Electrophysiological constituents of the P100 and N170 ERP complex: Deconstructing the critical timing and robustness of face processing using independent component analysis and robust estimation.

By

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Abstract

The initial timing of face-specific effects in event-related potentials (ERPs) is a point of contention in face processing research. Although effects during the time of the N170 are robust in the literature, inconsistent effects during the time of the P100 challenge the interpretation of the N170 as being the initial face-specific ERP effect. The interpretation of the early P100 effects are often attributed to low-level differences between face stimuli and a host of other image categories. Research using sophisticated controls for low-level stimulus characteristics (Rousselet, Husk, Bennett, & Sekuler, 2008) report robust face effects starting at around 130 ms following stimulus onset. The present study examines the independent components (ICs) of the P100 and N170 complex in the context of a minimally controlled low-level stimulus set and a clear P100 effect for faces versus houses at the scalp. Results indicate that four ICs account for the ERPs to faces and houses in the first 200 ms following stimulus onset. The IC that accounts for the majority of the scalp N170 (icN1a) begins dissociating stimulus conditions at approximately 130 ms, closely replicating the scalp results of Rousselet et al. (2008). The scalp effects at the time of the P100 are accounted for by two constituent ICs (icP1a and icP1b). The IC that projects the greatest voltage at the scalp during the P100 (icP1a) shows a face-minus-house effect over the period of the P100 that is less robust than the N170 effect of icN1a when measured as the average of single subject differential activation robustness. The second constituent process of the P100 (icP1b), although projecting a smaller voltage to the scalp than icP1a, shows a more robust effect for the face-minus-house contrast starting prior to 100 ms following stimulus onset. Further, the effect expressed by icP1b takes the form of a larger negative projection to medial
occipital sites for houses over faces partially canceling the larger projection of IC1a, thereby enhancing the face positivity at this time. These findings have three main implications for ERP research on face processing: First, the ICs that constitute the face-minus-house P100 effect are independent from the ICs that constitute the N170 effect. This suggests that the P100 effect and the N170 effect are anatomically independent. Second, the timing of the N170 effect can be recovered from scalp ERPs that have spatiotemporally overlapping effects possibly associated with low-level stimulus characteristics. This unmixing of the EEG signals may reduce the need for highly constrained stimulus sets, a characteristic that is not always desirable for a topic that is highly coupled to ecological validity. Third, by unmixing the constituent processes of the EEG signals new analysis strategies are made available. In particular the exploration of the relationship between cortical processes over the period of the P100 and N170 ERP complex (and beyond) may provide previously unaccessible answers to questions such as: Is the face effect a special relationship between low-level and high-level processes along the visual stream?
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Dedications

I dedicate this thesis to my children,

Mira and Remy.

You inspire me.
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Introduction

Overview

Event-related potentials (ERPs) provide an objective measurement of cortical activation related to predefined environmental events. Although the electrical fields that constitute ERPs include spatial resolution limitations that affect the localization of the specific anatomical sources of activation, the temporal resolution of the cortical responses is maintained. The high temporal resolution of the ERPs makes this method particularly well suited for examining psychological phenomena that are time sensitive. One such psychological phenomenon that is particularly well suited to the temporal resolution of ERPs is the time required by the cortex to extract sensory information for the encoding of faces. Unfortunately the spatial limitations imposed by the field potentials acquired with EEG make it difficult to dissociate spatio-temporally overlapping cortical processes. This problem is particularly pronounced in the face-processing literature as it is known that both low-level processes (related to stimulus characteristics) and high-level processes (related to top-down integrative perception) produce spatio-temporally overlapping field potentials during the first 200 ms following stimulus onset. Further, both low-level and high-level processing requirements can vary independently when comparing face stimuli to other images. Research published by Rousselet et al. (2008) minimized the potential effects of low-level processing on the timing of ERP differences by creating a sophisticated set of stimuli in which face images and house images were matched on a host of low-level characteristics. The goals of the present work extend from that of Rousselet et al. (2008) by unmixing the spatio-temporally overlapping field potentials that constitute the scalp ERPs using independent components analysis (ICA) rather than
controlling the low-level differences in the stimulus set.

The face effect critical timing controversy

Face specific processing in the visual and associate cortices has been widely studied through the effects expressed by the N170 event-related potential (ERP). The timing of the N170 ERP component and its differentiation for faces versus a wide variety of other stimulus categories span the post stimulus period from about 130 ms to 200 ms (Bötzel, Schulze & Stodieck, 1995; Eimer, 2000; Itier & Taylor, 2002; Rousselet, Husk, Bennett, & Sekuler, 2008). The timing of the N170 effect is argued to reflect the time necessary to extract low level stimulus information necessary for the categorization of faces versus other categories of objects. While the robust effect of the N170 in the face processing literature dominates the field, less reliable face specific effects preceding the N170 time window (the P100 effect) challenge the interpretation that the N170 is the first marker of face specific high level perceptual processing in the visual system (Debruille, Guillem, & Renault, 1998; George, Jemel, Fiori, & Renault, 1997; Halit, de Haan, & Johnson, 2000; Itier & Taylor, 2004; Mouchetant-Rostaing, Giard, Bentin, Aguera, & Pernier, 2000). Thus, the question is whether it is the P100 or the N170 that is the earliest electrocortical component that reflects face coding in the brain. More accurately, the controversy relates to the true timing of the initial face effect in the context of spatio-temporally overlapping electrophysiological processes in the visual and associative cortices.
Factors contributing to the controversy

Rousselet et al. (2008) outlined several factors that may account for the timing discrepancy reported for the initial face specific ERP effects. Two of the factors outlined by Rousselet et al. (2008) relate directly to the current analysis. First, the timing discrepancy reported in the literature may be due to low level differences between stimulus categories. The second potential source of the discrepancy in the literature relates to the lack of robustness in statistical designs. A third factor that is a focus of the current research is the spatial and temporal overlapping of multiple electrocortical generators projecting to the scalp over the occipito-temporal regions in the time period of approximately 80 ms to 200 ms following stimulus onset. Rousselet et al. (2008) confronted the face effect timing issue using a well-controlled stimulus set and sophisticated statistical treatment of the data. The current investigation explores the same face effect timing issue by employing a similar set of statistical treatments on the data, but rather than controlling the stimulus set, it uses ICA to unmix the spatio-temporally overlapping field projections that constitute the P100 and N170 scalp ERP complex and examines each of the resulting constituent processes independently.

Low-level and high-level processing

Within the first 200 milliseconds of a visual stimulation the human brain performs processes related to the physical characteristics of the stimulus as well as processes that relate to the integration of the information into a unified perception. The initial sensory processing that varies in relation to stimulus characteristics is referred to as low-level processing. This includes luminance, colour, contrast, spatial frequency, etc. The
integration of this low-level information is high-level processing. In practice, face stimuli have low-level characteristics that distinguish them from control stimuli. For example, stimuli that belong to the face category may share a specific mixture of low-level properties such as luminance, contrast, spatial frequency, etc. that is different from the control stimuli (such as house images or tree images, etc.). Such low level characteristics of visual stimuli are processed earlier than the N170 time window by the visual cortex, i.e., the P100 (Regan 1989). Because of such low-level differences, it is difficult (if not impossible) to rule out the potential confound of low-level visual properties when interpreting the electrophysiological results comparing face stimuli to other stimulus categories.

**Temporal precedence of low-level processing in stimulus related effects**

In randomized and properly controlled stimulus delivery paradigms, initial high-level perceptual processes are preceded by low-level processes in the task of effectively perceiving sensory events. This is to say, in the absence of participants being able to systematically predict, or being sensitized to properties of a stimulus sequence, the physical characteristics of the stimulus begin to be processed before any categorically specific high-level effects can occur. Using procedures that minimize the potential for systematic cuing, anticipation or sensitization effects, the timing of the initial high-level stimulus-related influence on the visual stream can be assessed by measuring changes in stimulus event-related potentials. The earliest high-level stimulus-related ERP face effect that is robust in the literature is the N170.
The N170 ERP component is a negative deflection that immediately follows the P100 (see Figure 1 above). Its maximum negative peak amplitude is distributed over bilateral occipito-temporal regions and occurs at a latency of about 170 ms following the onset of stimulus presentation. The N170 is best known for its larger response to faces than any other stimulus category (Bentin, McCarthy, Perez, Puce & Allison 1996), and more generally it is associated with early automatic high-level integrative processing associated with expertise (Bentin & Golland, 2002; Rossion, Collins, Goffaux, & Curran, 2007). While the N170 is mostly studied in terms of its relationship to high-level processing, research has also documented low-level effects of the N170 (Goffaux, Gauthier, & Rossion, 2003).

Inversion effect

One of the most convincing arguments regarding the inadequacy of low-level processes accounting for ERP differences for faces and other stimulus categories is the inversion effect. The inversion effect is a robust ERP difference in the literature that demonstrates a larger and later N170 deflection for inverted faces versus upright faces (Bentin et al. 1996). This inversion effect is characteristic of face processing and similar effects of inverting non-face stimuli are rarely observed. Not only is the inversion effect relevant due to its face category specificity, it also isolates the effect as a high-level process because this manipulation almost perfectly controls for low-level stimulus characteristics (since the comparison is between identical images that have simply been inverted). Thus, the inversion effect is crucial for demonstrating that the face related N170 effects are not presupposed by low-level stimulus differences.
**P100 and N170 ERP components**

The P100 ERP component is a positive deflection maximal over bilateral medial occipital scalp region with a peak latency of approximately 100 ms (see Figure 1 below). The P100 shows categorical effects that are generally associated with cortical sensitivity to low-level stimulus characteristics (Regan 1989). Although the low-level stimulus characteristics of an image are known to vary P100 amplitude, top-down processes affecting cortical sensitivity to the stimulus (such as attention allocation) have also been shown to affect P100 amplitude in the absence of low-level differences (Van Voorhis 1977). Notably, all of these influences on the amplitude of the P100 can easily confound early ERP differences in face processing research (Johnson & Olshausen, 2003).

Figure 1. ERP overlays for the face effect and the inversion effect.
Control of low-level stimulus characteristics

The development of specialized stimulus sets is another way of controlling for low-level differences between image categories. Research has compared face stimuli to noise images containing matched luminance, phase content and contrast (Allison, Puce, Spencer, & McCarthy, 1999). Rousselet, Husk, Bennett, & Sekuler, (2007, 2008) developed a stimulus set in which faces and houses were equated on low-level characteristics and determined that the face effect remained robust in the period of 130-200 ms. The studies performed by Rousselet et al. (2007, 2008) with their controlled stimuli are very convincing demonstrations that the N170 face effect is the first stimulus related high-level differentiation performed by the visual and associated cortices independent of low-level stimulus differences.

Although it is very important to demonstrate (as was done by Rousselet et al., 2008) that the robust N170 face effect is not presupposed by low-level categorical differences across stimulus categories, there are some reasons why highly controlled stimulus characteristics can limit the interpretation of the true N170 face effect. First, altering the characteristics of faces may deteriorate the true face effect by dulling the brain's response to important low-level information that it uses to trigger face-specific processing (note that this does not necessarily result in early ERP differences). Given that this effect is highly related to one's experience with the face perception, ecological validity in studying the face effect should be very important. Second, the complete face effect may not be an entirely high-level phenomenon, but rather a special relationship between high-level integrative processes and early low-level sensory processing. Third, controlling for low-level stimulus characteristics across image categories by equating
parameters such as frequency content can introduce systematic confounds related to the brain's greater sensitivity to face manipulations than other stimulus categories (Collin, Liu, Troje, McMullen, & Chaudhuri, 2004). For these reasons a desirable alternative to stimulus control when examining early face specific processing would be to examine the underlying electrocortical processes that inform the spatio-temporally overlapping ERP components in the context of unaltered and ecologically valid face perception.

**Independence of ERP components (underlying brain dynamics)**

In order to isolate potentially mixed low-level and high-level brain responses in the EEG signal, methods that go beyond controlling the stimulus characteristics are desirable. The tradition of ERP research treats peak voltages as independent events along the average event locked waveform, but advanced EEG analysis using un-mixing algorithms such as Independent Components Analysis (ICA) reveal that each ERP component is composed of the sum of temporally dynamic underlying cortical constituent processes (Makeig, Westerfield, Townsend, Jung, Courchesne, & Sejnowski, 1999). ICA is a method similar to factor analysis for blindly un-mixing a set of mixed signals (Bell & Sejnowski, 1995). This un-mixing algorithm works on the assumption that the patterns of voltage on the scalp that vary over time can be explained as a set of spatially fixed voltage maps that have independent and dynamic activation over time. Several ERP complexes have benefited from ICA in describing the relative contribution of constituent processes over time: Hu, Mouraux, Hu & Iannetti (2010) described a signal-to-noise benefit in measuring the N1 ERP component when using ICA to isolate the N2 related cortical processes; the decomposition of the N1 ERP component into functionally
dissociated constituent processes during a selective spatial attention task (Makeig et al., 1999); functional independence of processes underlying the novelty P3 and P3b (Debener, Makeig, Delorme, & Engel, 2005); partial stimulus-induced phase resetting of ERP constituent processes during a visual selective attention task (Makeig et al., 2002); identification of network activation patterns associated with distorted feedback during center-out drawing movements (Contreras-Vidal & Kerick, 2004); isolation of temporally and spatially overlapping stimulus and response related brain responses during a visual selective attention experiment (Jung, Makeig, Westerfield, Townsend, Courchesne & Sejnowski, 2001).

