Face Processing in Deaf and Hearing Individuals

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Neuroscience

by

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THE GRADUATE SCHOOL

We recommend that the thesis prepared under our supervision by

ELIZABETH A. GROESBECK

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Face Processing in Deaf and Hearing Individuals

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Abstract

Deaf individuals may possess enhanced visual processing abilities, particularly in the periphery. Deaf individuals may also be more accurate at discriminating between faces, compared to their hearing counterparts. We examined deaf and hearing subjects’ ability to discriminate between faces, in either the central or peripheral visual fields, using behavioral measures and EEG. In a delayed matching task, subjects were presented with a 'target' face and after a delay were required to identify which of two 'test' faces matched the target. In separate conditions, images were presented centrally and in the periphery. Thresholds were measured using a forced-choice, staircase procedure and were estimated using Weibull functions to determine the level of similarity between test images associated with 80% correct performance. Overall deaf subjects were more accurate than hearing subjects and this difference was most evident in the periphery. Neurophysiological responses to these images were then assessed using EEG and an oddball paradigm. In this paradigm facial images are presented at a base frequency (6 Hz) and within the sequence a different 'oddball' face is presented at a lower frequency (1.2 Hz). The presence of significant responses at the oddball frequency indicates the difference between the faces has been detected. In separate trials we presented subjects with base and oddball images that were more or less similar to each other. Across trials these images were presented either centrally or in the periphery. Both subject groups showed similar reductions in amplitude at the oddball frequency for images that were more similar to each other. However, compared to hearing subjects, deaf subjects showed a larger decrease in amplitude when images were presented in the periphery compared to centrally. Results of the behavioral experiment support earlier findings that deaf individuals may possess enhanced face discrimination abilities and further extend them by showing that these effects may be more prominent in the periphery. Furthermore, our results from the EEG experiment suggest that the enhanced processing ability in deaf for peripherally presented faces is not necessarily related to higher amounts of neurophysiological activity at the level of face coding. This discrepancy between the two experiments in the present study may be due to differences in the task demands, with the behavioral experiment reflecting more local feature discrimination, while the EEG experiment may reflect more holistic face coding.
Acknowledgments

I would first like to thank Fang Jiang, my advisor, and Scott Gwinn, a post-doctoral researcher in the lab. This project would not have been possible without their help and support. I would also like to thank my family, Robert, Mary, and Kate, for all of their support through my graduate student career, as well as all of my friends. My research team and I also thank the deaf communities in Nevada and California for their participation. This work was supported by the National Institutes of Health Pathway to Independence Award (EY023268 to Fang Jiang), with further support for core facilities provided by NIH COBRE P20 GM103650. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.
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Introduction

Recent studies show that when an individual loses one sense, another sense may exhibit a compensatory enhancement. A growing body of evidence indicates that upon unisensory deprivation, both humans and animals may experience a reorganization of their brain, resulting in the remaining intact senses showing heightened sensitivity as the brain attempts to compensate for the deficit (Loke & Song, 1991; Lomber, Meredith, & Kral, 2010; McCullough & Emmorey, 1997; reviewed in Bavelier 2006). This sensory compensation is thought to be due to a phenomenon known as neural plasticity, which posits that the brain is capable of change and can ‘rewire’ itself in response to sensory deprivation. When an area of the brain loses its sensory input, other senses may take over the deprived area, resulting in the functional gain in the perceptual capacities of the remaining senses (see Merabet & Pascual-Leon, 2010 and Merabet, Amedi, & Pascual-Leone, 2005 for reviews).

