination in Experiment 4.

These results are in contrast to a previous study by (Ng, Boynton, & Fine, 2008) that reported a null effect of adaptation on gender discrimination. There are two main methodological differences that may account for these conflicting results. One is that the morph continuum used by Ng et al contained multiple identities. The 50% neutral point on this mixed identity continuum was determined by taking the average of the subjective points of equality for several male to female continuums (e.g. Jane to Joe, Betty to Bob, etc). The second main difference is that adaptation in the paradigm used by Ng et al (2008) involved adapting to multiple identities. Both of these manipulations assume that Jane is just as female as Betty, so that moving 1% toward Joe represents the same shift in gender as a 1% step toward Bob. They also assume that changing identity does not affect the perception of gender.

Here we opted for a simple approach using a continuum that varied from a single female to a single male. This assured that shifting from 25% male to 50% male represented the same distance in the continuum as 50% male to 75% male and avoided any excess noise caused by integrating excess identities.

General Discussion

When does discrimination benefit from natural faces? If the discrimination task involves assessing differences in a face-specific property (e.g. Experiment 4), then discrimination is superior for the natural faces. Otherwise, discrimination does not benefit from natural faces. This is true even when the discrimination task involves comparing variations in spatial arrangement, which is a key component to face recognition (see Introduction, this chapter). Similarly, adaptation will only affect discrimination if the discrimination task is face-specific.

Discrimination and Adaptation of Non-Face-Specific Properties

Although face recognition relies on the accurate perception of spatial information, the task of assessing differences in distances between facial features is not face-specific. Faces are perceived holistically (e.g. Tanaka & Farah, 1993; Young, Hellawell, & Hay, 1987), and when a holistic percept is formed, the features and configuration become an integrated whole (Sergent, 1984). Therefore, the perception of spacing is inseparable from the rest of the face. If a discrimination task relies on isolating these spacings, the task cannot tap into face-specific mechanisms (e.g. Pallett & MacLeod, submitted).

After adaptation to a center-compressed face, an undistorted face appears center-expanded. Therefore if discrimination is best for center-expanded faces, discrimination for the undistorted face should improve after center-compressed face adaptation. It did not. This suggests that despite the impression of an increased distance between the eyes, there is a part of the visual system that is aware of the true intraocular distance and uses this information in the discrimination task. This part of the visual system is also sensitive to the restrictions of Weber's Law.

Adaptation of Face-Specific Properties

Experiment 3 used the same facial distortions as Experiment 2 to assess the affect of adaptation on the discrimination of typicality. Therefore, any differences between the results of Experiments 2 and 3 derive from the different foci of the discrimination tasks. Experiment 3 clearly demonstrated an effect of adaptation on discrimination. Although the physical distortions altered perceived typicality, the results from Experiment 3 imply that typicality is a face-specific attribute whereas the perception of intraocular distance is not. Furthermore, it seems that the ability of adaptation to alter face discrimination is dependent upon the assessment of face-specific attributes.

What does it mean to be a "face-specific" attribute? Prior adaptation results suggest that when adaptation alters face perception, the affected attributes are defined relative to an average face representation (see Introduction, this chapter). Gender and typicality are both prone to adaptation effects and in keeping with this, adaptation impacted the discrimination of differences in typicality and gender. If adaptation truly only affects the discrimination of face-specific attributes, then face adaptation in general may only apply to face-specific attributes. If so, then "face-specific" may be defined as an attribute that refers to an average representation. This predicts that any face-specific trait, such as race or emotion, should exhibit an effect of adaptation on discrimination.

Discrimination of Face-Specific Properties

Although discrimination of differences in intraocular spacing indicated no benefit for natural faces, the discrimination of gender differences showed a strong preference for natural faces. This suggests that discrimination of face-specific properties is superior for natural faces.

Does this mean that faces are special? Not necessarily. Face-specific attributes such as gender and typicality derive form a whole face percept, not individual parts. Similarly, both are defined relative to some average face representation. Therefore, either the formation of holistic percept or reference to an average could produce the preference for natural faces. Although both processes occur predominantly for faces, neither process is necessarily specific to faces. For example, exposure to a series of exemplars from one object category forms an average mental representation (i.e. prototype) for this category (Posner & Keele, 1968) against which new exemplars are compared. Similarly bird experts and car experts may perceive their objects of expertise holistically (see Introduction). Therefore, it is beyond the scope of this article to determine whether faces are special.

Conclusions

There is a benefit for natural faces when discrimination focuses on face-specific properties. Otherwise, discrimination conforms to Weber's Law. Similarly, adaptation only affects the discrimination of face-specific attributes.

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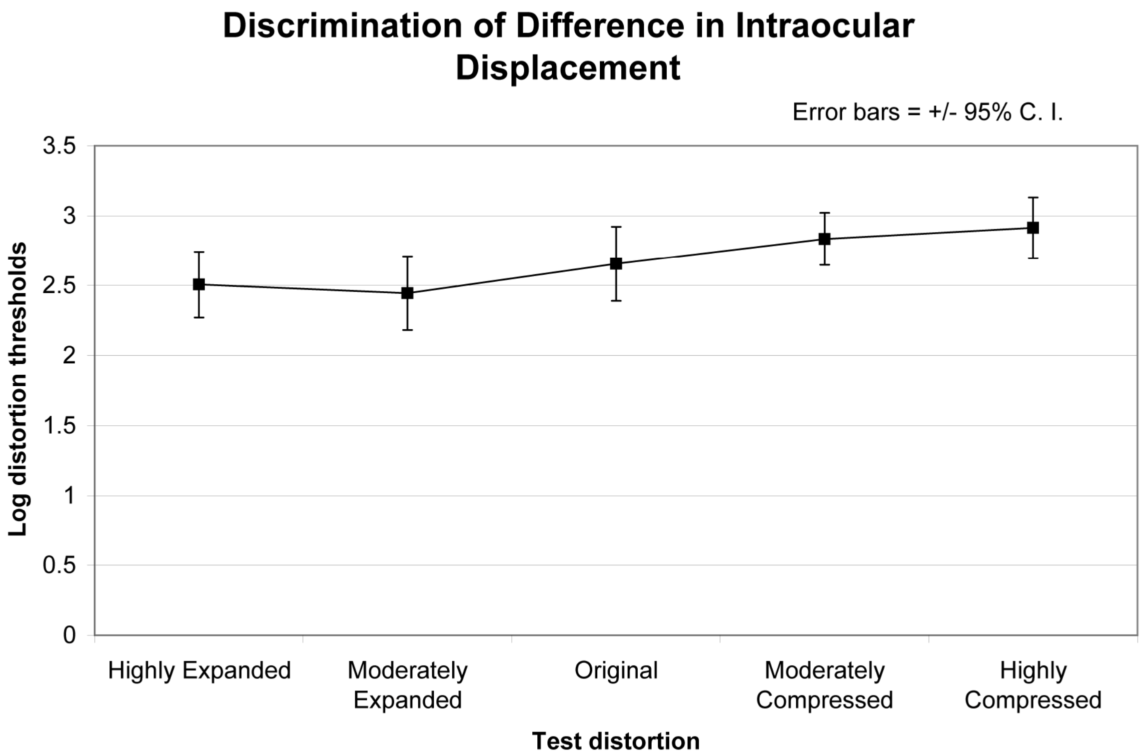

Figure 3.1. Sensitivity to differences in the horizontal displacement of the eyes, $n = 9$. As the test face increased in compression, the necessary amount of change to detect a difference in intraocular distance also increased.