Although the specific electrocortical phenomena that benefit from ICA are diverse, the nature of the information gained by each instance is quite similar. Namely, an increased signal-to-noise ratio at the level of the single trial that increases the power of statistical tests and the isolation of independent electrocortical processes that are otherwise mixed when assessed at a scalp recording site. Notably these two benefits of ICA often reveal effects that are not apparent at the scalp sites or reveal aspects of the ERP elements that are not accessible from the scalp sites.

\textit{Bootstrapping and Differential Activation Robustness (DAR)}

The critical timing controversy of the face effect is the result of an unreliable P100 effect in the literature. Therefore, in addition to isolating the electrophysiological constituents underlying the P100 and N170 ERP components, it is important to determine both the timing and the robustness of the various face related ERP differences. Testing group differences as they relate to the earliest peak difference in the ERP would miss
several important distinctions that need to be made regarding the critical timing of the face effect. Most notable are (1) the initial divergence of the ERP waveforms across two conditions (rather than the first peak amplitude difference), and (2) the single subject robustness of the differences at each time point in the ERP complex (likelihood of finding the effect rather than size of the effect). The current study uses bootstrapping methods introduced by Rousselet et al., (2008) to assess the timing of the differences between two ERPs as well as Differential Activation Robustness (DAR) (Rousselet et al., 2008) to assess the likelihood of finding effects at each time point.

**Single subject statistics versus group effects**

In a field that has a tradition of group based statistical design it is difficult (if not impossible) to differentiate whether unreliable effects in the literature are caused by weak effects in each individual versus robust effects in only some of the subjects. By using methods of robust estimation (bootstrapping and DAR) the current investigation aims to explore in a single study and at the level of the single subject the unique reliability reputations that the P100 and N170 have evolved in the face processing literature.

**Goals**

The general focus of this research is to examine the timing and robustness of ERP effects at the scalp and in the constituent electrocortical processes (obtained from ICA) during the period of the P100 and N170 complex for face versus house comparisons as well as stimulus inversion comparisons. The experimental paradigm and data analysis strategy have been designed to address four specific goals.
The first goal is to replicate the N170 effects reported by Rousselet et al. (2008) using a stimulus set that does not have sophisticated controls for low-level differences across conditions. If the N170 results obtained from highly controlled stimulus sets are valid for face processing in general, the same timing and robustness results for the N170 should be obtained from a similar paradigm using a relatively non-controlled stimulus set.

The second goal is to examine the P100 categorical effects in the context of minimal low-level stimulus controls. Using an experimental paradigm that is not designed to minimize the P100 or low-level categorical differences between categories, it is expected that this analysis will produce the P100 effect for face-versus-house comparisons that is sometimes documented in the literature.

The third goal is to describe the dynamic activation of ICs that constitute the P100 and N170 complex at the scalp. Although ERP components (such as the P100 and N170) are often interpreted as anatomically simple and temporally isolated, it is hypothesized here that each ERP component is constituted from multiple electrocortical processes, and similarly, each electrocortical process is a constituent to multiple ERP components. Further, it is hypothesized that the categorical effects at different periods along the ERP are attributable to different constituent processes.

Finally the fourth goal is to describe the robustness of the categorical effects over the period of the P100 and N170 complex at the scalp and in the ICs. For this goal it is hypothesized that the robustness of the N170 reported by Rousselet et al. (2008) will be replicated with the current paradigm. Furthermore, if a face-minus-house group effect is present for the P100, it is hypothesized that when it is examined as the average of single
subject DAR, this effect should be less robust than the N170 effect. This result of a smaller P100 robustness would reflect the lack of consistency in the literature for the face effect at the time of the P100.

Methods

Participants

Ten healthy adult volunteers took part in this study. All individuals had normal or corrected to normal vision; five were female, 9 were right handed. One male and one female participant had to be excluded from the analysis based on uncorrectable artifacts in the EEG collection, reducing the number of participants to eight.

Stimuli

Twenty-six unique images were used in this design. Sixteen were face stimuli, eight were houses and two were half-circle checkerboards. All stimuli were matched for outer shape and average pixel luminance. All face and house stimuli were front-view gray scale photographs with an oval crop and presented at a size of 8cm wide by 10cm high. The sixteen face stimuli were made up of four identities in two emotions (angry and fearful) and were either upright or inverted in orientation. The eight house stimuli were made up of four identities that were either upright or inverted. The remaining two stimuli were left and right half-oval checkerboards. Sample stimuli are depicted in Figure 2a.

Design and procedure

Subjects sat alone in a dark room with the experimenter's work station outside the door. The viewing distance was held at a constant 30cm using a chin rest. Stimuli were
a. Example stimulus sequence used in face/house/checkerboard task. Images were presented for 250 ms and included a random ISI ranging from 800 ms to 1200 ms. Participants were asked to respond as quickly and as accurately as possible by pressing a left or right button in response to the infrequent left or right half-circle checkerboards.
b. Example stimuli used as animation for trials in the fading blocks of the task. In these blocks stimuli faded into one another without a blank screen ISI. During these blocks participants were asked to respond with their dominant hand to the appearance of an infrequent full-circle checkerboard stimulus.
presented on a Dell CRT monitor (1024x768 screen resolution and 60Hz refresh). All stimuli were presented in the center of the screen behind a small gray fixation “+” that was displayed constantly for the duration of the task (E-Prime). Participants made their responses using both hands on a four key pad (Electrical Geodesics Inc.).

The task procedure consisted of eight blocks of trials. Trial blocks were separated by a short break that was terminated by the experimenter. Although each break had a variable duration the researcher attempted to keep the breaks to a duration of about 30 seconds. Each block alternated between two types of trial procedures (four of each) and the initial block type was counterbalanced across participants.

In one block type the stimuli were presented for 250 ms with a variable inter-stimulus interval between 800 ms to 1200 ms. Participants were allowed the entire trial duration to give their response. For the blocks of this type the participants were instructed to respond as quickly and accurately as possible to left and right checkerboards by pressing the left-most and right-most keys respectively.

In the other block type stimuli were presented as an animation of variable spatial frequency. Each image was filtered at various low pass intervals creating seven levels of spatial filtered gradient that, presented in rapid succession, appeared as an animation where each stimulus image appeared and then disappeared out of the background into a mean luminance blur (See Figure 2b for an example filter series). The average pixel luminance was held constant over the entire duration of these blocks where each stimulus presentation appears as a gradual increase and then decrease of spatial frequencies.

There were a total of three hundred trials per block consisting of fifty of each of the following stimulus types: upright faces, inverted faces, upright houses, inverted
houses, left checkerboards and right checkerboards. Identity was varied randomly for both face and house stimuli on every trial, as was emotion for face stimuli.

In order to control for task related effects across stimulus contrasts, all stimulus categories examined in this experiment were non-targets according to the participant's instructions. Further, the participant's task (respond with left or right finger press to left or right visual field half-checkerboard image respectively) in no way biased the perception of any non-target stimulus category (be it face, house, upright or inverted). Because top-down attentional factors are know to affect ERPs as early as 100 ms following the stimulus onset, when testing perceptual hypotheses it is paramount to not confound categories with task related salience effects. To this end, the current study not only limited its analysis to non-target stimuli, but also used a target stimulus set and employed a discrimination rule (e.g., is it only on the left or only on the right) that did not relate in any systematic way to the various stimulus categories among the non-target images.

Some characteristics of the stimulus delivery paradigm were chosen based on their potential benefit to ICA training. Because ICA decomposes a set of mixed signals (in this case EEG recordings from the scalp) into a set of maximally independent and spatially fixed factors (in this case estimates of independent cortical and non-cortical field potential generators), there are two situations that lead the ICA to group two or more sources of information into a single IC. The first situation is that in which two or more sources of information to the mixed scalp signals are coherent in terms of their activation pattern over time, regardless of the complexity of their joint projection to the scalp. The second situation is that in which two or more sources of information that have
independent activation patterns over time share a similar projection pattern to the scalp. Because the aim of this study is to assess the highly spatio-temporally overlapping constituent electrocortical processes informing the P100 and N170 ERP complex, ICA training strategies were used in the experimental design to help ICA "see" the independence between processes of interest. ICA training strategies refer here to the characteristics in the experimental design that do not relate to the hypothesis test but instead to the expression of independence of electrocortical processes at the scalp.

The first task characteristic that was chosen primarily as an aid to the ICA decomposition was the number of trials and the duration of in-task recording. Although 200 trials per condition are not required to establish clear face effects or inversion effects in the ERPs, ICA benefits from a long on-task recording time.

The second set of ICA training characteristics used in this design focused on the spatial independence of the P100 and N170. Although the P100 is generally localized to medial occipital regions of the scalp and the N170 is localized to bilateral occipitotemporal regions there is large spatial overlap of these two components. In order to minimize the spatial overlap of the electrocortical projections the current design takes advantage of the retinotopic properties of the P100. Because the topographical projection of the P100 is known to relate to the location of stimuli in the visual field (Clark, Fan, & Hillyard, 1994), the stimulus size employed here was kept relatively narrow to maintain a spatially concise and medial occipital P100. Further, the P100 is known to have an ipsilateral occipital field projection when a stimulus appears in the left or right visual field. By presenting the target stimuli in the left and right visual fields independently for target trials (one third of all trials) the varying spatial projections of the P100 should
dissociate itself to the ICA from non-visual field related phenomenon in the visual and associative cortices. Specifically, if a given cortical process shared a topographical projection with the P100 that was too similar for the ICA to distinguish, by manipulating the projection of the P100 in some trials those processes that share the same topography given central stimulation are more likely to be differentiated by the ICA.

The third ICA training characteristic focuses on the temporal coherence of independent sources of information. Again, if two or more independent sources of information are temporally linked in terms of activation pattern, ICA will likely resolve these processes into a single IC. Given this limitation of the ICA decomposition the standard procedure for producing ERPs itself may encourage independent cortical processes to be grouped together as they are all responding in an evoked manner to stochastic events in time. To counteract this bias towards mutually evoked activation during the in-task recording period, blocks of fading stimulus animations where employed. Although, in these fading blocks, the exact same images were depicted as in the harsh onset blocks there were no obvious “evoked” moments to extrinsically link cortical processes temporally. Because the participants were still performing a similar task and perceiving identical images, the same high level integrative processes should be informing the mixed scalp signal, however, in these blocks it would be doing so without a tight temporal link to all other evoked phenomena.

Although the blocked experimental paradigm used for this study was also designed to test the effects of the ICA training strategies on the outcome of the ICA decomposition, such analyses are beyond the scope of this paper and will be explored in future publications.
**EEG recording**

EEG data was recorded using ActiView software and a 128 channel BioSemi ActiveTwo hardware configuration. The analog signal was digitized at 1024Hz and online low pass filtered at 512Hz. Data were referenced online to the common mode sense. Electrode offsets were maintained below 50 units (BioSemi offset). All participants were given time at the beginning of the session to get comfortable with the EEG cap and recording environment. This time was also important to allow the cap and SignaGel to settle before beginning the recording and to allow the participants to explore the effects of eye blinks, eye movements, muscle activity (jaw clenching, facial expressions, squinting, neck and shoulder tension) and movement artifacts. Participants then practiced avoiding such artifacts while watching their online EEG signals.

**EEG pre-processing**

All pre-processing was performed in the open source toolbox EEGLAB (Delorme & Makeig, 2004) for Matlab. The first step in the pre-processing of the EEG data was the visual inspection of the continuous raw data for each block and each individual. In this first step any flat or unstable channels were removed from further processing. Unstable channels were identified based on persistent or transient activation patterns that deviated greatly from neighboring recording locations on the scalp. The full duration of each recording block was then bandpass filtered from 1-30Hz off line and re-referenced to the average of 32 interpolated channels that were equidistant, symmetrical, and spatially representative of the full EEG montage. A second visual inspection step was then performed to prune any more unstable channels revealed by the filtering and re-
referencing as well as any periods of time that contained non-biological noise (movement artifacts) or excessive biological artifacts (EMG or EOG).

**Independent component analysis (ICA)**

Following the initial pruning of the continuous EEG traces all eight blocks of data were appended and submitted to an extended infomax ICA algorithm. The ICA was applied to the entire continuous data set for each individual uniquely. The ICA decomposition was performed on participant files that had an an average of 107.63 (SD 11.81) channels and an average duration of 28.86 (SD 2.54) minutes. Output of this initial ICA decomposition was examined further for scalp channels and time periods that contributed to the deterioration of the stability of the ICA decomposition. Examining the topographical projections of the ICs reveals bad channels when a dominant IC (within the first 16 ICs ordered by voltage contribution to the scalp data) projects to a single recording site on the scalp. Such topographical projections of single ICs suggests that the single channel is unique and does not reflect the expected spatial dependence that results from field conduction to the scalp. Examining the time course of activation for the ICs revealed periods of excessive independence across channels when a period of time presented a burst in activity across multiple ICs spanning the total range of ICs. Most of the EEG power in the current data files could generally be expressed in the first 16 to 24 ICs (including cortical activity, eye activity, muscle activity, heart signal, etc.). Periods of excessive non-linearity however are clearly expressed in the output of the ICA as transient periods of time where there is an increase in power of several more ICs (as many as 50 or 60). These periods of time that require numerous ICs to describe the data
are the result of transient and substantial increases in the independence between recording sites often the result of movement artifacts or complex muscle activity. Following the pruning of bad channels and time periods revealed by the initial ICA decomposition, a subsequent ICA was applied to the remaining data. In some cases further rounds of pruning were required before the resulting IC results were clear of bad channels and periods of excessive independence between recording sites.