Of particular interest to the current study is the potential for changes in visual functions in response to auditory loss. In general, enhanced visual abilities are found to be limited to the processing of certain visual features, such as motion, rather than an overall improvement (Pavani & Bottari, 2012). Behavioral studies further suggest that peripheral vision might be selectively enhanced in deaf individuals, and that these enhancements might be due to an increased allocation of attention to the periphery (Bavelier, Dye, & Hauser, 2006; Hauthal, Neumann, & Schweinberger, 2012; Loke & Song, 1991; Lomber et al., 2010). This proposition is also supported by neuroimaging studies showing differences in levels of activation between deaf and hearing subjects when viewing motion stimuli (Neville & Lawson, 1987; Scott, Karns, Dow, Stevens, & Neville, 2014). Electroencephalography (EEG) has been used to show that peripherally-presented motion stimuli result in a larger increase in the amplitude of
event-related potentials (ERPs) in deaf subjects than in hearing subjects when the stimuli are attended to compared to unattended, while there is no significant difference between groups when stimuli are presented in the central visual field (Neville & Lawson, 1987). Functional magnetic resonance imaging (fMRI) has also shown differences in signal changes in response to peripheral stimuli and central stimuli across deaf and hearing groups, and has provided convincing evidence for the occurrence of neural reorganization (Scott et al., 2014). These enhanced motion/periphery functions seem to be at least partially linked to the recruitment of auditory cortex (Finney, Fine, & Dobkins, 2001; Scott et al., 2014).

Aside from the large body of evidence indicating that deaf people may have an enhanced ability to process motion in their periphery, there is also some evidence that deaf individuals possess heightened face processing capabilities (Bettger, Emmorey, McCullough, & Bellugi, 1997; McCullough & Emmorey, 1997; Parasnis, Samar, & Berent, 2003). One study found that deaf signers perform significantly better on a facial recognition task compared to hearing controls (Bettger et al., 1997), but this trend is not found in oral deaf individuals (Parasnis et al., 2003), suggesting that perhaps experience with American Sign Language (ASL) is facilitating the enhancement. However further research has suggested that deaf and hearing individuals may not differ in their ability to recognize faces or their configural processing of faces (McCullough & Emmorey, 1997). Instead the previously reported effects may reflect an enhanced ability to correctly identify and distinguish between local feature changes of the mouth region (McCullough & Emmorey, 1997).

In the present study we compared deaf signers’ and hearing non-signers’ ability to discriminate between faces in a delayed matching task, and examined whether their performance varied as a function of visual field eccentricity. Testing
performance in the central visual field (3.4 degrees from fixation) is similar to the experiment done by McCullough and Emmorey (1997), although we use whole face changes rather than local feature changes. Pilot testing suggested that images presented in the periphery were very difficult to process, and we found that asking participants to discriminate faces based on specific feature changes alone resulted in many participants performing at floor level. The peripheral condition (10 degrees from fixation) is a novel extension. Based on previous literature on motion processing in deaf, we hypothesize that compared to hearing non-signers, deaf signers may be more accurate at matching faces to a sample in the delayed matching task when face stimuli are presented in the periphery.

In the second experiment we examined how these face images appear in the same participants’ electrophysiological signal using EEG and an oddball presentation paradigm (Liu-Shuang, Norcia, & Rossion, 2014). This paradigm is a highly sensitive technique that can be used for examining face processing in which images are presented at set base frequency and recordings analyzed in the frequency domain (e.g. six images per second, resulting in a frequency of 6 Hz). Within this base frequency an ‘oddball’ image is presented at a lower frequency (e.g. every fifth image, resulting in a frequency of 1.2 Hz). The presence of significant responses at the oddball frequency in the amplitude spectrum indicates that the difference between the oddball image and the base images has been reflected in the neurological processes responsible for encoding these images, and a larger amplitude at this oddball frequency can be associated with better performance on a behavioral face processing task (Liu-Shuang et al., 2014). We hypothesize that as the similarity between the base images and the oddball image increases, the amplitude of the responses at the oddball frequency will show a reduction. We expect that the reduction in amplitude will be
greater in hearing subjects compared to deaf. Furthermore, we expect that the
difference between groups will again be more pronounced when faces are presented in
the periphery.