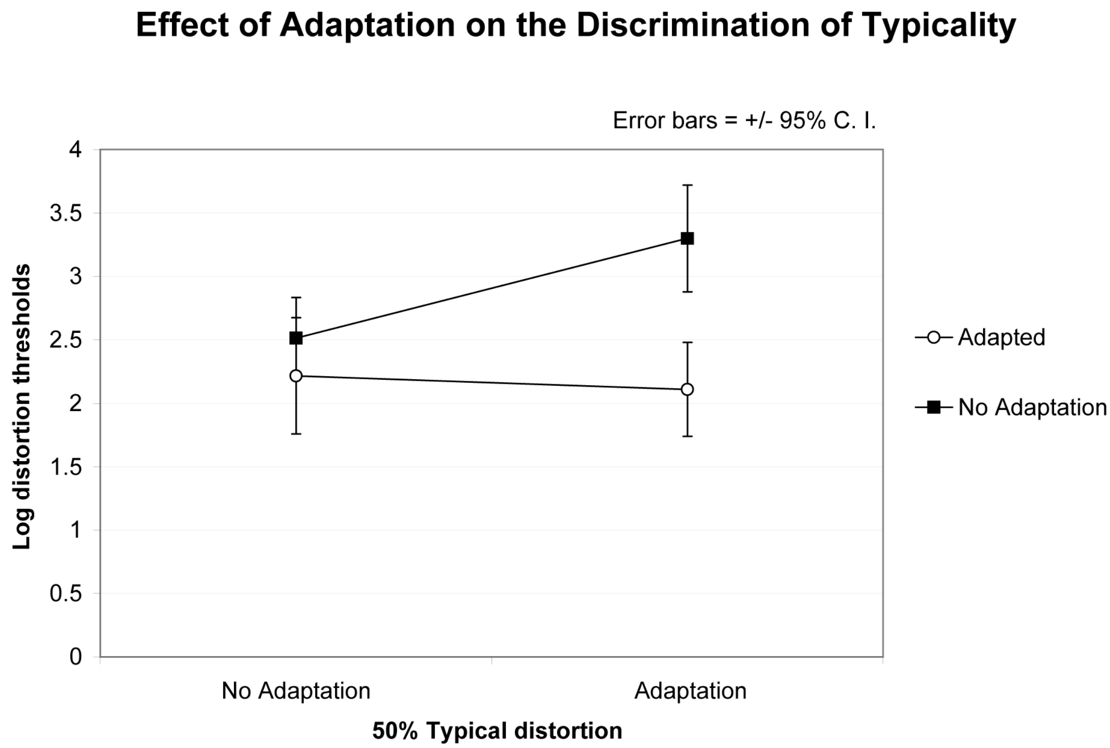

Figure 3.2. Adaptation increases sensitivity to differences in typicality for the face perceived as typical 50% of the time when adapted. This effect did not extend to the face perceived as typical 50% of the time when unadapted, *n* = 10.

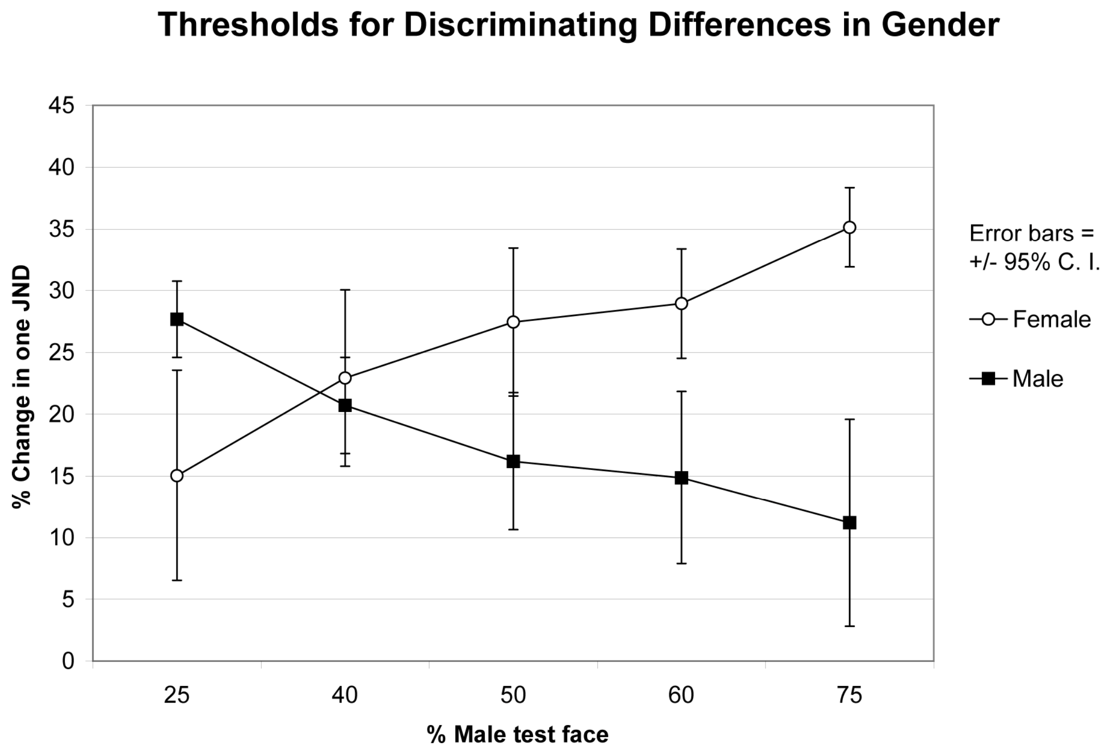

Figure 3.3. The percent increase or decrease in male contribution to the test face for 'just noticeably more male' and 'just noticeably more female' judgments depended on the gender of the test face, *n* = 18. When the test faces were female, the 'just noticeably more female' differences were smaller, but when the test faces were male these differences were larger. Similarly, male test faces produced the smallest 'just noticeably more male' differences and female faces produced the largest 'just noticeably more male' differences.