All of the visual pruning was performed on the continuous data with task event markers displayed (to help identify break periods for removal). The categorical information was not contained in displayed event markers to ensure that unintentional categorical favoring in the pruning process could not occur. Table 1 contains the means, standard deviations, minima and maxima for the number of trials remaining in each condition following all pruning stages. The equality of the number of trials across stimulus conditions suggest that the no categorically systematic pruning effects occurred.

Table 1. Number of trials remaining by condition after pruning.

<table>
<thead>
<tr>
<th></th>
<th>Face Upright</th>
<th>Face Inverted</th>
<th>House Upright</th>
<th>House Inverted</th>
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</thead>
<tbody>
<tr>
<td>M</td>
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<td>168.75</td>
<td>169</td>
<td>170</td>
</tr>
<tr>
<td>SD</td>
<td>19.53</td>
<td>18.51</td>
<td>18.86</td>
<td>22.5</td>
</tr>
<tr>
<td>Minimum</td>
<td>142</td>
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<tr>
<td>Maximum</td>
<td>192</td>
<td>192</td>
<td>193</td>
<td>196</td>
</tr>
</tbody>
</table>

ICA artifact correction

Once that the continuous data was pruned and a stable ICA decomposition was
achieved the ICs that described biological artifacts in the EEG signal were removed before performing further analysis. Although major ocular and EMG artifacts were removed from the continuous EEG signal prior to the ICA, many electrophysiological artifacts remained in the data that were clearly identified in the ICA decomposition. ICs accounting for eye blinks, lateral and horizontal eye movements, forehead, temple and neck EMG as well as ECG artifacts were identified and remove based on scalp projection characteristics and their signature time courses of activation.

**Segmentation**

Stimulus-locked ERPs were calculated relative to the onset of all non-target trials that were deemed to be artifact free. Trials were pooled into four categories representing all non-target stimulus categories, namely, face-upright, face-inverted, house-upright and house-inverted. The period of -200 ms to 0 ms relative to stimulus onset was used as baseline.

**IC identification**

Independent components were selected for categorical effects analysis based on topographical projection and voltage dominance in the total EEG envelope during defined time periods. Specifically, the IC representing activation of the N170 ERP component (icN1a) was defined as the IC whose projection to the scalp accounted for the greatest occipito-temporal negative deflection and mid-frontal positive deflection at the time of the scalp N170 peak voltage. Similarly the IC representing activation of the P100 ERP component (icP1a) was defined as the IC whose projection to the scalp accounted
for the greatest medial-occipital positive deflection at the time of the scalp P100 peak voltage. In two cases the icN1a was also the dominant component in the total scalp envelope at the time of the P100 peak voltage. In these cases the next largest IC at the time of the scalp P100 peak voltage was defined as icP1a. The topographies of the selected ICs in these two cases corresponded to the expected topographical signatures of the N170 and P100 ERPs respectively. It should be noted that the strategy of selecting relevant IC based on timing of signal dominance never produces a discrepancy between time course of IC activation and topography in determining the functional identity of the ICs. This is to say that using the time course of activation in determining the functional identity of the relevant ICs was sufficient in all cases and that the examination of the IC's projection to the scalp served only as a confirmation.

In addition to the two dominant ICs at the time of the P100 and N170, two other ICs made large contributions to the posterior scalp ERP in the first few hundred milliseconds following stimulus onset. Six of the eight subjects produced a second IC that expressed a clear ERP at the time of the P100 and had a medial-occipital projection to the scalp. This second IC whose peak ERP activation occurred at the time of the downward slope of the P100 was labeled icP1b. In three of the subjects, a second IC also contributed a clear ERP at the time of the N170 and had a bilateral occipito-parietal projection to the scalp. This component was labeled icN1b.

Although there was no absolute threshold value on a measure that determined the number of ICs required to explain the scalp ERPs over the period of the P100 and N170, measures such as the voltage of IC back projections and spatial variance accounted for at the scalp were examined for each individual in the task of determining IC inclusion.
Tables 2 through 5 present the IC back-projected percentage of spatial variance accounted for in each individual as well as the group means and standard deviations. The percentage of spatial variance accounted for is calculated for each IC (and collection of ICs) at each time point along the ERP as the residual variance (variance of the total scalp data minus the back projected IC) divided by the total scalp variance. Tables 2 and 3 present the percentage of spatial variance accounted for in the face ERP for the duration of the P100 and N170 respectively. Tables 4 and 5 present the percentage of spatial variance accounted for in the face-minus-house difference ERP for the duration of the P100 and N170 respectively. This measure can change substantially from time point to time point and can also be a negative value (indexing suppression at the scalp by ICs that simultaneously project overlapping voltages of different polarities). While this measure does not provide an objective cutoff point for IC inclusion it does express a clear pattern of relative dynamic contribution of the ICs. Specifically that the icP1a and icN1a tend to express the dominant contribution to the face ERP scalp variance during the P100 and N170 respectively. Also, although icP1b does not account for as much of the data during the P100 ERP to faces as the icP1a, its contribution to the face minus house difference ERP over the period of the P100 is often greater than that of icP1a. Finally, icN1b expresses some high percentage of variance accounted for but is inconsistently expressed across individuals and for those individuals who produced the icN1b a clear pattern of variance accounted for is lacking.

Bootstrapped group statistic

The statistical treatment employed in this study follows closely the procedures used by Rousselet et al. (2008) and introduced by Wilcox (2005). Categorical differences
Table 2. Percentage of P100 scalp variance accounted for by each IC in the face ERP.

<table>
<thead>
<tr>
<th>Subject</th>
<th>icP1a</th>
<th>icP1b</th>
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Table 3. Percentage of N170 scalp variance accounted for by each IC in the face ERP.

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Table 4. Percentage of P100 scalp variance accounted for by each IC in the face minus house ERP difference.

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Table 5. Percentage of N170 scalp variance accounted for by each IC in the face minus house ERP difference.

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<td>10.55</td>
<td>4.33</td>
<td>12.43</td>
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</table>
between ERPs were assessed for the group using a percentile bootstrap technique averaged across individuals. In this study 20% trimmed means were used in the place of the full means across all artifact free trials for a given stimulus category. The trimmed mean was chosen for the analyses in this study based on its benefit in representing electrophysiological data which can often be contaminated with extreme values (see Rousselet et al. 2008 and Wilcox 2005 for a detailed description of the benefits of the 20% trimmed mean).

All of the robust estimation methods (bootstrapping, Monte Carlo, etc.) described in this section rely on surrogate sets of data. A surrogate set is a random sample of data points obtained with replacement from the full sample of data points available. For example, a surrogate set of trials for a given stimulus condition containing 100 epochs is a set of 100 data trials selected randomly with replacement from the full set of 100 trials. Although both the original set and the surrogate set have an identical number of trials and all of the trials present in the surrogate set are present in the original set, variability between the surrogate sets occurs due to the over- and under-sampling of specific trials from the original set, this is a function of the replacement in the random sampling procedure.

In order to estimate the alternative hypothesis (H1) distribution for a given data set, 1000 surrogate set trimmed mean ERPs were obtained from the segments of each category and subject. Averaging surrogate ERPs across subjects produced 1000 surrogate set grand ERPs per stimulus condition. From these 1000 surrogate set grand average ERPs, estimates of the H1 distributions for each contrast were then obtained by subtracting the surrogate set grand ERPs of one condition from another. The four specific
contrasts examined in this procedure were upright-face minus upright-house, inverted-face minus inverted-house, inverted-face minus upright-face and inverted-house minus upright-house (the condition that is predicted to be larger is first in the subtraction for all cases). The 99% confidence intervals at each time point in the surrogate set grand ERP contrasts for H1 were calculated and periods where the interval did not include zero were considered significant. A Bonferroni correction for multiple comparisons was used to account for the 129 time points being compared in each of the categorical contrasts resulting in an alpha level of 0.0000775 (p0.01/129 = 0.0000775, critical z value of 3.78).

**Differential activation robustness**

Considering that the critical timing controversy regarding face specific effects in ERP research revolves around an unreliable differentiation between faces and other stimulus categories during the time of the P100, it is important to the goals of this study to not only examine the early effects if they exist but also to measure the robustness of the early ERP effects. Further, an important distinction to make is whether the effect is frail in each individual or whether the effect is robust but only in some individuals. Both of these sources of instability in group effects could explain the current state of the literature describing face specific P100 effects.

The measure of differential activation robustness simply adds one layer of surrogate set sampling to the bootstrapping procedure described above. The additional surrogate set sampling is added before performing a bootstrap test in a Monte Carlo procedure where the re-sampling and testing is repeated 100 times. At the end of the 100 Monte Carlo experiments the Boolean values for each data point (0 = fail to reject H0, 1
= reject H0) are summed to create a measure of the likelihood of finding an effect at each
data point given the current data set. Although the original trial sequence is never
explicitly tested in this procedure, by testing 100 variants of possible outcomes this
measure achieves a likelihood (rather than magnitude) measure of a given effect (not that
likelihood and magnitude are entirely independent).

Results

ERP analysis overview

The ERP results presented in the following sections each partially inform the four
main goals of this research; (1) the replication of the N170 effects documented by
Rousselet et al. (2008); (2) the examination of the P100 for categorical effects given that
the stimulus set has no sophisticated controls for systematic low-level differences; (3) the
description of the underlying electrocortical dynamics (obtained by ICA) that constitute
the scalp ERPs and their categorical effects; and (4) the examination of the robustness of
the effects at each time point along the P100 and N170 ERP complex.

The ERP analyses and results are organized such that they progress from global
measures to local measures along two dimensions. The first dimension is the spatial
characteristic of the ERP effects. The global-to-local spatial progression of the analysis
specifically moves from the total scalp global field amplitude (GFA) that takes in the
entire topography in a single waveform, to the multiple EEG site analysis (each site
representing multiple mixed sources summing at the scalp at a specific location) and
then finally to the independent components (each IC signal representing estimates of
temporally independent and spatially fixed source activation). The second dimension of
the analysis concerns the scope of the data, starting from group effects, progressing to the single subject effects considering the single-trial influence on the robustness of effects within the individual. The global-to-local data scope progression of the analysis specifically moves from the bootstrap significance tests of the group grand averaged ERPs for each categorical contrast (producing the generalized effects relating to most of the research in the face processing literature), to the DAR measure expressing the consistency of the group effects at the level of the single subjects without ignoring individual differences and examines the stability of when different sets of single trials are used in the bootstrap tests.

*ERP characteristics*

Before describing the global-to-local statistical outcomes of this study, the following few paragraphs outline some key features of the ERPs produced in this data set. The grand average scalp ERP waveforms for forty-four interpolated channels and topographical maps (between 80 ms and 220 ms at 20 ms intervals) for each of the four non-target stimulus categories (upright face, inverted face, upright house, inverted house) are presented in Figure 3. A clear P100 ERP component is present in each of the four categories listed above. The P100 ERP components are then followed by the N170s that are expressed as clear positive and negative peaks across the entire scalp envelope for the two face categories; however, this component is less defined in the house categories. For the house ERPs, the N170s are not distinct peaks when looking at all forty-four channels but rather they are lumps on the increasing slope of the later P2 ERP component. Following the N170 components all stimulus categories show a large broad activation
apparently encompassing the P2, N2 and P3 ERP components.

The topographies of these ERP components follow the expected pattern for early visual evoked potentials. The P100 starting at around 80 ms following stimulus onset expresses itself to the scalp as a broad medial occipital positivity that persists for approximately 60 ms. The positive polarity medial-occipital topography shifts bilaterally and then becomes negative in polarity over the occipito-temporal scalp areas at the onset of the N170 (approximately 150 ms following stimulus onset). This occipito-temporal bilateral (although right dominant) negative topography persists for approximately 50 ms before the projection returns to a medial-occipital positivity over the period of the P2 ERP component. Figure 4 is the same data from Figure 3 except that it only displays a subset of traditionally scored channels for the P100 and N170 complex. The gray waveform corresponds to channel FCz, the black waveform corresponds to Oz, the red waveform corresponds to PO7 and the green waveform corresponds to PO8.

Because the focus of this research is directed toward early face specific processing, ERPs later than the P2 are not addressed. Taken together the ERP characteristics described above inform the goals of this research by first replicating the time course and topographical maps reported by Rousselet et al. (2008). Second, the distinction between the topographical maps associated with the P100s and the N170s begin to speak to the electrocortical dynamics underlying these ERPs as well as their anatomical independence.