Methods

Subjects
Nine hearing (6 male) with a mean age 34.22 (SD = 9.51) and nine severe to
profoundly deaf (2 male) with a mean age of 40.89 (SD = 10.41) participated in this
study. An independent samples t-test showed that the difference in ages between
groups was not significant ($t_{16} = 1.42, p = .1752, d = 0.67$). All participants had normal
or corrected-to-normal vision, and were all right-handed. All participants except for
one were Caucasian. The single non-Caucasian participant was an African American
male in the hearing group. We compared his performance to the average performance
of the hearing group (calculated without his data) and found that he performed
comparably (within one standard deviation of the group mean). Deaf subjects had no
history of neurological disorders and had a binaural hearing loss greater than 80 dB.
All of the non-hearing participants were fluent in American Sign Language, and none
of the hearing participants were signers. All participants received monetary
compensation for taking part in the study.

Apparatus and Stimuli
The face stimuli used in the study were computer generated faces originally taken
from Retter and Rossion (2016). For our purposes we selected one male and one
female example, each with an additional anti-face (four images total). Anti-faces are
the physical opposite of an original face in terms of features and their configuration,
but do not cross genders. Therefore, for the purpose of this study, the anti-face of an original face that is male will also be male, and this is the same for female faces.

The difference between each face and anti-face was exaggerated by caricaturing the images using the program Abrosoft Fantamorph 5 (USA) and following standard morphing procedures. The images were caricatured to help ensure performance was above floor in the periphery condition. This involved placing a series of landmark points on each face at locations intended to encapsulate the shape and position of the features, such as the eyes and mouth. The position of pixels at these points were then shifted away from the average of the face pair. The degree to which these points were shifted was determined individually for each face pair as the most extreme change possible while still maintaining a normal appearance, as judged by the researchers. At this stage the average of each face pair was also saved as a separate image. Each caricatured face and anti-face pair were morphed together in 1% steps, resulting in 100 images for each pair that gradually change in likeness from being 100% the original face to 0% original face (i.e. the anti-face) (see figure 1).
Figure 1. Face morph percentages for both face sets, showing the progression from being 100% original face down to being 0% original face (i.e. the anti-face) in increments of 25%. Note that in the full image sets these were in increments of 1%. Images were presented on a NEC AccuSync 120 monitor at a working resolution of 1280 x 960 pixels and refresh rate of 60 Hz. All images were a standard height of 310 pixels and at a viewing distance of approximately 57 cm subtended 9.7 degrees of visual angle.

**Procedure**

**Behavioral**

At the beginning of each trial a target face was presented in the middle of the screen for 1.5 s. Subjects were instructed to study the target face in preparation for a following matching task and during this time were allowed to freely move their gaze about the image. After the target face had left the screen and following an inter-stimulus interval (ISI) of 2 s, two test images would simultaneously appear on either side of a central fixation cross. One was identical to the target face while the other was more similar to the anti-face. Participants were required to indicate which of the two faces (left or right) matched the first by pressing either the left or right mouse
button. The sequence of one trial is shown in figure 2. The presentation of images was controlled using a three-down, one-up staircase with a 25% step level. This meant that every time three correct responses were given in a row the task would become harder by reducing the morph level of the non-matching face by 25%, thus making the two test images more similar. Beginning at the maximum 100% difference, this would first reduce to 75%, then 56%, 42% and so on. If one incorrect response was given the task would become easier by increasing the morph level by the same proportion. The staircase continued until 60 trials had been completed. The proportion of correct responses at each viewed morph level was calculated and fit with a Weibull function. Thresholds were determined by the morph level corresponding to an 80% correct response level.
Figure 2. Schematic diagram of the sequence of the procedure. The screen was initially left blank for 2 seconds and then the target face was presented for 1.5 seconds. The target face then disappeared and the screen was blank for 2 seconds. The two test faces appeared for 1 second, and then disappeared after that 1 second.