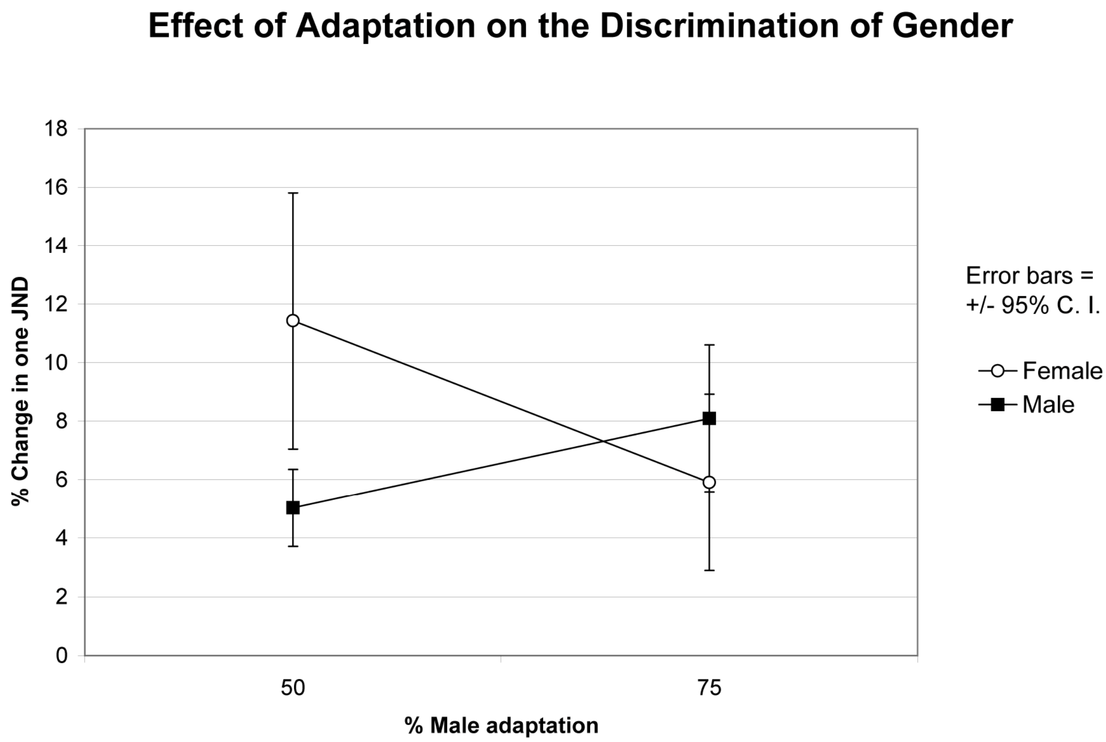

Figure 3.4. Discrimination of differences in gender from a 60% male face before and after adaptation, $n = 9$. Adaptation to the 75% male face decreased the 'just noticeably more female' differences, $t(8) = 3.00$, $p < .05$, and increased the 'just noticeably more male' differences, $t(8) = -2.44$, $p < .05$.

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Chapter 4

Holistic Face Processing Decoded

Face perception is strongly holistic, but how this holistic percept forms is unknown. Here, in three experiments, we explore the nature of holistic processing by demonstrating that the perceived shape of a face's external contour is dependent upon the internal arrangement of its facial features. By altering the eye to mouth distance inside a face, we caused participants to perceive illusory lengthening or shortening of the external facial contour. We also show that the extent of these illusory changes is determined by the amount of deviation away from typical eye to mouth distances and external facial contour lengths.

The classic Gestalt maxim that the whole is more than the sum of its parts is fairly well established for faces. What remains unknown is how this happens. Faces, unlike many objects, are strongly holistic (reviewed in Maurer, LeGrand, & Mondloch, 2002). Holistic processing binds the facial features to their spatial arrangement and the external contour of the face (Sergent, 1984), and this binding is essential to face and individual facial feature recognition (Tanaka & Farah, 1993).

The effect of this holistic binding produces a phenomenon known as the composite-face effect. In the composite-face effect, two faces with identical top halves are aligned with different bottom halves, causing the identical top halves to appear different. However, when the top and bottom halves of the composite face become misaligned, the top halves are now correctly perceived as identical (Young, Hellawell, & Hay, 1987). Misalignment thus disrupts the holistic perception of the face, which allows for the independent perception of each face half. In contrast, when the face halves are aligned, holistic binding occurs and the identical top halves become inseparable from the different bottoms, ergo the composite-face effect.

Holistic processing affects face processing in another manner. Lee & Freire (1999) demonstrated that the perception of a face framed in an oval will affect of the perceived shape of the oval. When the distance between the eyes and mouth of a face was elongated, the oval frame appeared elongated; when the distance between the eyes and mouth of a face was compressed, the oval frame appeared compressed. In all cases, there was no physical change made to the oval frame. This illusory difference in oval shape likely reflects a holistic binding of the oval frame to the interior of the face. This was further supported by a reduction in the amount of perceived change with inversion.

Given the demonstrated influence of holistic processing in face perception, faces make ideal stimuli to investigate how a holistic percept is formed. The current study seeks to expand upon the observations of Lee and Freire (1999) by using the external contour of the face in an analogue of the oval illusion. By examining the effect of varying vertical spacing between internal facial features on the perception of the external facial contour, we hope to understand the underlying processes that form a holistic face percept.

We conducted two experiments to measure illusory changes in external facial contour length after increases and decreases in eye to mouth distance. This provided a measure of the influence the internal facial feature distances have on the perceived shape of the external facial contour and allowed us to determine the driving forces behind the resulting holistic face percept.

Experiment 1

This experiment establishes the existence of an external facial contour analogue to the oval illusion reported by Lee and Freire (1999). Participants viewed a test face and selected the face with the matching external contour length from a set of comparison faces. Test faces contained three different eye to mouth distances: the original, elongated, compressed. Comparison faces contained the original eye to mouth distance but varied in external contour length. This provided a direct measure of any illusory differences in external facial contour length caused by different eye to mouth distances.

Method

Subjects. Twenty-nine participants from the University of California, San Diego participated in exchange for course credit.

Stimuli. Stimuli were created from a single Caucasian male face. There were three test faces, each with different eye to mouth distances: the original eye to mouth distance, eye to mouth distance increased by 20%, and eye to mouth distance decreased by 20%. Comparison faces were created by vertically stretching or compressing the original face. The most elongated face was stretched by 42.56 pixels, and the most compressed face was shortened by 30.99 pixels. Then we used Adobe Photoshop CS3 to replace the stretched or compressed internal facial features with the original feature arrangement. This produced 41 comparison faces with identical eye to mouth distances but different external contour lengths: 20 longer than the original, the original, and 20 shorter than the original. Faces were presented in an offset manner to prevent the use of low-level visual cues such as edge matching. The initial comparison face was selected to be maximally elongated on half the trials and maximally compressed on the remaining half.

Stimuli were viewed on a 51 cm Iiyama HM204DT A CRT-monitor with a gray background using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Participants were seated at a distance of 90 cm. Images were 640 x 480 pixels and presented at a resolution of 1200 x 1024 pixels. On average, each face encompassed 4.7 x 6.6 degrees visual angle.

Procedure. Each trial commenced with a beep. Participants panned through an array of faces using a mouse roller ball and viewed each face one at a time. The matching external contour length was selected with a click of a mouse button. The next trial then began automatically. No feedback was provided. Each test face was presented in a random order and viewed six times. There were 18 total trials for each subject.

Results

If no illusion occurred, then all three test faces should correspond to the same matching external contour length. This was not the case. The internally elongated test face was matched to faces with significantly longer external contour lengths than the original face matches. The mean match was 4.38 pixels longer, S. E. = .71, t (28) = 7.20, $p < .01$. Similarly, the internally compressed test face matches were significantly shorter that the original face matches – on the average 2.45 pixels shorter, S. E. = .86, t (28) = 3.09, $p < .01$. Therefore, participants experienced a significant illusory perception of external contour lengthening when the test face contained an elongated eye to mouth distance, and perceived a significant shortening when the test face contained a compressed eye to mouth distance.

Using a regression analysis to determine the exact relation between perceived external contour length (L_P) and eye to mouth distance (D_{EM}), we found that perceived external contour length was roughly a linear function of eye to mouth distance with a gradient of 1/3, a substantial illusion. The perceived external contour length was represented by:

$$L_P = .33\ D_{EM} + 149.99$$

Figure 1 shows the average of the matches selected by each participant for each test face and the corresponding regression function. Notably, the amount of shift away from the true external contour length was least for the compressed test face. For comparison, Figure 1 also shows the eye to mouth distances and true external contour lengths of 19 Caucasian faces as a presumably representative sample of natural faces. Comparison of the matches with the distribution of natural faces suggests that the shift in perceived length is in the direction to make the atypical face a better fit within the typical face distribution.

Discussion

This experiment clearly demonstrated that altering the feature arrangement within a face directly affects the perceived shape of the external facial contour. This effect results from an inability to separate the internal feature arrangement from the external facial contour: a hallmark of holistic perception.