**ERP IC characteristics**

The IC cluster contributions to the grand average scalp ERPs are illustrated in
ERPs and topographical maps of faces in the top quadrants and houses in the bottom quadrants. The left and right quadrants depict upright and inverted ERPs and topographical maps respectively. Black waveforms depict the overlay of 44 channels representing the entire EEG montage with. Colored plots are the topographical maps illustrating the spatial distribution of activity on the head at distinct time points along the ERP starting at 80 ms post-stimulus onset with a 20 ms inter-plot-intervals up to 220 ms.
Figure 4. Scalp ERPs at Fcz, Oz, PO7 & PO8.

ERPs to faces in the top quadrants and houses in the bottom quadrants. The left and right quadrants depict upright and inverted ERPs respectively. These are the same data as depicted in Figure 2 except the number of channels are reduced to 4. Specifically sites FCz (grey), Oz (black), PO7 (red) and PO8 (green).
Figure 5. The thick black lines in these plots represent the voltage envelope of all the scalp channels at every time point. These thick black lines correspond exactly to the maximum and minimum voltage values for each time point plotted in Figure 3. Each of the four coloured envelopes represent the maximum and minimum voltage values projected to the scalp by the IC clusters accounting for the scalp ERP during the first 200 ms post stimulus onset. The gray area in these plots represents the voltages accounted for at the scalp by all four IC clusters taken together.

The scalp voltages (dark black lines) are described above in the “ERP characteristics” section and are only included in Figure 5 as a reference point for the IC contributions.

The ICA decomposition revealed four IC clusters that accounted for the scalp data during the first 200 ms following stimulus onset. The ICs from each individual that contribute to the grand IC clusters were identified based on topographical projection and time course of activation during the period of the ERPs of interest. Two of the four IC clusters contained ICs contributed by all eight of the subjects analyzed in this study.

One IC that was identified in each subject contributed the largest voltage range during the time of the P100 ERP component and had a broad medial occipital topographical map. This first IC cluster is named icP1a in all figures, and is illustrated with green lines. The topographical maps depicted in Figure 5 are connected to their relative envelope waveforms by a straight line. This line connects to the IC’s respective upper envelope waveform at the time of its maximum contribution to the scalp ERP signal. The icP1a cluster is the first to reach peak contribution in all four stimulus categories. Although icP1a was identified based on its contribution to the total scalp
Figure 5. Scalp ERPs with IC cluster contribution.

ERPs to faces in the top quadrants and houses in the bottom quadrants. The left and right quadrants depict upright and inverted ERPs respectively. IC envelope plot. Black lines represent the envelope around the data presented in Figure 2, each coloured envelope represents the contribution of each of the four ICs, namely, icPla (green), icPlb (red), icNla (orange), icNlb (blue). The topographical projections of each IC is connected to its envelope by a coloured line. The gray area represents the total data projected by all four ICs taken together.
signal during the time of the P100 it's activation increases again during the descent of the N170 and persists over the period of the P200.

A second IC was identified in all subjects and contributed the largest voltage range during the time of the N170 ERP component and had a right-dominant bilateral occipito-temporal negative projection (as well as a medial fronto-central positive projection, thus describing the N170 and vertex positive potential (VPP) scalp ERP components in a single IC). Because this is the dominant IC during the period of the N170 in all subjects it is labeled icN1a in all figures. Although this component was identified based on its contribution to the total scalp ERP voltage range during the N170 time period, it is clear that this IC is also active (with a positive polarity at posterior sites) during the period of the P100. In two subjects the icN1a contribution exceeds the contribution of icP1a during the time of the P100. The icN1a is also active (with a positive polarity at posterior sites) following the N170 during the latency of the P200, peaking at about 250 ms following the stimulus onset.

Two other ICs were identified in several subjects and made large contributions to the total scalp ERP. The first of these two was identified in six of the eight subjects and had a distinctive occipital pole projection and peak activation closely following that of the icP1a. This IC is labeled icP1b in all figures. Another defining characteristic of this IC is that it is similarly responsive to the offset of the stimulus as to the onset.

The final IC that was identified as contributing to the ERPs during the first 200 ms following stimulus onset was apparent in only three of the eight subjects. This final IC was maximally active in the ERP at approximately the same time as icN1a but had a more medial and dorsal bilateral occipito-parietal topography that was equally distributed on
each side of the sagittal plane.

The grand average scalp voltage ranges described by these four IC clusters taken together (gray areas in the plots of Figure 5) illustrate the sufficiency of these four IC clusters for describing parsimoniously the total scalp ERPs during the first 200 ms following stimulus onset. Similarly, the percentage of spatial variance accounted for presented in tables 2 through 5 reflect the descriptive power of these ICs.

Although we would not expect the gray areas in the plots of Figure 5 to match exactly the areas between the thick black lines (representing the total scalp voltage range at each time point) there are two counter-intuitive patterns between the summed IC cluster voltage range (gray areas) and the total scalp voltage range (thick black lines). The first is the upward voltage shift of the scalp range accounted for by all of the IC clusters taken together (gray areas in Figure 5) as compared to the total scalp amplitude range (thick black lines in Figure 5) during the period of the N170 for face ERPs. During the time of the N170 ERP component the range accounted for by all four IC clusters taken together describes a voltage that is both more positive and less negative across the entire scalp than the total scalp ERP envelope. Although this shift in voltage range described across the scalp by the four IC clusters can have several explanations it is likely that this shift is due to a series of ICs that contribute very little individually to the ERP but summed together account for an artifact in the data that is expressed as a spatially global slow wave drift in the ERP starting at about 100 ms following the stimulus onset.

The second counter-intuitive relationship between the voltage range projected by the four IC clusters and the total grand average scalp ERP envelope is the augmentation of the IC cluster projection during the period of the N170 for houses over the scalp data.
resulting in the voltage range of the IC clusters being larger than the total scalp ERP voltage range. Although this phenomenon may also have several explanations it is likely that there are ICs that contribute little to the ERP individually but taken together cancel out activation of these four IC clusters. This situation can be achieved when ICs that have overlapping topographical projections are active simultaneously with opposite polarities and cancel each other out at the scalp.

Taken together, the ERP IC characteristics inform the third main goal of this research relating to the underlying electrocortical dynamics that constitute the P100 and N170 ERP complex. The constituent processes obtained from the ICA decomposition reveal that each ERP component (e.g., P100 and N170) is constituted by multiple cortical sources. Further, each of the ICs are constituents to multiple ERP components at the scalp. Although the P100 and N170 share constituent processes, the relative contribution of the ICs appears to be different for the two ERP components. This begins to speak to the hypothesis that the P100 and N170 can have anatomically independent categorical effects.

Contrasts

Stimulus related ERP responses were examined in relation to four categorical contrasts. Although the tasks performed by the participants included a target detection constituents, all ERP comparisons described in this section are between non-target stimulus categories. Specifically, the four categorical contrasts are between image categories upright-face and upright-house, inverted-face and inverted-house, inverted-face and upright-face, as well as inverted-house and upright-house. For each of the contrasts listed above the stimulus category that is hypothesized to produce the largest
N170 ERP (if a difference is expected) is named first. Similarly, in the comparisons the difference waves were calculated by subtracting the second image category from the first in the above list.

The four comparisons described in this paper are a partial replication of the time course and robustness analyses described by Rousselet et al. (2008). The present study examines four contrasts of the possible sixteen non-target stimulus contrasts so as not to confound image category (face or house) with inversion (upright or upside-down) in any single contrast. This is to say that image category and inversion are unique independent variables and the four contrasts examined here represent all combinations of image category (without inversion) and inversion (without image category).

**Group bootstrap test on GFA**

Beginning at the most global level of analysis in respect to spatial specificity and data scope the first measure that is compared across the four contrast described above at the level of group analysis is the Global Field Amplitude (GFA, standard deviation across channels of an ERP, described in Methods section). This measure is described first as it is the most global (describes the entire scalp ERP in a single signal), and presents a clear comparison to the data presented by Rousselet et al. (2008; See Appendix). This set of GFA results is focused on informing the first main goal of this study, namely, replicating the N170 scalp results reported by Rousselet et al. (2008). They also address the second goal of this research relating to the presence or absence of an effect for stimulus category during the period of the P100 at the scalp.

The GFA results are illustrated in Figure 6. The four contrasts, namely upright-face minus upright-house, inverted-face minus inverted-house, inverted-face minus
The four subplots present specific GFA ERP categorical contrasts, namely: Upright face minus upright house at the top left, inverted face minus inverted house at the top right, inverted face minus upright face at the bottom left and inverted house minus upright house at the bottom right. GFA ERP category overlays depict the first waveform entered into the subtraction in bold black and the second waveform entered into the subtraction in narrow black. The light gray overlaid waveforms represent all 1000 bootstrapped surrogate difference waves. The dark gray lines represent the upper and lower boundaries of the 99% confidence interval for the differences. The zero line (H0) is red where the confidence interval does not include zero and the waveforms are considered to be significantly different from one another.
upright-face, as well as inverted-house minus upright-house are presented in individual plots. Each plot contains the respective GFA ERP overlay (two black lines, the bold line being the first category entered into the subtraction to create the difference waves), each of the 1000 surrogate ERP difference waves produced by the bootstrapping procedure (thin light gray lines), the 99% confidence intervals of the differences (thin dark gray lines), the zero line (null hypothesis [H0] which is plotted as a white line over points where there was a failure to reject the null hypothesis) and the periods of significant differences between the two conditions (red diamond on the zero line for each time sample that is significant).

The GFA effects during the N170 spanning the time period from about 150 ms to 200 ms following the stimulus onset match very closely the effects found by Rousselet et al. (2008; see Appendix A). Namely, the GFA waveform is significantly differentiating the face versus house stimulus categories (for both upright and inverted orientations) over the period of about 150 ms to 200 ms. The inversion effect is also significant for face stimuli during this period taking the form of a larger and later deflection for inverted faces over upright faces during the period of about 165 ms to 220 ms. The latency shift of this contrast results in a short period during the initial slope of the N170, at approximately 150 ms, to be larger in upright faces over inverted faces. This initial N170 inversion effect that is due to the latency of the N170's onset was also found in Rousselet et al. (2008; see Appendix A). Finally, although Rousselet et al. (2008) found a small period of significance preceding 200 ms for the inversion effect in house stimuli, no such effect was found in the current study. The absence of the inversion effect for houses is an anticipated result that speaks to the specificity of the N170 effect to faces independent of
low-level stimulus characteristics.

In addition to the large effects found during the period of the N170 ERP component, for face versus house comparisons (regardless of orientation of the stimulus) the GFA effects were also strong during the period of the P100 over the time of about 100 ms to 150 ms following stimulus onset. A late face inversion effect was also found in the GFA signal during the terminating slope of the P100. This inversion effect in the P100 was only found for face stimuli and the form of this inversion effect was different from the face versus house comparisons. In the face versus house comparisons the GFA P100 effect is a clear amplitude difference starting just prior to 100 ms post-stimulus onset. The face inversion effect during the time of the P100 is brief (from approximately 130 ms to 145 ms) and takes the form of a latency difference of the trailing slope of the P100. Voltages of the P100 peak amplitudes for upright and inverted faces are not significantly different. No inversion effects were present during the P100 time period for the inversion contrast of house images.

Taken together the GFA results inform several important characteristics of the early evoked responses during face and house perception. In general these result support the conclusion of Rousselet et al. (2008) that the GFA transform provides a sensitive and parsimonious time course of the P100 and N170 ERP components across the entire scalp. These results also inform the first goal of this research relating to the replication of the N170 results reported by Rousselet et al. (2008) who used stimuli that were controlled for low-level characteristic differences across face and house categories. The P100 effects for face and house contrasts in the current GFA results, considered together with those of Rousselet et al. (2008), provide strong evidence that the controversial P100 effect in the
face-processing literature is likely a function of categorically systematic low-level stimulus differences. These P100 effects inform the second goal of this study relating to the nature of the P100 effects in the face-processing literature. These results are in agreement with the hypothesis that the P100 effects for image category are related to low-level stimulus characteristics because they are present in the absence of sophisticated low-level image controls (current study) but absent in the presence of sophisticated low-level image controls (Rousselet et al. 2008).

**Group bootstrap test on interpolated montage**

Although the GFA results (taken together with the results of Rousselet et al., 2008) begin to identify the P100 as a process that is independent from the N170 face specific effects they are not able to speak to the physiological independence of the cortical regions that produce the P100 and N170 ERP effects at the scalp. The following results describe the same level of data scope (group based bootstrap significance tests) but represent the next step in the global-to-local progression along the spatial dimension examining the effects at specific scalp locations rather than the GFA. This analysis begins to inform the third goal of this research relating to the dynamics of the underlying cortical processes of the P100 and N170 ERP complex by considering the changing scalp topography of the relevant categorical effects.

In order to begin exploring the topographical characteristics of the P100 and N170 effects the same bootstrapping technique that was used to assess the GFA effects was applied to forty-four interpolated scalp channels. The results of this analysis are displayed in Figure 7. The contrast plots of Figure 7 are presented in the same order as the GFA
Figure 7. Scalp site overlay of masked z scores and topographical maps.