The experiment was repeated across two different conditions run in separate blocks. In one condition the test images were presented at an eccentricities of 3.4 degrees, while images in the other condition were presented at 10 degrees from the center of the screen. These distances approximate to the central and peripheral areas of vision, respectively. The order of conditions was counterbalanced across participants, and the position of the matching target face (left or right) was randomized across trials. During the test phase participants were instructed to keep their gaze on a central fixation cross. Face sets were varied between participants but were matched across the hearing and non-hearing groups. Each block took approximately 6 min and the entire behavioral experiment lasted for approximately 12 min.
EEG

The whole session for each participant lasted approximately 1.5 hrs, including 30 min of preparation and 1 hr of recording. Images were presented using the fast periodic visual stimulation (FPVS) technique (Rossion, 2014a, 2014b) and custom software running over Java (Oracle, USA). A single trial consisted of a 30 s sequence in which stimuli were shown at a fixed rate of six images per second (6 Hz) by means of a square wave modulation at a 100% duty cycle. To reduce the potential impact of low-level properties of the images contributing to possible observed effects, the size of the images varied randomly across five steps between 85% and 115% of the original image size at each stimulus presentation cycle (Dzhelyova & Rossion, 2014). During each trial participants were required to fixate on a small cross in the center of the screen. To help ensure attention was maintained, the fixation cross would briefly change to a square eight times during each trial at random intervals and participants were required to press a key to indicate they saw the change.

The experiment comprised 6 conditions, defined by the location at which the images were presented (central or peripheral) and the level of difference between the base images and oddball images. For the central conditions these differences were 100%, 75% and 50%. For the peripheral conditions these differences were 100%, 88% and 75%. More extreme differences between faces in the peripheral field were chosen because pilot testing indicated that these were required to obtain significant responses at the oddball frequency. Twelve trials were run for each condition. In half of these trials the anti-face was the oddball image and in the other half the original face was the oddball. Data from both trial types were combined during analyses. The experiment was divided into two blocks with 36 trials in each. Within each block trials from all conditions were randomly intermixed.
**EEG acquisition**

The data were recorded using a BioSemi ActiveTwo system with a 128 Ag-AgCl Active-electrode array (BioSemi B.V., Amsterdam, Netherlands; for exact position coordinates, see [http://www.biosemi.com/headcap.htm](http://www.biosemi.com/headcap.htm), for a conversion of these coordinates to a more standard 10-20 nomenclature, see Rossion, Jacques, & Liu-shuang, 2015). Four additional electrodes were used to record vertical and horizontal electrooculogram (EOG): two electrodes were placed above and below participants’ right eye and two were placed lateral to the external canthi. EEG electrode offsets were kept below 40mV, referenced to the common mode sense (CMS). The EEG and EOG were digitized at a sampling rate of 2048 Hz and later down sampled to 512 Hz.

**EEG Analysis**

Analyses were performed using Letswave 5, an open source toolbox ([http://nocions.webnode.com/letswave](http://nocions.webnode.com/letswave)), running over MATLAB R2013b (MathWorks, USA). Recordings were filtered using a fourth order zero-phase Butterworth band-pass filter, with cutoff values of .1 Hz to 120 Hz. A Fast Fourier Transform (FFT) multi-notch filter with a width of .5 Hz was then applied to remove electrical noise at three harmonics of 60 Hz. Data were then segmented by trial, including 1 s before and after the beginning of the 30 s stimulation sequence. Eye blink correction was performed using independent component analysis (ICA) with a square matrix (Hyvarinen & Oja, 2000). One component that matched the profile of recordings from the EOG electrode positioned above the eye was removed for two deaf participants and two hearing participants. These were participants who blinked more than .2 times/s on average during the 30 s stimulation sequences (Retter &
Channels containing artifacts across multiple trials were replaced with the average of 3-4 neighboring channels. This was performed for a maximum of four channels per participant. All channels were then re-referenced to the average of all EEG channels. Trials were re-segmented to exclude the 1 s before and after the 30 s stimulation sequence. Trials were then averaged within each condition for each subject.