So then, why do longer eye to mouth distances produce illusions of longer external facial contours? We suggest that when perceiving a face, the observer compares it to a known standard or average face. Surrounding this face is a probability distribution of external facial contour lengths and a probability distribution for internal feature arrangements that is determined by the natural statistics of our environments. By altering the internal feature arrangement, we shifted the most probable external contour length.

When presented with a face containing an atypical feature arrangement, one possible perceptual result is an accentuation of differences between the face and the typical face distribution. This would form a caricature that could easily be recalled later. If true, then a face with an elongated eye to mouth distance should appear to have a shorter external contour. Similarly, a face with a compressed eye to mouth distance should appear to have a longer external contour. This did not occur.

Alternatively, since perception is prone to error, the brain perceives the most probable external contour length rather than the true external contour length. This could produce a shift in the perceived length of the external facial contour and also explains why the match selected for the compressed reference was the closest to the true length of the external contour. If the combination of feature arrangement and external contour length fits the natural probability distribution, little illusion should occur. This suggests that such illusory effects are happening on a daily face. The distribution of matches for the original face observed in Figure 2 support this suggestion, since they lie above the true external contour length, closer to the distribution of natural faces.

Therefore, we propose that the illusory perception of lengthening or compression develops from reconciling the combination of internal facial feature arrangement and external contour length with the known probability distribution for faces in general. However, Experiment 1 used only a single identity, so it is unknown whether these results will persist when multiple identities are included. Therefore, in Experiment 2, we further explored the relation between internal feature arrangement and perceived external facial contour length using multiple faces.

Experiment 2

Experiment 1 involved variation within a single identity; however our results need to apply to multiple individuals, not a specific identity. Therefore, Experiment 2 uses the method of paired comparisons to assess differences in perceived external facial contour length due to altered eye to mouth distances, and uses Thurstonian scaling to obtain an average z-score of perceived external contour length for each eye-mouth configuration. These results should reflect the slope attained in the regression equation from Experiment 1.

Method

Subjects. Twenty students from the University of California, San Diego participated in exchange for course credit.

Stimuli. Using Adobe Photoshop 7.0.1, we applied increments and decrements of 20% and 40% of each original eye to mouth distance to 10 Caucasian male and 10 Caucasian female faces. For each original face, this produced a set of five faces. Each face was then exhaustively paired with every other face in the set to produce 20 pairings per face set and 400 total face pairs.

Faces pairs were displayed on a black background with one face in the upper left and the other in the lower right corner of the display. This again prevented edge matching. Centered at the bottom of the display below the faces was the question, “Does the length of these heads appear different or the same?” If subjects reported a difference, they were then asked “Which head appears longer?” Subjects viewed stimuli on a 17-inch Dell flat-panel monitor and sat 85 cm from the display. On average, faces subtended 3.7 x 5.7 degrees.

Procedure. Each trial started with a 500 ms fixation, followed by two faces. Participants answered “same” or “different” and “left” or “right” by depressing either n or m on the keyboard. A response terminated the trial. There was no feedback.

Data analysis. Paired comparison data were accumulated across face sets and subjects and the probabilities of ‘longer’ judgements were converted to perceived length scores on a Thurstonian scale, a well-established psychophysical metric for measuring attitudes (Thurstone, 1972). Values obtained in Thurstonian scaling represent average z-scores for the measure in question. In this case, the Thurstonian scores represent the perceived external facial contour length at each of the tested eye to mouth intervals.

Results

Perceived external contour length varied with eye to mouth distance. Faces with smaller eye to mouth distances received negative z-scores, reflecting a perceptible decrease in the length of the external contour of the face, $Z_{20\ decrease} = -1.09$, $Z_{40\ decrease} = -1.07$. Faces with larger eye to mouth distances received positive z-scores, representing the increased perceived external contour length, $Z_{20\ increase} = .76$, $Z_{40\ increase} = 1.85$. The z-score for the unaltered faces was -.45. These z-scores are shown in Figure 2. This replicates the results in Experiment 1 and further supports our suggestion that manipulating the eye to mouth distance in a face will correspondingly alter the perceived length of the external contour.

We determined the slope of the line between a proportional increase of .20 and a proportional decrease of .20. Using the across test face standard deviation for the external contour length matches in Experiment 1 and the average physical external contour length for each of the 19 faces plotted in Figure 2, we converted the Thurstonian scores (i.e. average z-scores) to estimates of perceived external contour length. Using regression analysis, we again assessed the relation between eye to mouth distance and perceived external contour length. Following Experiment 1, perceived external contour length formed a linear function with eye to mouth distance. The resulting equation was:

$$L_P = 0.30D_{EM} + 161.01.$$

This equation is remarkably similar to the one obtained in Experiment 1, with the crucial difference that this equation represents a set of 20 faces rather than one face. Both experiments indicate that an increase of about 3 cm in the eye to mouth distance generates a perceptual elongation of 1 cm in the external contour...

Discussion

This experiment successfully replicated the results of Experiment 1, while adding to its generalizability. Therefore, we may confidently state that altering the internal feature arrangement of a face, specifically the eye to mouth distance, alters the perceived shape of the external facial contour.

General Discussion

The effect of internal feature arrangement on the perceived shape of the external facial contour can be taken as evidence of holistic processing that binds elements into a greater whole. Moreover, we have gained insight into how the greater whole is formed. Our perception of the whole is determined by a combination of the physical stimulus dimensions and our experiences with natural faces.

The natural face distribution and illusory differences in external contour length

Given face with an average eye to mouth distance, there is a probability distribution of expected external contour lengths. In the center of this distribution lies the average external contour length. As deviations from the average external contour length increase, the probability of observing such a length decreases, and the amount of perceived illusion increases. Likewise, given any eye to mouth distance, there is a similar probability distribution in which the average external contour length for the given eye to mouth distance lies in the center.

This is not the first instance of faces being encoded relative to an average, but rather adds to a body of research suggesting that reference to an average is critical for face perception. Adaptation to a center-compressed face causes the average or normal face to shift in the direction of the adapting face (Webster & MacLin, 1999), with similar affects observed for gender, race, emotion (Webster, Kaping, Mizokami, & Duhamel, 2004), attractiveness (Rhodes, Jeffery, Watson, Clifford, & Nakayama, 2003), and identity (Leopold, O'Toole, Vetter, & Blanz, 2001). Altogether, this strongly suggests that faces are encoded relative to an average.

The illusory differences in external contour shape as a research tool

If our hypothesis of an inverse relation between the amount of perceived illusory difference and deviation from a probability distribution of external contour lengths is correct, then this also predicts that young children who have less developed probability distribution, i.e. only partially developed holistic processing, should experience a weaker illusion. This could be tested by first examining the perceived normality of faces with identical external contours but different internal feature arrangements, and then testing for the perception of an illusion. If a face is perceived as normal by children then it is considered probable. Therefore, even if the face is known to produce an illusion with adults, it should not produce an illusion with children. This provides a new method for testing the development of holistic processing skills.

One potential outcome of this is a new venue for assessing the face inversion effect. All objects are better recognized when upright, but the recognition decrement associated with inversion is much larger for faces (Yin, 1969). Therefore this disproportionate impairment is called the face inversion effect. Inversion also mars the recognition of individual features within the face (Tanaka & Sengco, 1997). Similarly, the composite-face effect (Young et al., 1987) disappears with inversion (Goffaux & Rossion, 2006). Altogether, this suggests that face orientation is a critical prerequisite for holistic processing. If true, then the perception of illusory differences in external facial contour should not occur with inverted faces.