The four subplots present significant z scores over time for each channel for specific categorical contrasts, namely: Upright face minus upright house at the top left, inverted face minus inverted house at the top right, Inverted face minus upright face at the bottom left and inverted house minus upright house at the bottom right. Overlay of 44 scalp channel where the y-axis is in z scores of the distance between zero and the confidence interval of the differences obtained by performing a bootstrap test on each channel. The left topographical map in each subplot illustrates the spatial distribution of the z scores at peak P100 differentiation and the left topographical map illustrates the same for the N170 differentiation.
results in Figure 6. Each of the four plots contains an overlay of the forty-four channels (black lines). The y-axis is in z-scores that correspond to the distance of the H1 confidence interval from zero. These waveforms are equal to zero during period where the confidence interval for H1 encompasses H0 (zero). The topographical maps display the same values as the waveform but each display a single time point corresponding to timing of the peak P100 and N170 effects. The means and standard deviations for peak z-scores at the scalp and ICs for the P100 and N170 across subjects are presented in Table 6. Peak scalp effects during the time of the P100 and N170 are greater than the critical z value of 3.78 for all contrasts except for house inversion.

These results match those established by the GFA measure with added information about the polarity and location of the effects on the scalp. The top row of subplots describes the face versus house comparisons (for upright and inverted respectively) which show a clear distinction in the topography of the effects during the period of the P100 and N170 respectively. As is commonly found in the face processing literature, the P100 effect projects a medial occipital positivity while the N170 projects a bilateral occipito-temporal (right dominated) negativity. Although the face and house comparisons produced effect topographies that correspond to independent electrocortical sources for the P100 and N170 ERPs, the face inversion effect that manifested as a latency difference in the trailing downward slope of the P100 shared a similar topography with the N170 face inversion effect. This result regarding the topography of the late P100 inversion effect suggests that the P100 and N170 inversion effects for faces are the result of a single underlying electrocortical generator.
Table 6. Mean and standard deviation peak z-scores by contrast.

<table>
<thead>
<tr>
<th>Score</th>
<th>Face – house upright</th>
<th>Face - house inverted</th>
<th>Face inversion</th>
<th>House inversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalp P100 M</td>
<td>7.85*</td>
<td>8.33*</td>
<td>5.7*</td>
<td>0.97</td>
</tr>
<tr>
<td>SD</td>
<td>2.34</td>
<td>3.4</td>
<td>2.21</td>
<td>3.82</td>
</tr>
<tr>
<td>IcPla P100 M</td>
<td>7.41*</td>
<td>7.84*</td>
<td>0.62</td>
<td>0.67</td>
</tr>
<tr>
<td>SD</td>
<td>4.04</td>
<td>4.68</td>
<td>4.57</td>
<td>3.88</td>
</tr>
<tr>
<td>IcPlb P100 M</td>
<td>11.06*</td>
<td>11.16*</td>
<td>2.01</td>
<td>0.67</td>
</tr>
<tr>
<td>SD</td>
<td>4.64</td>
<td>6.15</td>
<td>5.38</td>
<td>2.47</td>
</tr>
<tr>
<td>Scalp N170 M</td>
<td>12.23*</td>
<td>13.85*</td>
<td>6.13*</td>
<td>1.41</td>
</tr>
<tr>
<td>SD</td>
<td>3.38</td>
<td>3.63</td>
<td>2.3</td>
<td>3.08</td>
</tr>
<tr>
<td>IcN1a N170 M</td>
<td>15.24*</td>
<td>17.66*</td>
<td>8.2*</td>
<td>0.26</td>
</tr>
<tr>
<td>SD</td>
<td>3.94</td>
<td>2.55</td>
<td>1.97</td>
<td>2.5</td>
</tr>
</tbody>
</table>

* Indicates z-scores that are greater than the critical value of 3.78.
The categorical ERP overlays and bootstrapped confidence intervals at scalp sites FCz, Oz, PO7 and PO8 are presented in Figures 8 and 9 (from top to bottom respectively). The plots in these figures use the same colour template as in Figure 6. Namely, each plot contains the respective scalp site ERP overlay (two black lines, the bold line being the first category entered into the subtraction to create the difference waves), each of the 1000 surrogate ERP difference waves produced by the bootstrapping procedure (thin light gray lines), the 99% confidence intervals of the differences (thin dark gray lines), the zero line (null hypothesis [H0] which is plotted as a white line over points where there was a failure to reject the null hypothesis) and the periods of significant differences between the two conditions (red diamond on the zero line for each time sample that is significant).

In Figure 8 the results for the upright face minus upright house are presented in the left column and the inverted face minus inverted house are presented in the right column. These contrasts illustrate a clear difference in the peak voltage of the P100 (largest at Oz), as well as the N170 (largest at PO8). Notably, significant differences during both the period of the P100 and the N170 can be seen at all of these scalp locations. For the inversion effects in Figure 9 (inverted face minus upright face on the left and inverted house minus upright house on the right) there are clear differences in the form of the ERP effects from those found in the face minus house contrasts. Firstly, there are no significant differences between the ERPs to upright and inverted houses. Secondly, the inversion effect for faces is not only a larger peak for the N170 but also a latency shift. Specifically the inverted faces produce a larger and later N170 peak voltage. Thirdly, the Inversion effect for faces that occurs in the time period of the P100 is not a
Figure 8. Scalp site ERP categorical overlays and bootstrapped confidence intervals.

The two columns present specific categorical contrasts, namely: Upright face minus upright house on the left and inverted face minus inverted house on the right. From top to bottom the subplots present data from the scalp sites FCz, Oz, PO7 and PO8 respectively. The ERP category overlays depict the first waveform entered into the subtraction in bold black and the second waveform entered into the subtraction in narrow black. The light gray overlayed waveforms represent all 1000 bootstrapped surrogate difference waves. The dark gray lines represent the upper and lower boundaries of the 99% confidence interval for the differences. The zero line (H0) is red where the confidence interval does not include zero and the waveforms are considered to be significantly different from one another.
Figure 9. Scalp site ERP categorical overlays and bootstrapped confidence intervals.

Inverted face – Upright face

Inverted house – Upright house

The two columns present specific categorical contrasts, namely: Inverted face minus upright face on the left and inverted house minus upright house on the right. From top to bottom the subplots present data from the scalp sites FCz, Oz, PO7 and PO8 respectively. The ERP category overlays depict the first waveform entered into the subtraction in bold black and the second waveform entered into the subtraction in narrow black. The light gray overlayed waveforms represent all 1000 bootstrapped surrogate difference waves. The dark gray lines represent the upper and lower boundaries of the 99% confidence interval for the differences. The zero line (H0) is red where the confidence interval does not include zero and the waveforms are considered to be significantly different from one another.
peak difference of the P100 but rather a latency shift during the trailing downward slope of the P100 (initial slope of the N170).

These results inform the third goal of this research regarding underlying dynamics that produce the P100 and N170 effects by providing evidence that the various categorical effects during a specific ERP component (namely the P100 in this case) are not necessarily attributable to a single underlying electrocortical domain, but rather many functionally and spatially distinct processes may contribute to the effects identified at the scalp. These results speak to the importance of defining effects based on their topography across the scalp rather than at a few preselected channels. Further, given that various spatio-temporal underlying electrocortical constituents can affect a single ERP component, and similarly, a single electrocortical constituent can affect several ERP components at the scalp, these results demonstrate the importance of un-mixing the scalp data into its set of relevant independent components in order to more accurately describe the effects at different times during the ERP.

**Group IC cluster projections to contrast envelope characteristics**

At the most local level along the spatial dimension in this set of analysis is the ICA. The description of the categorical effects at the level of the ICs informs the third goal of this research that is related to explaining the underlying dynamics of the ERP effects at the scalp. The grand average IC clusters that were previously described for their contribution to the ERPs of each of the non-target stimulus categories were examined for their contribution to the grand average difference wave envelopes. The plots in Figure 10 correspond directly to the plots described in Figure 7 except that these waveforms
Figure 10. Scalp ERP contrast envelopes with IC cluster contributions.

The four subplots present IC contribution to the total scalp ERP for specific categorical contrasts, namely: Upright face minus upright house at the top left, inverted face minus inverted house at the top right, Inverted face minus upright face at the bottom left and inverted house minus upright house at the bottom right. Each IC envelope plot of differences shows the envelope the total voltage differences across the scalp in black lines, each coloured envelope represents the contribution of each of the four ICs of the differences observed at the scalp, namely, icP1a (green), icP1b (red), icN1a (orange), icN1b (blue). The topographical projections of each IC is connected to its envelope by a coloured line. The gray area represents the total data projected by all four ICs taken together.
represent the differences of the total scalp envelope and each IC cluster for the four non-target stimulus category comparisons. The dark black lines in these plots represent the contour of the overlayed channels in Figure 7 with the exception that the current plots are in micro volts rather than z-scores and they are not masked for significance. The topographies for the IC clusters that show periods of significance within the first 200 ms of each comparison are displayed above the waveform envelopes and are displayed in the order with which they maximally contribute to the total scalp voltage difference range.

The N170 effects for the first three comparisons are largely accounted for by icN1a followed (in terms of contribution size) by the icN1b which was only identified in three of the eight participants. It is also apparent that for the face inversion effect the icN1a cluster not only accounts for the N170 effect (posterior negativity between about 160 ms and 250 ms) but also accounts for the dominant portion of the inversion effect during the downward slope of the P100 at the scalp (posterior positivity between about 135 ms and 160 ms). This plot confirms the result described above in the forty-four channel bootstrapping results pertaining to the topography of the significant face inversion effect at the time of the downward slope of the P100 and its dissociated topography from the P100 effects for face versus house comparisons.

Although the icN1a accounts for the dominant portion of the scalp inversion effects during the downward slope of the P100, the face versus house P100 effects are dominantly accounted for by two other IC clusters, namely, icP1a and icP1b. In the P100 face versus house effects (both upright and inverted) the icP1a and icP1b account relatively equally for differences found at the scalp. Interestingly, the temporal sequence of the peak voltage range projected in the difference waves reveal that although icP1a
reaches its peak activation level prior to that of the icP1b when looking at the activations for each category independently (see Figure 5), the peak icP1b differentiations for stimulus categories occurs prior to the peak icP1a differentiation.

The IC cluster difference envelopes provide specific information regarding the complexity of the effects within the first couple hundred of milliseconds of face and house processing. These IC cluster contributions to contrast envelope results contribute to the above section ERP IC envelope plots where it was found that individual scalp ERP components can be made up from several underlying electrocortical processes and similarly, a single electrocortical process can account for activation of several scalp ERP components. This section speaks to the notion that ERP difference waves at the scalp are made up of complex electrocortical brain dynamics. It also reveals that the sequence of peak activation times for the IC clusters in individual category ERPs does not necessarily match the sequence of peak differentiations across stimulus comparisons. This shift in the order of IC cluster differentiation is particularly interesting due to the linear medial to lateral sequential pattern of activation from the concentrated medial occipital pole (icP1b), to the distributed dorsal occipital region (icP1a), to the slightly lateralized occipito-parietal projection (icN1b), to the far lateralized right dominated occipito-temporal topography (icN1a) only being present as a function of category differentiation (rather than the sequence of activation for a single category ERP).

*Group bootstrap test on icP1a, icP1b, icN1a & icN1b*

In order to elaborate on the specific nature of the ERP effects described in the GFA and scalp channel bootstrap tests described above, the identical bootstrap procedures
were performed on the activation waveforms of the four IC clusters. This section of results present the most local level of analysis along the spatial dimension starting with the most global (group analysis) along the data scope dimension. This set of results specifically informs the third main goal of this research relating to the underlying cortical dynamics of the scalp ERPs and the hypothesized anatomical independence of effects at different time points within the first 200 ms following stimulus onset.

Results of the IC bootstrap tests are shown in Figures 11 and 12, where comparison type defines the columns (from left to right respectively in Figure 11 are upright face minus upright house and inverted face minus inverted house, and similarly for Figure 12 are inverted face minus upright face and inverted house minus upright house) and IC clusters define the rows. The top row presents the results for icPlb, the second row from the top presents the results for icPla, the third row is icNlb and the fourth row presents the results for icNla. Each plot consists of the same line configuration as the initial GFA results in Figure 6. Specifically, each plot contains the respective IC activation ERP overlay (two black lines, the bold line being the first category entered into the subtraction to create the difference waves), each of the 1000 surrogate ERP difference waves produced by the bootstrapping procedure (thin light gray lines), the 99% confidence intervals of the differences (thin dark gray lines), the zero line (null hypothesis which is plotted as a white line over points where there was a failure to reject the null) and the periods of significant differences between the two conditions (red diamond on the zero line for each sample that is significant). Again, the means and standard deviations for peak z-scores at the scalp and ICs for the P100 and N170 across subjects are presented in Table 6. Peak respective IC effects during the time of the P100
Figure 11. IC ERP categorical overlays and bootstrapped confidence intervals.