An FFT was computed for each subject, condition and channel, and then grand averaged across all subjects. Recordings were analyzed using a right occipito-temporal (ROT) region of interest (ROI)\(^1\), comprising electrodes P8, P10, PO8, PO110, PO12, POI12 and I2. The ROT ROI is similar to that selected in previous studies and has been shown to be sensitive to neurophysiological responses associated with face processing (Dzhelyova & Rossion, 2014; Retter & Rossion, 2016). Unlike previous studies we also chose to include two additional and more medial electrodes, POI12 and I2, as scalp topographies appeared to show a slightly more medial locus of activation.

The presence of significant responses at the frequency of interest (1.2 Hz) and its harmonics was identified using z-scores ($z = (x - \text{baseline})/\text{standard deviation of the baseline}$). Baselines were defined as the twenty bins surrounding the bin of interest ($x$), excluding the immediately adjacent bins (Rossion, Prieto, Boremanse, Kuefner, & Belle, 2012; Srinivasan, Russell, Edelman, & Tononi, 1999). When displaying the amplitude spectra and comparing differences in amplitude across conditions and subject groups, baseline corrections were applied to account for differences in

\(^1\) In other analyses not reported here we also considered responses in a left occipito-temporal (LOT) ROI however these did not reveal any additional differences between the two subject groups.
baseline noise across participants and across the frequency spectrum within participants. This involved a baseline subtraction in which the average of the twenty surrounding bins, excluding the immediately adjacent bins and the local maximum and minimum amplitude bins, was subtracted from the bin of interest ($x' = x - \text{baseline}$). When determining the presence of a significant signal at the oddball frequency, a sum of harmonics of the frequency of interest and the surrounding bins was computed (see Heinrich, 2009). The number of harmonics summed was determined by the morph level with highest continuation of significant harmonics. For both the central and periphery conditions this was the 100% morph level, with significant harmonics up to and including the eighth harmonic (9.6 Hz) in the central condition, and the seventh harmonic (8.4 Hz) in the peripheral condition. For both conditions the fifth harmonic was not included in the sum as this is confounded with the presentation rate of 6 Hz.

Results

Behavioral

One hearing and one deaf subject produced thresholds that were beyond the possible image range (i.e. greater than a 100% morph level) and their behavioral data were excluded from further analyses. Average thresholds for the remaining participants can be seen in figure 3. Thresholds for hearing and deaf subjects appear similar for the central condition whereas in the peripheral condition, thresholds for deaf subjects appear lower than for hearing subjects. These data were formally analyzed using a 2 x 2 repeated measures ANOVA with the between subjects factor of ‘group’ (hearing vs. deaf) and within subjects factor of ‘condition’ (center vs. periphery). A significant
main effect of condition was found ($F_{1,14} = 9.95, p = .007, \eta_p^2 = .42$) with thresholds lower in the central condition ($M = 24.43, SD = 12.04$) compared to the peripheral condition ($M = 35.62, SD = 21.45$), indicating that across groups performance was worse in the peripheral condition. A significant main effect of group was also found ($F_{1,14} = 5.47, p = .035, \eta_p^2 = .28$) with deaf subjects producing lower thresholds ($M = 22.15, SD = 13.28$) than hearing subjects ($M = 37.9, SD = 13.64$), indicating that across conditions deaf subjects performed better than hearing subjects. Analyses also revealed a significant condition*group interaction ($F_{1,14} = 6.11, p = .027, \eta_p^2 = .3$). To further explore this interaction two independent sample t-tests were performed separately comparing thresholds for deaf and hearing subjects for each condition. For these two comparisons a Bonferroni correction was applied and the critical alpha adjusted to $\alpha = .025$. For the central condition, thresholds for hearing subjects ($M = 27.92, SD = 11.26$) were not significantly different to thresholds for deaf subjects ($M = 20.94, SD = 12.5$) ($t_{14} = 1.17, p = .26, d = .59$). In contrast, in the peripheral condition thresholds for hearing subjects ($M = 47.88, SD = 20.57$) were significantly higher than thresholds for deaf subjects ($M = 23.37, SD = 14.82$) ($t_{14} = 2.76, p = .016, d = 1.37$). These results indicate that differences between deaf and hearing individuals in face matching accuracy may be most prominent when stimuli are presented in the visual periphery.
Figure 3. Average thresholds for deaf and hearing subjects for faces presented in the central and peripheral visual fields. Thresholds correspond to the morph level associated with 80% accuracy. Error bars show standard error of the mean (SEM).