The relation between perceived shape and the internal feature arrangement need not apply solely to faces, but may extend to any holistically perceived object. Neuronal responses to birds, cars, dogs, and other objects of expertise can be similar to the responses for faces (e.g. Gauthier & Curby, 2005; Gauthier & Tarr, 2002), suggesting that holistic processing may not be entirely unique to face perception. If true, then the illusion should extend to the perception of such objects. When a robin's breast coloration and wings are enlarged in one image and decreased in another with the external contour kept the same, the two altered robins should appear to have a different shape, e.g. Figure 3. Therefore, future research may wish to use this method to further investigate the commonalities between face and object perception.

Conclusions

Altering the internal facial feature arrangement, e.g. eye to mouth distance, produces illusory shifts in the perceived shape of the external facial contour, e.g. lengthening. These illusory shifts result from matching the facial feature arrangement with a known distribution of probable external contour shapes. It is this process that underlies the formation of a holistic percept.

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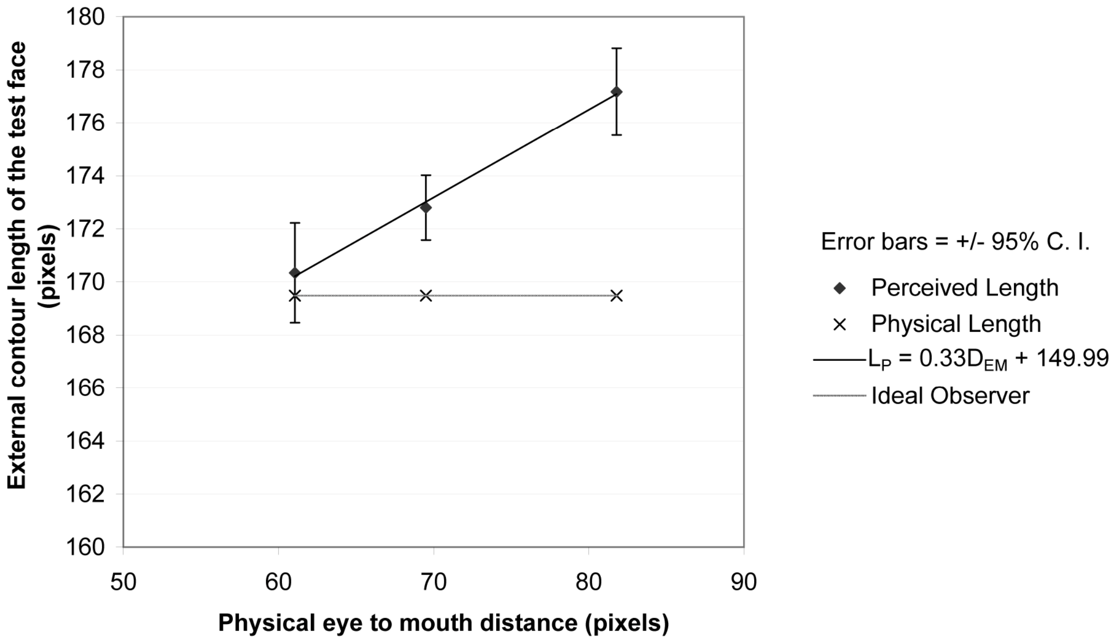
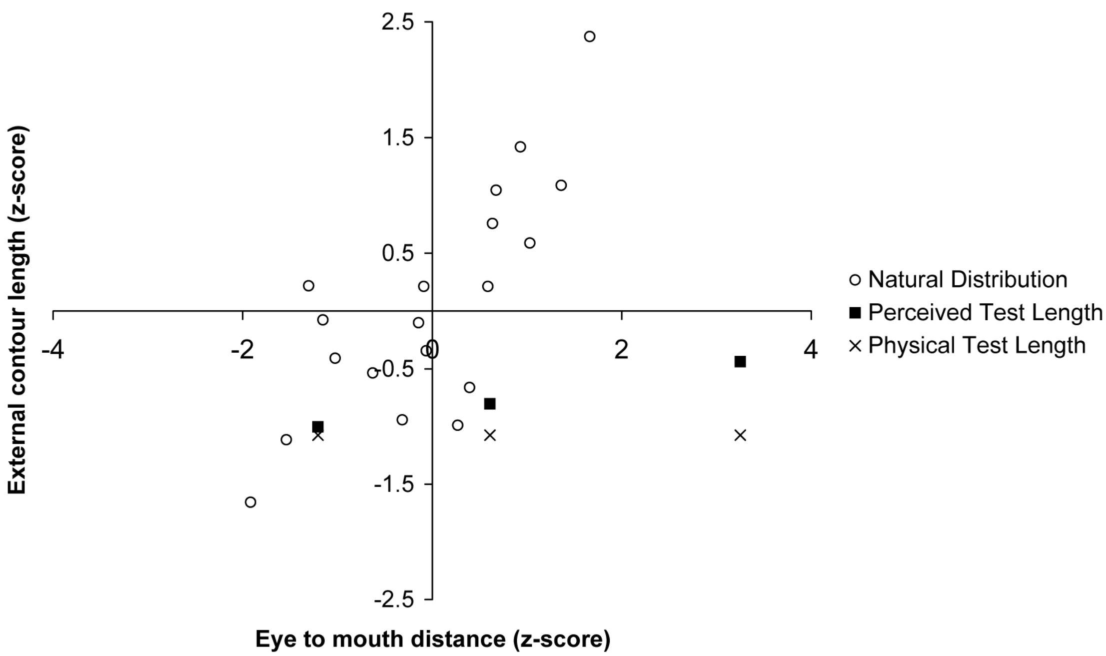
Figure 4.1. Black diamonds represent the average external contour lengths selected by each participant for three different eye to mouth displacements, $n = 29$. The black Xs represent the perceived external contour length for an ideal observer. A. There is a significant shift in perceived length with change in the eye to mouth distance. B. The illusory shift in perceived external contour length at a given eye to mouth distance is toward the center of the natural distribution of faces. Open circles indicate the eye to mouth distances and physical external contour lengths of 20 Caucasian faces.