The two columns present specific categorical contrasts, namely: Upright face minus upright house on the left and inverted face minus inverted house on the right. From top to bottom the subplots present data from the ICs icP1b, icP1a, icN1b and icN1a respectively. The ERP category overlays depict the first waveform entered into the subtraction in bold black and the second waveform entered into the subtraction in narrow black. The light gray overlayed waveforms represent all 1000 bootstrapped surrogate difference waves. The dark gray lines represent the upper and lower boundaries of the 99% confidence interval for the differences. The zero line (H0) is red where the confidence interval does not include zero and the waveforms are considered to be significantly different from one another.
Figure 12. IC ERP categorical overlays and bootstrapped confidence intervals.

The two columns present specific categorical contrasts, namely: Inverted face minus upright face on the left and inverted house minus upright house on the right. From top to bottom the subplots present data from the ICs icP1b, icP1a, icN1b and icN1a respectively. The ERP category overlays depict the first waveform entered into the subtraction in bold black and the second waveform entered into the subtraction in narrow black. The light gray overlaid waveforms represent all 1000 bootstrapped surrogate difference waves. The dark gray lines represent the upper and lower boundaries of the 99% confidence interval for the differences. The zero line (H0) is red where the confidence interval does not include zero and the waveforms are considered to be significantly different from one another.
and N170 are greater than the critical z value of 3.78 for all contrasts except for house inversion and the P100 effect for face inversion. Notably all effects of the icP1b and icN1a are larger than their respective scalp measures. Also of interest is the P100 effect for face inversion at the scalp that is not expressed by either icP1a nor icP1b.

The first result to be described for the IC cluster group bootstrap tests is the negative control contrast of house inversion. Specifically, for the comparison of inverted houses minus upright houses none of the four IC clusters showed significant differences preceding 200 ms. This null finding is important for the assessment of sporadic findings across contrasts. The face processing literature suggests that the inversion effect is specific for faces, hence it is important to establish the null result for non face inversion effects. This set of null findings is particularly persuasive given that all four IC clusters produced large and clear ERPs for each house category independently. The size and clarity of the IC cluster ERPs to the two house stimulus conditions suggests that the null effects are not due to large error variance but rather due to precisely similar electrophysiological responses across the two stimulus conditions.

Perhaps the most anticipated result of this study is the behaviour of the icN1a. There are two important benefits to isolating the IC for the N170 face effect. The first relates to assessing the behaviour of the fusiform face area without the confounding mixtures of other occipital generators at the scalp. The second is to assess whether or not the unreliable P100 face effect in the literature is partially accounted for by differential activation by this IC during the time of the P100 (but often masked by numerous other processes preceding 150 ms). The fourth row of Figures 11 and 12 depicts the clear differentiation of upright face minus upright house, inverted face minus inverted house as
well as inverted face minus upright face. The icN1a N170 differentiation of upright faces and houses starts at about 130 ms and persists for about 70 ms, a similar result for inverted faces and houses except the differentiation is larger and delayed by approximately 20 ms. In these face house contrasts it is important to note that the icN1a ERP contains a positive deflection that peaks at about 125 ms closely corresponding to the timing of the peak P100 face effect at the scalp. Although this 125 ms positive deflection is clear in all stimulus categories, all categorical differences for this IC cluster emerge following this initial peak.

The icN1a face inversion effect takes a different form from the icN1a face versus house effects. Although the face versus house effects take the form of a clear phasic increase of a negative deflection, the face inversion effect has in addition to a phasic increase a clear latency shift where the inverted face stimulus starts its negative descent later than the upright face response. This latency difference begins at about 130 ms. This early latency shift of the icN1a response describes the results discussed for the scalp data above which could easily be misinterpreted as a P100 low-level inversion effect.

Most of the icN1a results preceding 200 ms are very large, however; in the inverted face minus inverted house contrast small effects were found preceding 50 ms as well as a period prior to stimulus onset. These specific results are difficult, perhaps even impossible, to interpret given that they precede the stimulus onset of a randomly assigned stimulus sequence. These results appear to be due to an interaction of slow wave activity in the baseline and overly restrained confidence intervals related to grand averaging. This issue is addressed later in a description of differences between group level DAR and average single subject DAR.
Other than the sporadic pre-50 ms results of the inverted face versus house contrast the results of the icN1a precisely match the scalp results reported by Rousselet et al. (2008). A second difference between the icN1a results reported here is that the Rousselet et al. (2008) reported a brief period of significant difference preceding 200 ms in the house inversion contrast. The high degree of replication between the current icN1a results and the scalp results of the Rousselet et al. (2008) suggest that the pure high-level face effect obtained through sophisticated low-level stimulus control can be obtained in non-controlled low-level stimulus sets by means of ICA analysis. The relevance of this replication is further enhanced by the need for ecological validity in the stimulus imagery eliciting early ballistic high-level processing.

The P100 effects are divided into two medial occipital IC clusters, the icP1a and the icP1b. The icP1a is the first IC cluster to have a peak potential in each category individually; however, the form of the effects for this IC cluster are expressed as a systematic latency shift for faces over houses. This latency delay for face stimuli is most pronounced on the downward slope of the P100 ERP. This presents an interesting dissociation from the icN1a differentiation where the latency shift was in response to inversion rather than image category (face or house). The result that the latency shift prior to 200 ms in the icP1a is related to stimulus category rather than inversion suggests that this effect is responsive to low-level stimulus characteristics.

The second IC cluster to peak during the time period of the P100 is icP1b. The relatively complex morphology of the ERP for the icP1b cluster is remarkably similar across stimulus categories containing a bi/tri-phasic oscillation beginning around 75 ms following both the onset and offset of the stimulus presentation. Interestingly however,
the robust effects between stimulus conditions for this IC cluster begin far before its peak activation. Although this IC cluster is maximally active at approximately 125 ms following stimulus onset its robust differentiation for face and house contrasts (for both upright and inverted comparisons) begins at about 80 ms. This early effect persists as a relatively constant offset difference over the period of a full 8-10Hz cycle ending at about 200 ms. The voltage characteristics of this effect take the form of a greater negative projection to medial occipital sites for houses than for faces. While there are many possible interpretations of the morphology of this effect, one of the simplest is that this IC cluster has a greater negative activation for houses than faces. This increased negative activation for houses over faces when mixed with icP1a at the scalp would lead to a misinterpretation of the P100 effect for face versus house contrasts as a smaller positive activation for houses.

Both the icP1a and icP1b clusters show periods of significance difference preceding 200 ms for the face inversion contrast. These effects may be very important as they would possibly relate to high-level processing characteristics of inversion effects. These effects however are much smaller than the face versus house differences, and due to their similar strength to the effects found in the baseline period of the icN1a cluster in the inverted face versus house contrast it may be necessary to consider effects of this size as Type II errors.

IC cluster icN1b was only identified in three of the eight participants. This IC cluster showed significant differentiation between face and house stimulus categories (for both upright and inverted comparisons) over the period of about 130 ms to 170 ms following stimulus onset.
Taken together the bootstrap tests on the individual IC informs the first and third main goals of this study. First, the timing of effects in the icN1a (effects at the time of the N170 but not at the time of the P100) replicate the scalp results of Rousselet et al. (2008) in the absence of sophisticated controls of low-level stimulus characteristics. Also, the effects at the times of the P100 and N170 are captured by different ICs further supporting the hypothesis that the P100 and N170 effects have independent anatomical sources.

**Differential activation robustness**

Beyond measuring the consistency of the timing of significant effects across individuals the Differential Activation Robustness (DAR) measure is an estimate of the likelihood of finding an effect at each time point along the ERP contrasts. This set of analyses informs the fourth and final goal of this study by describing the categorical effects in terms of robustness. The DAR measure is the most local level along the data scope dimension and is presented simultaneously for both the most global (GFA) and local (ICA) measure along the spatial dimension. The DAR results are presented in Figure 13. Plots in Figure 13 are organized such that each of the four columns represent a contrast, namely from left to right, upright-face minus upright-house, inverted-face minus inverted-house, inverted-face minus upright-face and inverted-house minus upright-house. Each row block that is outlined by a black rectangle contains the results of a single waveform, namely from top to bottom is GFA, icP1b, icP1a, icN1b and icN1a. Each row block contains ten sub-rows of plots that depict the results of different levels of analysis. The plots in the top most sub-row of each signal block outlined in a red box depict the DAR results calculated as a group statistic. The second top-most sub-row of each signal
Figure 13. GFA and IC differential activation robustness.

Differential Activation Robustness (DAR) results for each of the four categorical contrasts over the time period of -100 ms to 400 ms relative to stimulus onset. Dark blue represents a 100% robust effect where category one is below category two in the contrast, dark red represents a 100% robust effect where category one is above category two in the contrast, and green represents 0% robustness. Each of the four columns represent a contrast, namely from left to right, upright-face minus upright-house, inverted-face minus inverted-house, inverted-face minus upright-face, and inverted-house minus upright-house. Each row block that is outlined by a black rectangle contains the results of a single waveform, namely from top to bottom is GFA, icP1b, icP1a, icN1b, and icN1a. Each row block contains ten sub-rows of plots that depict the results of different levels of analysis. The plots in the top-most sub-row of each signal block outlined in a red box depict the DAR results calculated as a group statistic. The second top-most sub-row of each signal block outlined in a blue box depicts the DAR results calculated as the average single subject statistic. The remaining eight sub-rows illustrate the DAR results calculated for each subject uniquely. ICA decompositions that did not contain an icP1b or icN1b are masked in gray and the group results are calculated without them.
block outlined in a blue box depicts the DAR results calculated as the average single subject statistic. The remaining eight sub-rows illustrate the DAR results calculated for each subject uniquely. ICA decompositions that did not contain an icP1b or icN1b are masked in gray and the group results are calculated without them.

An important characteristic of the DAR measure relates to the differences found between the group measures and the averaged single subject measures. The periods of high robustness can differ between these two measures due to two main circumstances. The first is when a group effect is the result of relatively few subjects showing a robust effect. The second is when several (or all) subjects show unreliable effects individually, but taken together as a group the effect is robust.

An example of the first type of discrepancy between the group measures and average single subject measures described above is the GFA effects for upright-face minus upright-house. In this contrast the group effect shows 100% robustness during both the period of the P100 as well as the N170. In contrast the average single subject DAR statistic only reaches 100% briefly during the period of the N170, and only reached approximately 70% robustness during the period of the P100. This discrepancy is clearly explained by the single subject DAR results where half of the subjects expressed strong robustness during the period of the P100 and all subjects showed strong robustness during the time of the N170.

An example of the second type of discrepancy between the group measures and average single subject measures described above is expressed in the results of the icN1a for the inverted-face minus inverted-house contrast. The group effect DAR for this comparison shows strong robustness prior to 100 ms (even extending back into the
baseline period) although the average of single subject DAR results does not show strong robustness until 150 ms post stimulus onset. Examining the single subject DAR results it is apparent that the group DAR effects preceding 100 ms is the result of weak and sporadic robustness across several individuals. These circumstances describe important distinctions that need to be made in order to accurately describe unreliable results in the literature. In general the effects that differ between these two levels of DAR measurement are assumed to represent effects that would produce unreliable results in the group study literature.

For the current discussion the group effects are displayed to illustrate the windows of robustness given a blanket group statistic. The average of individual robustness measures are examined here as the accurate probability of finding an effect at each time point for each contrast. As in all previous measures it should be noted that the inverted-house minus upright-house contrast yields a clear negative control, this facilitates the interpretation of the results in the face related contrasts.

**GFA DAR**

The GFA (most global spatial measure) and DAR (most local data scope measure) results at the level of the average single subject illustrate two clear periods of likely effects for all three face related contrasts. The most robust period of effect for the GFA waveform is between 150 ms and 200 ms for the two face minus house contrast. The face inversion contrast produced a less robust effect starting at 170 ms and persisting for about 40 ms. The single subject DAR results reveal that all participants produced robust face minus house effects starting at around 150 ms. The less robust average single subject
effect for the inversion effect is expressed as increased variability in both degree of robustness and latency at the level of the single subjects.

The GFA DAR results described above reflect a clear replication of the effects presented by Rousselet et al. (2008) for the GFA N170 face effects (see Appendix B left column). Comparing the current results to those of Rousselet et al. (2008) also reveals a clear manipulation of the P100 effect achieved by the current experimental procedure (exclusion of low-level stimulus control). The P100 DAR effects at the level of the average subject for the face related contrasts are not as robust as the DAR results found over the period of the N170. This reduction in the DAR effect over the period of the P100 relates directly to the conflicting results in the group statistic literature of P100 face related effects. In effect the current data not only presents a P100 manipulation in which uncontrolled low-level stimulus characteristics result in P100 ERP differences but the robustness expressed by the DAR statistic over the this period reflect the unreliability of the P100 effects in the group statistic literature. The reduced DAR values over the period of the P100 relative to that of the N170 are the result of increased individual differences rather than consistent single subject unreliability.

The following set of results describe the ICA effects (most local spatial measure), assessed by means of DAR (the most local data scope measure).

\textit{icN1a DAR}

Having successfully manipulated the low-level influence on the face effect, the most relevant finding of the current study is that the DAR statistic for \textit{icN1a} replicates precisely the initial face effect reported by Rousselet et al. (2008) starting just prior to
150 ms for the upright face minus house contrast. This suggests that even in the presence of low-level confounds the pure face specific effect can be retrieved using ICA. The inverted face minus house contrast shows almost identical DAR except that it is shifted later in time by about 10 ms starting at 150 ms. The face inversion effect is shifted later still expressing a larger negative deflection for inverted faces starting at approximately 160 ms. The inversion DAR effect also shows a period of greater positivity to inverted faces over upright faces prior to 150 ms. As described in the bootstrapping results this increased positivity for inverted faces takes the form of a latency shift in the downward slope of the N170 where inverted faces are later than upright faces.