**EEG**

**Central**

Amplitude spectra can be seen in figure 4 and scalp topographies in figure 5. For both hearing and deaf subjects, significant responses at the sum of the first eight harmonics (excluding the fifth) of the oddball frequency (1.2 Hz) were observed for all morph levels (see table 1). Average baseline subtracted amplitudes summed across the first eight harmonics are shown in figure 6. Amplitudes appear lower for the 75% and 50% morph levels compared to the 100% level, and amplitudes appear similar across subject groups. These data were formally analyzed using a 2 x 3 repeated measures ANOVA with the between subjects factor of ‘group’ (hearing vs. deaf) and the within subjects factor of ‘morph level’ (100%, 75%, 50%). A significant main effect of morph level was found ($F_{3,30} = 75.01, p < .0001, \eta_p^2 = .82$). Paired sample t-tests with a Bonferroni corrected critical alpha of $\alpha = .017$ showed that amplitudes for the 100% morph level ($M = 1.44, SD = .57$) were significantly larger than for the 75% level ($M$
= .29, SD = .21) \( (t_{17} = 10.36, p < .0001, d = 2.68) \) and 50% level \( (M = .27, SD = .31) \)
\( (t_{17} = 8.83, p < .0001, d = 2.55) \), while the difference between the 75% and 50% levels was not significant \( (t_{17} = .3, p = .764, d = .07) \). The main effect of group was not significant \( (F_{1,16} = 2.36, p = .144, \eta_{p}^2 = .13) \), indicating similar responses amplitudes between hearing and deaf subjects. The interaction of morph level*group also was not significant \( (F_{2,32} = .65, p = .531, \eta_{p}^2 = .04) \), indicating a similar decrease in amplitudes across morph levels for both hearing and deaf subjects. The similarity in response amplitudes for centrally presented stimuli is perhaps to be expected given the similarity in performance between the two subject groups in the behavioral task.
Figure 4. Average baseline subtracted amplitude for deaf and hearing subjects for the central condition at the 100%, 75% and 50% morph levels. Darker stems show harmonics of the oddball frequency (1.2 Hz) up to the eighth harmonic (9.6 Hz). Top head model shows the area and seven electrodes defined as the ROT ROI.
Figure 5. Scalp topographies for deaf and hearing subjects in the central condition for the 100%, 75% and 50% morph levels.

Figure 6. Average baseline subtracted amplitudes summed across the first eight harmonics of the oddball frequency (1.2 Hz) for deaf and hearing subjects in the central condition for the 100%, 75% and 50% morph levels on the right side. Error bars show SEM.
Table 1. Z-scores for the oddball signal (1.2 Hz) summed across the first eight harmonics for deaf and hearing subjects for the central condition and the 100%, 75% and 50% morph levels.