A. **Illusory Differences in External Contour Length**



B. **Illusory Shift Toward the Natural Distribution**



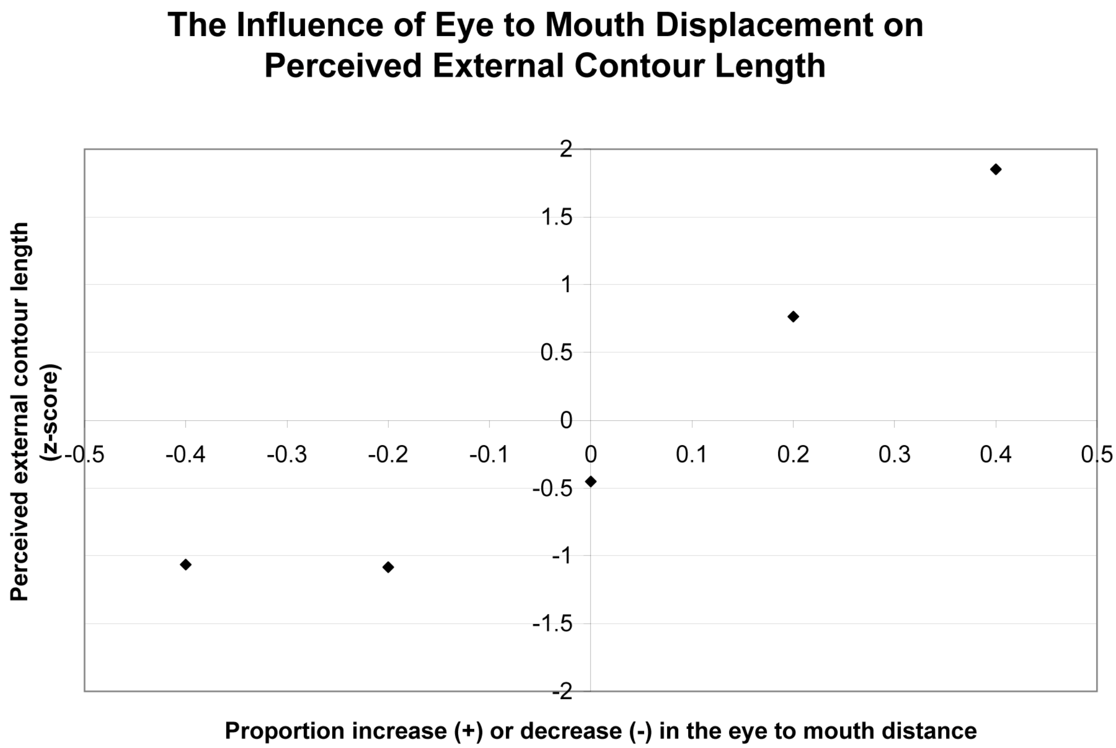


Figure 4.2. Thurstonian scores for perceived external contour length computed across participants and face identities, *n* = 20. These scores represent averaged z-scores and display a psychometric function relating eye to mouth distance and perceived external contour length.

Figure 4.3. An extension of the illusory differences in external contour shape to objects of expertise: a robin with enlarged breast coloration and wing (left) and a robin with compressed breast coloration and wing (right). The bird on the left may appear longer and narrower than the one on the right, and this effect should be strongest for bird experts.

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Chapter 5

A New "Golden" Ratio for Facial Attractiveness

The enduring quest to discover the geometrical dimensions of facial beauty has seen limited success. To date, the closest discoveries include: 1) that spatial relations between facial features are crucial to individual facial aesthetics, and 2) that averageness makes a face attractive. Here by connecting these two findings, we show that for any individual face there exists an ideal attractiveness state. When the distance between the eyes and the mouth of a face is approximately 36% of the face length, and the distance between the eyes is approximately 46% of the face width, the face is most attractive. Although the actual attractiveness of different faces varies, these new "golden" ratios remain constant. Furthermore, these ratios correspond with those of an average face.

Humans prefer attractive faces over unattractive ones (Dion, Berscheid, & Walster, 1972; Eagly, Ashmore, Makhijani, & Longo, 1991; Griffin & Langlois, 2006). Our preference for attractive faces exists from early infancy and is robust across age, gender and ethnicity (Rubenstein, Langlois, & Roggman, 2002). The quest to define facial beauty either by the size or shape of isolated facial features (e.g. eyes or lips) or by the spatial relations between facial features dates back to antiquity, when the Ancient Greeks believed beauty was represented by a golden ratio of 1:1.618 (Atalay, 2006). Although there is little support for the golden ratio (Green, 1995), averaging a group of faces results in a face more attractive than any of the originals (Langlois & Roggman, 1990; Rhodes, 2006). Furthermore, a sufficiently large increase in the distance between the eyes and mouth of an individual face can make the face appear grotesque (Searcy & Bartlett, 1996; Bartlett & Searcy, 1993). Together, these findings suggest that any individual's facial attractiveness can be optimized when the spatial relations between facial features approximate those of the average face. However, no evidence to date has confirmed this suggestion. Here we tested this hypothesis.

Two types of alterations can be made to the spatial relations between facial features. One may alter the vertical distance between the eyes and the mouth; this alteration results in a change in the ratio of this distance to the face length, which is measured by the distance between the hairline and the chin. The ratio is henceforth referred to as the length ratio. The other alteration is to change the horizontal distance between the pupils; this change alters the ratio between this distance and the face width, which is measured between the inner edges of the ears. This ratio is henceforth referred to as the width ratio. Here we used three experiments to assess the contribution of length ratio and width ratio to facial attractiveness.

General Methods

Stimuli

Faces were presented side by side on a 51 cm Iiyama HM204DT A CRT-monitor with a black background at a resolution of 600 x 800 pixel and a distance of 90 cm.

Design & Procedure

Each face pair was presented twice to counter balance display location. Participants judged which face in each randomly presented pair appeared more attractive. Participants indicated left or right by depressing m or n on a computer keyboard. Each face pair remained on display until the participant's response.

Data analysis

Paired comparison data for each experiment were converted to an attractiveness score on a Thurstonian scale, a well-established psychophysical metric for measuring attitudes (Thurstone, 1972).

Experiment 1

Here we assessed the contribution of vertical feature spacing to perceived attractiveness and predicted that there would be an ideal length ratio for attractiveness that would be constant across individual faces.

Methods

Participants. Twenty participants in Experiment 1 (4 male, 16 female) provided informed consent to participate in the experiment, each of which was approved by the University of California, San Diego Human Research Protections Program internal review board. All participants were undergraduates from the University of California, San Diego and each participated in exchange for course credit.

Stimuli. We used Adobe Photoshop 7.0.1 to either increase or decrease the distance between the eyes and mouth in a female face while keeping the internal facial features and face contour constant. For each original face, we created a set of new faces that were identical to the original except in their length ratios. Example faces are provided in Figure 1. To create paired comparisons, the face stimuli in each set were then paired with each other.

This procedure was applied to create a set of 10 new faces for each of 10 Caucasian female faces (320 x 240 pixels). The amount of eye and mouth displacement was determined by measuring the vertical distance between the eyes and nose, as well as the nose to mouth distance in each original face, then increasing or decreasing the distances proportionally. The proportional increases and decreases to vertical distances included 0, .10, .20, .30, .40 or .50. This resulted in 110 faces in Experiment 1 (100 derived from the 10 altered faces with each identity plus the 10 original faces).

Results

Figure 2A shows the relations between each face's Thurstonian attractiveness score and its length ratio in Experiment 1. Using a regression analysis to determine the exact function between the attractiveness score and the length ratio, we found that facial attractiveness follows a curvilinear function with the length ratio (Figure 2A). Therefore when L represents a given length ratio, the Thurstonian attractiveness (T_A) is represented by

Equation 1. $T_A = -51L^2 + 37L - 6.$

This function was a strong predictor of Thurstonian attractiveness, F (107, 2) = 252, R^2 = .83, $p < 0.001$. The length ratio for the maximally attractive face according to the above equation was 0.36. This ratio is also the length ratio obtained by averaging the length ratios of 40 Caucasian female faces, M = .36, SD = .017. This result suggests that the observed ideal length ratio may reflect a preference for an average vertical spacing between facial features. However, we did not have direct evidence to support this suggestion because participants were never asked to judge the attractiveness of faces with a length ratio of .36, therefore we ran a second experiment on a new set of faces including average length ratios to address this issue more precisely and directly.

Experiment 2

Methods

Participants. Thirty-four participants (4 male, 30 female) provided informed consent to participate in the experiment, each of which was approved by the University of California, San Diego Human Research Protections Program internal review board. All participants were undergraduates from the University of California, San Diego and each participated in exchange for course credit.

Stimuli. We used the procedure from Experiment 1 to create a set of 6 new faces for each of 10 new Caucasian female faces (320 x 240 pixels). The proportional increases and decreases to vertical distances included 0, .10, .20, or .30. We additionally altered the length ratios of the original faces to derive 10 new faces with the length ratio of .36, the average length ratio obtained by averaging the length ratios of 40 Caucasian female faces, M = .36, SD = .017.

This resulted in 80 face pairs (70 derived from the 10 altered faces with each identity plus the 10 original faces).