Another important characteristic of the icN1a DAR results is the consistency of individuals' results across the two face house contrasts. Although the upright and inverted face minus house contrasts share no common trials the pattern of robust effects across these comparisons are remarkably similar reflecting an individual's signature of reliable face specific processing. Interestingly the individuals' signature pattern of face minus house effect is not repeated in the inversion effect for faces. The unique pattern of DAR effects for the face inversion contrast at the level of the single subject may be interpreted as clear evidence that the inversion effect is not the same as the face effect. Although the inversion effect is a powerful tool for controlling low level stimulus characteristics during face processing it is important to note that the inversion effect does not represent the entire face effect.

icP1a DAR

As the icN1a DAR results matched the GFA DAR results over the period of the
N170, icP1a DAR results matched the GFA DAR results over the period of the P100. Specifically, icP1a reaches a probability of 70% by approximately 100 ms and persists for about 30 ms in the upright face minus house contrast. For the inverted face minus house contrast the DAR effect is shifted later by approximately 10 ms compared to the upright face minus house contrast. The single subject explanation of the reduced DAR is an inconsistency of effects from subject to subject rather than unreliable effects in each individual. Two of the eight subjects showed no icP1a effect over the period of the P100, the other six participants showed relatively short durations of robustness that was not consistently timed across individuals.

icP1b DAR

The second most robust average subject DAR results (following icN1a) for face minus house contrasts come from the icP1b. Notably, although this effect is among the most robust, it does not appear in the GFA DAR results. The absence of this effect in the GFA DAR results can be due to two characteristics of the icP1b, (1) the relative localized spatial scalp projection may be under represented in the standard deviation across channels, (2) this effect takes place at the same time and over the same scalp areas as the larger voltage and variance producing icP1a.

This icP1b begins robust differentiation prior to 100 ms, is at least 90% robust during the period of 100 ms to 130 ms, and the robustness persists at lesser degree until approximately 190 ms. Interestingly this IC's pattern of DAR shows a single subject signature that does not seem to shift in latency when comparing the upright and inverted contrasts. Although there are periods of high DAR in the grand average calculation for
icP1b over the time period of the P100 and N170 complex, examination of the single subject and average single subject DAR reveal that these results are sporadic across subjects. These results suggest that the icP1b is sensitive to the low-level differences across face and house stimulus categories.

*icN1b DAR*

The icN1b although only isolated in three of the eight subjects produces some average single subject DAR results for the face related contrast starting just prior to 150 ms. Because it was only isolated in three of the eight participants this component is not discussed any further.

**Discussion**

*What is addressed in this study?*

The experimental paradigm and analysis strategy employed in this experiment informed four main goals. The first goal relates to the replication of the N170 effect timing reported by Rousselet et al. (2008). The second goals relates to the description of the P100 effect that is sometimes reported in the face processing literature. Third is the description of the underlying eletrocortical dynamics that inform the P100 and N170 ERP complex obtained by ICA. Finally, the fourth goal focuses on the robustness of the various effects in the first 200 ms following stimulus onset at the scalp and among ICs. The following sections describe the specifics of how the analyses inform these goals as well as provide commentary on the implications of the outcomes.
Electrophysiological constituents of the P100 and N170 ERPs

The spatial dimension of this set of analyses culminates in the analysis of the ICA derived waveforms across stimulus conditions. Although it is accepted in the ERP literature that individual ERP components reflect the summation of multiple event related cortical processes whose electrical projections are both temporally and spatially overlapping, the spatial distribution and relative voltage contribution of each constituent is difficult (if not impossible) to determine by examining the signals as recorded at the scalp. By performing an ICA decomposition on the artifact rejected continuous EEG traces, this study clearly identified four independent electrophysiological processes that accounted for the ERP voltages at the scalp during the period of the P100 and N170 complex. Notably, all four processes were relatively active over the period of both the P100 and N170 time periods.

The icN1a produced the event related activation pattern that was most closely related to goals one and three of this analysis. Specifically, This IC answered the question: is the N170 cortical source accounting for differences found at the time of the P100, but often masked by other lower level processes of the striate cortex during the interval of 80 ms to 150 ms? The answer provided by this study is “no”. Although the icN1a which describes the familiar N170 face effect is active in a manner that projects a positive voltage over occipital scalp regions during the time of the P100, this activation does not differentiate stimulus conditions until about 140 ms following the stimulus onset. The timing of the face effects expressed by icN1a in the context of a minimally controlled stimulus set closely replicates the scalp findings of Rousselet et al. (2008).

The less reliable P100 effect found in this analysis is accounted for by two ICs,
namely icP1a and icP1b. The activation patterns of icP1a reveal two characteristics of this cortical domain that would not be determined by examining the scalp data alone. The first is that this constituent process of the P100 differentiates stimulus categories in the form of slope differences during the tailing descent of the peak following 100 ms post-stimulus onset. While this effect is quite systematic (although only about 70% likely determined by the DAR statistic) and potentially meaningful, it would not be detected by traditional peak picking strategies. It can therefore be determined that this process alone is not likely the process that is accounting for P100 peak controversy in the literature. However, it should also be noted that the P100 peak at the scalp occurs later than the P100 peak of icP1a. This single constituent slope difference likely contributes to what is expressed as a summed peak difference shortly following 100 ms post-stimulus onset.

The second constituent process that contributes to the P100 face effect is the icP1b. This process reveals two important characteristics that are not apparent at the scalp. The first is that its categorical effects are robust (100% likely in all six subjects whose data expressed this IC) often starting before 100 ms. The second important characteristics revealed by this constituent process is that it takes the form of a larger negative voltage at central occipital scalp sites for houses over faces. This characteristic demonstrates an opposite effect than what would be interpreted at the scalp with Occam's razor, specifically, that a smaller scalp voltage is the result of decreased activation rather than an increased cancellation between two opposing processes. This small but robust voltage difference taken together with the slope difference of the icP1b describe the underlying dynamics and robustness of the controversial P100 face effect.
**Timing of the N170 face effect**

Beyond the fact that the icN1a does not seem to be confounded by P100 effect processes, the N170 effects expressed by this IC are both earlier and more robust than the N170 scalp GFA effects. The average single subject DAR results of the GFA measure at the scalp for the upright face minus upright house contrast indicates a robust effect for the N170 starting at about 150 ms. This effect is more robust and starts approximately 10 ms earlier when measured on the icN1a than the GFA. This pattern of the icN1a revealing earlier and more robust effects than the scalp GFA is repeated across all face related contrasts including the face inversion effect. It is important to note at this point that although using icN1a increases the likelihood of finding effects during the period of the N170 (at an earlier latency) the negative control contrast of house inversion is maintained in the results. This suggests that the increased likelihood of finding earlier and more robust N170 results in the icN1a time course is not at the expense of increased type II errors.

*icN1a effect timing reflects findings obtained with low-level stimulus control*

This study’s most direct link to the face processing literature is that the most local spatial analysis (ICA) replicates stimulus control results. Given a data set that contains a P100 group effect for face/house contrasts at the scalp, the icN1a face/house effects replicates scalp studies that show no P100 effects. This is to say that the activation patterns of the icN1a mimic the scalp EEG collected during the presentation of face and house stimuli that have sophisticated controls for low-level physical characteristics (e.g., Rousselet et al. 2008). This is a particularly intriguing finding given the fact that both
P100 and N170 effects were found at all traditional P100 and N170 scalp sites (e.g., Oz, P07, P08, etc). This suggests that careful selection of EEG scalp channels is not sufficient for isolating unique effects of the P100 or N170 and that on the head surface the cortical sources for the effects at these two time intervals are largely overlapping at key scalp sites.

The ability to isolate the N170 face effect source from the P100 effects in continuous EEG signals has implications for the study of face related processing. Under many circumstances it is desirable to study the timing of face specific processing in the context of non-manipulated stimuli. The ecological validity of face stimuli is important in order for a given study to access the full effect of face specific processing. Further, because the face effect is considered more generally to be one of the earliest top-down sensory/perceptual processes in the visual stream, robust measures that relate the timing of earliest categorical ERP deviations are paramount. Because ecologically valid stimuli and timing of effects are both paramount in the study of top-down sensory perceptual processing it is important for the interpretability of the results that the constituents underlying the ERP effects at different latencies be un-mixed.

Constituents of effect robustness

The data scope dimension of this set of analyses culminated in the DAR measures on both scalp signals and IC signals. N170 effects in the face processing literature have developed a reputation for being robust, while P100 effects in the same literature have developed a reputation for being unreliable. Within this study the average single subject DAR measure addresses the underlying form that these reputations have. The DAR
average single subject GFA scalp results reflect the reputations of the P100 and N170 ERP components mentioned above. Namely effects during the time of the N170 are more likely to be obtained across Monte Carlo iterations than the effects found over the period of the P100. The robust N170 effects measured in the average single subject DAR at both the scalp and icN1a are expressed as periods of robust effects in each of the eight individuals and the timing of the effects across individuals is largely consistent. The less reliable P100 average single subject DAR results at the scalp are described as less consistent in time across individuals as well as not present in all subjects. The P100 DAR results are not increased when measured on icP1a. The average single subject DAR results for icP1a largely reflect the P100 effect robustness at the scalp and take a similar single subject form, namely, relative inconsistency in timing and not present in all individuals.

The icP1b average subject DAR is surprising in that it is an effect that is not expressed at the scalp. This effect is robust in all six subjects who produced an icP1b component starting prior to 100 ms and in four of the cases this effect persisted until almost 200 ms. The large difference in effects expressed at the scalp and in icP1b is likely due to the fact that the icP1b effect is not a large voltage difference but rather a very consistent difference. This consistency of the differences is depicted in the confidence intervals of Figures 11 and 12. Notably, small and consistent differences are only robust in the absence error variance. Because several other processes are contributing to the ERP at the time of the P100 it is likely that their larger error variance often masks the effects of icP1b at the scalp.
Single subject characteristics

By combining local spatial measures and local data scope measure together the current study is able to examine the sample at the level of individual differences. In order to assess the nature of an unreliable effect documented in literature by examining the data from a single study, quantification of the various effects at the level of the single subject is paramount. In its simplest form a robust single subject strategy can dissociate unreliable effects as being the result of deprecated within or between subject robustness. The question more clearly: is the unreliable P100 effect due to this differentiation being present in only some individuals, or is the categorical differentiation present in all individuals but unreliable in each? The present analysis reveals two forms of unreliability for the P100 effect. The first form of unreliability has to do with the P100 effect's short duration at the single subject level which is further confounded by a relatively large latency jitter (relative to its total duration) from subject to subject. In a point by point temporal analysis this latency jitter of the effect timing can account for most unreliability, however, in the tradition of peak analysis this subject jitter would be accounted for. The second form of unreliability expressed by this analysis is that not all subjects showed a P100 effect for faces versus houses at the scalp or in icP1a. This evidence has implications when taken together with the fact that all individuals showed a robust N170 effect for faces minus house at the scalp and in icN1a. This is evidence that while examining the face effect in the context of uncontrolled low-level stimulus presentation the P100 effect that precedes the N170 in time may be present in many individuals, but for those individuals where it is not present we see that it is clearly not a prerequisite for a robust N170 effect.
This dataset reveals clear single subject signature effects. These signature time sequences of effects are particularly pronounced in the single subject DAR time courses across face minus house contrasts both upright and inverted. By examining the DAR colour bars of each individual in the columns 1 and 2 of Figure 13, a clear within subject consistency emerges although between subject patterns can be quite divergent. Notably these two contrast (upright-face minus upright-house and inverted-face minus inverted-house) share no trials between each other. The single subject results expressed in this analysis provide encouraging evidence that with advanced signal processing and robust estimation strategies the analysis of EEG traces can take advantage of the individual's specific characteristics (both spatially and temporally) rather than being restricted to studying the electrophysiological phenomenon that share specific embodiment parameters across subjects (as is the case in group based designs). For example, although each individual's icN1a had a unique spatial projection and temporal pattern of categorical stimulus differentiation, these parameters as a whole are considered the individuals N170 face effect, as opposed to the specific voltage difference at a given ERP peak latency and channel coordinate match across subjects.

*Necessity rather than sufficiency of ICA analysis in face research*

There are considerable processing costs involved with using ICA. A stable ICA decomposition is computationally demanding and requires a substantial amount of data that has been stringently pruned of spatially non-linear noise. Further, once a stable ICA decomposition has been established the resulting components need to be assessed, and comprehensively categorized for further treatment (as either biological artifacts, noise, as
well as task-relevant and task-irrelevant cortical processes). Given the added data processing costs associated with ICA it is not enough for the outcome of the ICA to be sufficient, or equivalent to the scalp results, but rather there needs to be clear and substantial benefits to the investment. The following paragraphs describe some specific benefits obtained by using ICA in this study.

The N170 is a very large and distinctive ERP component at the scalp and produces robust effects between stimulus categories. Although the N170 is one of the most distinct scalp ERP components it is largely temporally and spatially overlapped at the scalp with the field potentials of the P100 and P200 electrocortical generators. Although it is possible to experimentally constrain the effects of the overlapping P100 ERP when attempting to assess the initial timing of face specific processing (Rousselet et al. 2008), the low-level stimulus manipulations may systematically affect faces differently than other stimulus categories (Collin, Liu, Troje, McMullen, & Chaudhuri, 2004). The icN1a results in this analysis replicate the scalp results reported by Rousselet et al. (2008) regarding the timing of the face effect. This is more than a replication given that this assessment of N170 face effect timing was achieved in the context of low-level stimulus confounds and strong P100 effect for stimulus condition. By assessing the independent effects of unique electrocortical processes (derived from ICA) research questions no longer need to be constrained by strict experimental controls, or the interpretation of scalp EEG signals that are potentially made up of variable and undetermined mixtures of multiple electrocortical field potentials. Rather the effects may be described as spatially and temporally overlapping phenomenon within the context of complex psychological processing.
Aside from gaining the ability to examine the constituent process of the N170 face effect independently from the P100 effects found in this study, the ICA decomposition revealed a counterintuitive result relating to the P100 effect. At the scalp, the P100 had a smaller amplitude for houses than for faces over the medial occipital scalp surface. The ICA decomposition revealed that this scalp effect was the result of two medial occipital constituent processes identified here as icP1a and icP1b. Notably, these two ICs illustrate that the P100 effect is not simply a smaller peak voltage for houses than faces. Rather, (1) icP1a has a quicker descending slope of the P100 for houses than for faces (not necessarily a peak difference) and (2) icP1b expresses a larger voltage for houses than for faces at the time of the P100 but with a negative polarity over medial occipital regions. These IC results produce interpretations that are in stark contrast to the interpretations that would be derived from the scalp signals alone. Namely, the scalp results suggest less low-level processing (smaller P100) for houses vs. faces, while the IC results do not suggest less processing for houses but rather a larger response in the initial icP1b constituent, followed by a quicker resolution of the icP1a constituent process for houses over faces.

Although the independence of the experimentally relevant constituent electrocortical processes takes center stage in the current analysis, a more general benefit of the ICA relates to the gains in signal-to-noise ratio at the level of the single trials. This is to say that, although the isolation of experimentally related constituent processes is the ultimate goal of the current experiment, the isolation of task-relevant processes from otherwise uncorrectable sources of noise variance is a justification for the method in itself. The main benefit of the isolation of task-relevant electrocortical processes from noise is clearly expressed in the $z$-scores of the ERPs when comparing ICs to the scalp.
data (see Table 6). This increase in the signal-to-noise ratio greatly increases the power of the experiment and makes statistical testing at the level of the single subject more palpable.

*What can be addressed using these methods in further studies*

Although some crucial benefits of ICA revealed themselves in the procedures that were carried out in the current analysis, perhaps what speaks most strongly to the necessity of ICA is the access that it gains to further methods of describing cortical activity. The primary assumption that underlies ICA is that a set of mixed signals can be decomposed into a set of maximally independent factors that each describe a fixed linear relationship (weights) across input signals. If the set of input signals can be described as a set of fixed linear relationships across input signals, the ICA returns the weightings that describe each fixed linear relationship that contributes to the mixed input signals as well as the dynamic contributions (loadings) of each factor to the mixed input signals over time. In the context of EEG analysis ICA characteristics translate into the assumption that the movement of field potentials on the scalp over time can be described as a parsimonious set of spatially fixed projections that are each independently and dynamically active over time. This assumption agrees with the view that a field potential large enough to be expressed in an EEG trace is the result of a relatively large number of neurons that are synchronously active within a fixed network (either locally or distally). Thus, the output of ICA performed on EEG data can be interpreted as a data driven estimation of fixed cortical network recordings.

These estimates of fixed cortical network recordings derived from ICA are not
constrained by models, nor are they constrained by spatial complexity (e.g., a network can be a distributed set of regions spanning the entire cortex, not simply individual dipoles). Further, while these network estimations are obtained through independence maximization, the transient dependencies or relationships across networks are maintained. Given that the output of ICA can be interpreted as estimates of fixed cortical network recordings many new analysis strategies are made available. Two main constraints of scalp EEG activity that limit analytical progress of the medium are poor signal-to-noise ratio in the raw continuous signal (too many sources of information mixing at each recording location) and an undetermined and dynamic dependence across signals (the number of shared information sources at each recording site and their relative contribution at each time point is unknown). By performing ICA the signal-to-noise ratio of the data is greatly increased; further, the dependence across signals that is caused by shared information sources is removed leaving only dependencies between networks to be interpreted.

Many novel findings have been expressed in the current study as a result of using ICA and robust estimation, but what is just as important as the analyses already carried out are the new analyses that can be performed and tested at the single subject level which are not possible or are uninterpretable when performed at the scalp level with group based designs. Among the most universally applicable sets of measures for electrophysiological research that this data processing strategy makes possible is the analysis of single trial functional or effective connectivity as obtained by assessing power or phase relationships between ICs. Because EEG signals at the scalp are the sum of a dynamic mixture from multiple cortical areas, increases in coherence (of any form, being
it power correlation, phase-coupling, etc.) between two scalp sites can always have at least two interpretations. The first (and often desired) interpretation is that different cortical areas (ideally, but not necessarily directly adjacent to the electrode sites being analyzed) become linked in some form of activation pattern possibly representing communication between these brain regions. The second (less interesting) interpretation of the exact same coherence result at the scalp is that there is a relative increase in the summed signal of a single electrocortical process (being the result of increased activation of the single process, or diminished activation of other summed processes) as projected to both sites being analyzed.

Further to the uninterpretability of the coherence measures obtained at the scalp, the signal-to-noise ratio of scalp sites (including mixed signals from multiple unrelated cortical phenomenon as well as extra cortical phenomenon [e.g. EMG, EOG, ECG, machine line noise, etc]) make it difficult to take advantage of the information in single trial variability to perform robust estimation at the level of the single subject.

Evidence from this study also provides insight for future analysis strategies that are specifically related to face processing. Most notably is the evidence expressed here that the pure time course of face specific processing (as measured in icN1a and likely produced by a right dominated bilateral fusiform network) can be extracted as an independent electrocortical process from the continuous EEG trace among otherwise confounding processes of the visual cortex likely related to low-level stimulus characteristics. The ability to isolate and account for low level-processes (rather than disregarding or misinterpreting the effects) should give researchers more confidence in their interpretations of early stimulus related categorical ERP effects and provide
increased freedom for the use of important ecologically valid stimuli that do not require sophisticated control parameters for low-level characteristics.

Taken together, the analysis strategies used in the current analysis provide evidence that a more comprehensive view of the essential face effect may be examined. One particular direction towards the larger picture of the face effect (as well as the more general efficient integrative sensory processing, or perceptual fluency) is the notion that these early top-down effects may more accurately be described as a special relationship between low-level sensory cortical areas and higher-level integrative sensory/perceptual cortical centers. The ability of low-level sensory cortical areas to ballistically recruit top-down integrative functioning from high-level processing areas (as an example of networking between transiently dependent brain regions) may not only shed light onto the special phenomenon of face processing but much more broadly reflect at the individual level a metric for generalized cortical efficiency.

What is not addressed by this study?

In order to study the electrophysiological dynamics underlying the P100 and N170 ERP effects during face and house perception, the current study used relatively non-manipulated realistic stimuli that were not controlled for low-level stimulus characteristics (other than average pixel luminance and contour). Because of the potential confound of low level stimulus characteristics in accounting for the differences between face and house categories, it is difficult (if not impossible) to unequivocally determine the degree to which each of the effects described above could be attributed to top-down or bottom-up processes. Although the potential confound of low-level stimulus
characteristics inhibits a clear interpretation of this study assessed in isolation, taken in
the context of N170 literature it is likely that icN1a reflects top-down integrative
processing, and icP1a as well as icP1b reflect bottom-up processing.

Although there were no systematic manipulations of the stimulus images
implemented to test low-level electrophysiological correlates independent from the
face/house categorization, further investigation of this data set could provide insight into
the relationship between P100 constituent ICs and the N170. In particular, the improved
signal-to-noise ratio obtained through the ICA decomposition may provide useful single
trial peak scores that could be used in regression analysis across ICs and ERP peak
latencies.

Conclusion

Four main goals were informed by the results obtained from the present
experiment. First, the N170 effects reported by Rousselet et al. (2008) were replicated in
the context of a stimulus set having minimal controls of low-level stimulus differences
across image categories. Implications of this replication relate to the generalization of
Rousselet's findings beyond the context of highly controlled stimulus sets. Also this
replication has implications for research in that the ICA decomposition was able to
extract the pure N170 effect in the presence of mixed P100 effects at the scalp.

Second, the lack of low-level image characteristic controls produced a P100 effect
for image categories. Having achieved the P100 effect that is sometimes reported in the
literature, further investigation of the anatomical independence of P100 and N170 effects
was possible.
Third, examining the underlying electrocortical dynamics informing the P100 and N170 complex at the scalp revealed that multiple electrocortical constituent processes (isolated using ICA) are dynamically active during multiple ERP components. Similarly, each ERP component in the first 200 ms is made up of several electrocortical constituent processes. The constituent processes accounting for the N170 face effect (named icN1a here) does not account for the effects found during the period of the P100. Two underlying constituent processes account for the scalp effects at the time of the P100 (named icP1a and icP1b here). The examination of icP1a and icP1b reveal a form of the P100 effect that could not be detected at the scalp. Namely, the smaller positive peak voltage for houses over faces is actually a mixture of two constituent effects, the first (icP1a) having a quicker descent from the peak for houses than for faces and the second (icP1b) projecting a larger negative voltage for houses than for faces at medial occipital sites.

In regards to the fourth goal, by examining the robustness of the effects during the first 200 ms following stimulus onset, scalp effects at the time of the P100 were found to be less reliable than the N170 effects. The smaller P100 reliability relative to the N170 effect took the form of fewer subjects showing the effect and those subjects who did show P100 face effects having large between-subject latency jitter. The robustness results obtained by this study reflect the state of the face processing literature in which N170 group effects are very robust but P100 group effects are less frequently found or reported.

Beyond the results reported in the present study that directly inform the goals mentioned above, these results also lead to new analysis strategies that could inform more sophisticated hypotheses. First, the increased signal to noise ratio in single trials of ICs
over scalp data makes the potential for single subject analysis more powerful allowing for better measures of individual differences. Second, the ability to isolate the anatomically independent constituent processes of the visual cortex that mix at the scalp makes it possible to investigate more diverse image sets with less concern for the confounding mixture of the low-level effects. Third, having unmixed the constituent processes of the P100 and N170 ERP complex into independent components it possible to test the functional or effective connectivity among the cortical processes. Such analyses could inform the more general and relatively illusive question of whether the root of the face effect is a special relationship between low-level and high-level processes in the cortex.
Reference List


Appendix A. GFA overlays and bootstrapped confidence intervals from Rousselet et al. 2008.

From Rousselet et al. 2008
Figure 3. Comparisons of all condition pairings of GFA data. For each cell, the gray line is the difference between the conditions plotted in thick and thin black lines (respectively the first and the second element of the cell’s title). The shaded gray area around the gray difference line is the confidence interval of the difference between the two conditions (percentile bootstrap, 1000 sample trials, p G .01). When the confidence interval does not include zero, the difference is significant, as indicated by the thick horizontal red lines along the 0 2V.
Appendix B. GFA differential activation robustness by contrast for each subject and the group from Rousselet et al. 2008.

From Rousselet et al. 2008.

Figure 8. Robustness of ERP differential activities evaluated by a Monte Carlo simulation. Because a significant proportion of single trials do not show the effect observed on the trimmed means, it is somewhat misleading to make binary judgments about the statistical significance of an effect. This figure constitutes an alternative description of the data in terms of the probability of finding a difference at any time point between two conditions. The analysis was carried out on the GFA for each subject (S1-S16). The mean across the 16 subjects is plotted below the dashed line. The bottom of the figure depicts the result of the analysis performed across subjects. For each of the 100 Monte Carlo samples, the GFA for all subjects were used to compute an analysis across subjects, exactly like the one presented in Figure 3 (p < .01, 1000 sample trials). The three gray rectangles show, in black, the time points at which a significant difference between conditions, averaged across subjects, was observed for each of the 100 Monte Carlo samples. The color bars at the very bottom of the figure show the mean across the 100 Monte Carlo samples.
Appendix C. Brock University Research Ethics Board Approval.

FROM: Michelle McGinn, Chair
Research Ethics Board (REB)

TO: Sid SEGALOWITZ, Psychology
Jane DYWAN

FILE: 04-131 - SEGALOWITZ
Faculty Research

DATE: March 15, 2010

The Brock University Research Ethics Board has reviewed the research proposal:

Brain Electro cortical Functioning During Visual Processing of Faces and Objects

The Research Ethics Board finds that your modification request to an ongoing project involving human participants conforms to the Brock University guidelines set out for ethical research.