Results

Experiment 2 completely replicated the findings of Experiment 1: Attractiveness scores again followed a curvilinear function with the length ratio. The length ratio and length ratio^2 together were significant predictors of attractiveness, F (77, 2) = 84, R^2 = .69, $p < 0.001$[1]. The ideal length ratio that maximized the attractiveness of this new set of faces was .37. This corresponds well with the average length ratio of .36. As shown in Figure 2B, faces with an average length ratio tended to be rated as more attractive than faces with other length ratios.

Experiment 3

Here we assessed the contribution of horizontal feature spacing to perceived attractiveness. Similar to length ratio, we now predicted that there would be an ideal width ratio for attractiveness that would remain constant across individual faces.

Methods

Participants. Thirty participants in Experiment 3 (9 male, 21 female) provided informed consent to participate in the experiment, each of which was approved by the University of California, San Diego Human Research Protections Program internal review board. All participants were undergraduates from the University of California, San Diego and each participated in exchange for course credit.

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[1] $T_A = -90L^2 + 66L - 12$.

Stimuli. We used Adobe Photoshop CS3 extended edition to either increase or decrease the interocular distance. Using a procedure similar to that of Experiment 1 and the average length ratio faces from Experiment 2, we created 4 new faces for each original face. This involved proportional increases and decreases of 0, .10 or .20 of the original interocular distance. In addition, we created faces with an average width ratio derived from averaging the width ratios of 40 Caucasian female faces, M = .46, SD = .022. This resulted in 60 face pairs (50 derived from the 10 altered faces with each identity plus the 10 original faces).

Results

Here we expected to find an ideal width ratio for facial attractiveness. Results supported our prediction and indicated that facial attractiveness also follows a curvilinear function with the width ratio, $F\ (57, 2) = 26$, $R^2 = .48$, $p < 0.001$[2]. Similar to the length ratio, the ideal width ratio that maximized attractiveness was 0.46, the same as the average width ratio. Figure 2C displays the relation between deviation from the average width ratio and attractiveness.

Discussion

The present findings provide an important step forward in our understanding of facial attractiveness. Many previous experiments on attractiveness involved comparing faces that differed in both facial features and the spatial relations between them. This comparison is affected by the presence of different features that may be more or less attractive and could obscure any effect of variation in feature spacing on attractiveness.

[2] When the width ratio is represented by W, $T_A = -89W^2 + 82W - 19$.

Also, prior research comparing an average face to individual faces failed to discover the ideal length and width ratios because the averaging process tends to not only average the spatial relations between facial features but also smoothes the facial features and skin texture (Rhodes, 2006). This smoothing effect could artificially increase the attractiveness of the average face, again obscuring the effect of average spatial relations on facial attractiveness.

Our study is uniquely able to demonstrate the ideal ratios for attractiveness because we make attractiveness comparisons between faces with the same features but different spacings, thus controlling for the attractiveness of individual features. Therefore, we could identify the ideal length and width ratios for facial beauty, which have attracted a tremendous amount of pursuit but yet eluded discovery for centuries. Furthermore, the present findings suggest that although faces vary greatly in attractiveness, for any particular face, there is an optimal spatial relation between facial features that will reveal its intrinsic beauty. The present finding may explain some basic daily observations, such as why some hairstyles can make an unattractive face appear more attractive or vice versa. By changing one's hairstyle, one may alter the perceived face length or face width, as well as their related length and width ratios, therefore affecting the perceived attractiveness of the face.

Why should we find a face with an average length and width ratio attractive? Two existing theories provide explanations at two different levels (Langlois & Roggman, 1990). At the evolutionary level, it has been suggested that humans prefer to reproduce with other healthy mates (Jones et al., 2001). Generations of healthy mate selection may act as an evolutionary "averaging" process. This process leads to the propagation of healthy individuals with physical characteristics, including faces, that approximate the population average. As a result, we are biologically predisposed to find average faces attractive. At the cognitive level, it is well established that after exposure to a series of exemplars from one object category, we form a prototype (i.e., an average) for this category. One robust consequence of prototype formation is that we find the prototype more attractive than any individual category members because the prototype is easier to process. Due to this same cognitive averaging mechanism, the average face is perceived as more attractive than any individual face (Rubenstein, Kalakanis, & Langlois, 1999).

We suggest that while the two theories provide different levels of explanation, they may work together to account for our preferences for the ideal length and width ratios for facial beauty. The evolutionary process predisposes us to find average length and width ratios attractive; the cognitive process prescribes what the average length and width ratios are by averaging the ratios of individual faces we have encountered to date. In addition to the present findings of these new "golden" ratios, this cognitive-evolutionary theory can also account for many of the facial attractiveness findings reported to date.

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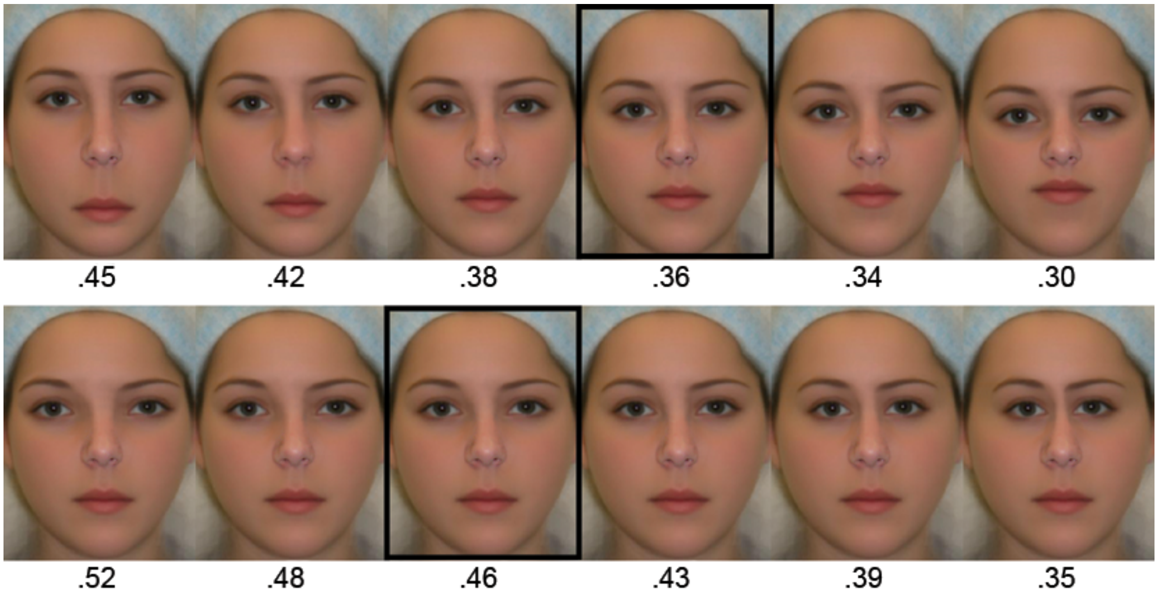
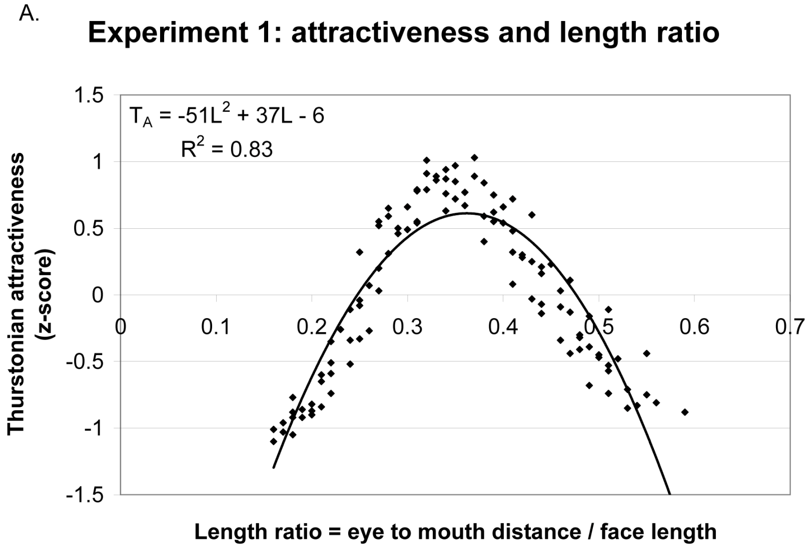


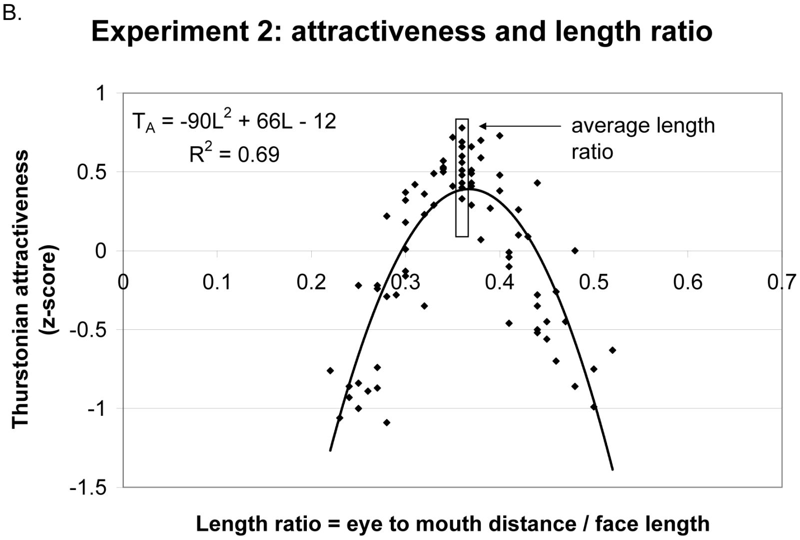
Figure 5.1. Example faces with different length and width ratios; faces with an average length or width ratio are framed in black.

Figure 5.2. The relation between length ratio (A&B), width ratio (C), and Thurstonian attractiveness scores. Based on observers' responses, we created an attractiveness score based on the Thurstonian scale for each identity to determine the attractiveness of the spatial arrangements. Each scale indicated which ratio was perceived as most attractive for each face identity.

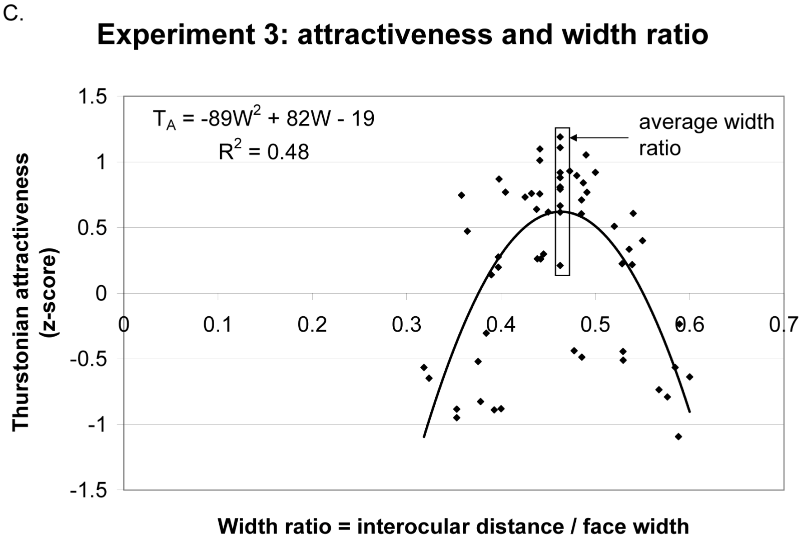
A.


Experiment 1: attractiveness and length ratio
T_A = -51L^2 + 37L - 6
R^2 = 0.83
Thurstonian attractiveness (z-score)
Length ratio = eye to mouth distance / face length

B.


Experiment 2: attractiveness and length ratio
T_A = -90L^2 + 66L - 12
R^2 = 0.69
average length ratio
Thurstonian attractiveness (z-score)
Length ratio = eye to mouth distance / face length

C.


Experiment 3: attractiveness and width ratio
T_A = -89W^2 + 82W - 19
R^2 = 0.48
average width ratio
Thurstonian attractiveness (z-score)
Width ratio = interocular distance / face width

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This chapter, in full, has been submitted for publication of the material as it may appear in Psychological Science, Pallett, Pamela M.; Link, Stephen; Lee, Kang. The dissertation author was the primary investigator and author of this material.

Conclusions

Face perception is distinct from most object perception in that it is strongly holistic. Chapter 2 demonstrates this by examining the source of the disproportionate impairment caused by inversion on face recognition compared to object recognition (Yin, 1969). Previously it was unclear whether the face inversion effect on recognition resulted from an inability to perceive the spatial arrangement of facial features or an inability to integrate the elements of the face into a single face percept. By having participants discriminate differences in feature spacing, we successfully demonstrated that the ability to perceive such information is not affected by face orientation. This conclusively eliminates the theory that the face inversion effect on recognition results from an inability to perceive spacing information. Moreover, by measuring reaction times during the feature spacing discrimination task, we found that participants take longer to make judgments when faces are upright rather than inverted. This suggests that participants are actively disengaging from holistically processing the face in favor of a more beneficial part-based approach.

Since face recognition is impaired by inversion while object recognition is comparatively spared, these results further suggest that the difference between face perception and object perception lies in the ability to use holistic processing. This face inversion effect is one example of how face perception is special and distinct from object perception. This assertion that faces are special has been the subject of much heavy debate (Gauthier & Bukach, 2007; McKone & Robbins, 2007; Robbins & McKone, 2007). Chapter 3 examined this claim using the discrimination of natural and unnatural faces. Natural faces only provided a benefit for face perception when the focus of the discrimination task was on a face-specific attribute (e.g. gender), whereas the discrimination of non-face-specific elements (e.g. intraocular distance) exhibits no benefit for natural faces. Similarly, adaptation will only affect discrimination when the focus of the discrimination task is on a face-specific attribute. Given that the results from Chapter 2 support a holistic approach to face perception, it is likely that the special effects observed for faces such as the face inversion effect result from holistic processing.

Therefore it is natural to ask, how is a holistic face percept formed? Chapter 4 investigated this process by examining the source of perceived illusory difference in a face's external contour length corresponding with alterations to internal feature arrangement. When the directions of these illusory shifts in perceived length are compared with the distribution of natural faces, it appears that the illusion results from reconciling the abnormal stimulus with the known distribution of faces. In other words, the perceived lengths shifted toward the more probable, natural lengths. This suggests that formation of a holistic percept depends on reference to the population average.

It is well known that average faces are attractive (reviewed in Rhodes, 2006), however no studies have isolated the contribution of average features versus average facial feature arrangement to attractiveness. Chapter 5 approaches this question by applying the same variations from Chapter 4 to a set of female faces in addition to creating average facial feature arrangements. This provides the unique opportunity to assess the contribution of average feature arrangements on facial attractiveness independent of facial feature attractiveness. Results from this experiment show that feature arrangement does alter attractiveness, and the most attractive arrangement is the average facial feature arrangement.

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