<table>
<thead>
<tr>
<th></th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing</td>
<td>18.11</td>
<td>4.62</td>
<td>3.74</td>
</tr>
<tr>
<td>Deaf</td>
<td>24.47</td>
<td>4.48</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Note: All $p < .0001$

**Periphery**

Amplitude spectra can be seen in figure 7 and scalp topographies in figure 8. For both hearing and deaf subjects, significant responses at the sum of the first seven harmonics (excluding the fifth) of the oddball frequency (1.2 Hz) were observed for the 100% and 88% morph levels, but not the 75% level (see table 2). Average baseline subtracted amplitudes summed across the first seven harmonics are shown in figure 9. Amplitudes appear lower for the 88% and 75% morph levels compared to the 100% level, and amplitudes appear similar across subject groups. These data were formally analyzed using a 2 x 3 repeated measures ANOVA with the between subjects factor of ‘group’ (hearing vs. deaf) and the within subjects factor of ‘morph level’ (100%, 88%, 75%). A significant main effect of morph level was found ($F_{2,32} = 5.39, p = .01, \eta^2_p = .25$). Paired sample t-tests with a Bonferroni corrected critical alpha of $\alpha = .017$ showed that amplitudes for the 100% morph level ($M = .23, SD = .29$) were not significantly larger than for the 88% level ($M = .15, SD = .16$) ($t_{17} = 1.84, p = .084, d = .36$) or the 75% level ($M = .01, SD = .18$) ($t_{17} = 2.43, p = .026, d = .91$). The difference between the 88% and 75% levels was also not significant ($t_{17} = 2.28, p = .035, d = .81$). The main effect of group was not significant ($F_{1,16} = 1.06, p = .32, \eta^2_p = .06$), indicating similar responses amplitudes between hearing and deaf subjects. The interaction of morph level*group also was not significant ($F_{2,32} = 1.07, p$
= .36, \eta_p^2 = .06), indicating a similar decrease in amplitudes across morph levels for both hearing and deaf subjects. The similarity in response amplitudes for peripherally presented stimuli is somewhat unexpected as it was at this eccentricity that the differences in performance between the two subject groups in the behavioral task was clearly seen.
Figure 7. Average baseline subtracted amplitude for deaf and hearing subjects for the peripheral condition at the 100%, 75% and 50% morph levels. Darker stems show harmonics of the oddball frequency (1.2 Hz) up to the seventh harmonic (8.4 Hz). Top head model shows the area and seven electrodes defined as the ROT ROI.
Figure 8. Scalp topographies for deaf and hearing subjects for the peripheral condition and the 100%, 88% and 75% morph levels.

Figure 9. Average baseline subtracted amplitudes summed across the first seven harmonics of the oddball frequency (1.2 Hz) for deaf and hearing subjects for the peripheral condition and the 100%, 88% and 75% morph levels. Error bars show SEM.
Table 2. Z-scores for the oddball signal (1.2 Hz) summed across the first seven harmonics for deaf and hearing subjects for the peripheral condition and the 100%, 88% and 75% morph levels.

<table>
<thead>
<tr>
<th></th>
<th>100%</th>
<th>88%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing</td>
<td>5.76***</td>
<td>3.03**</td>
<td>-.23</td>
</tr>
<tr>
<td>Deaf</td>
<td>1.67*</td>
<td>2.2*</td>
<td>-.1</td>
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</tbody>
</table>

Note: *p < .05, **p < .01, ***p < .0001

Central versus periphery

In the current study both the 100% and 75% morph levels were seen in the center and in the periphery. The effect of the location of presentation of the stimuli on response amplitudes can be seen in figure 10. For both subject groups, response amplitudes appear lower when the same stimuli are presented in the periphery, however for deaf subjects the decrease in amplitude may be larger. These data were analyzed using a 2 x 2 x 2 repeated measures ANOVA with the between subjects factor of ‘group’ (hearing vs. deaf) and the within subjects factors of ‘morph level’ (100% vs. 75%) and ‘eccentricity’ (central vs. periphery). Here we will focus on the significant and theoretically relevant three-way interaction of group*morph level*eccentricity ($F_{1,16} = 5.91, p = .027, \eta_{p^2} = .27$), which indicates that between subject groups the effect of eccentricity differs across morph levels. To further explore this result we ran separate 2 x 2 repeated measures ANOVA’s for each morph level with the factors ‘group’ and ‘eccentricity’. For the 100% morph level a significant interaction of group*identity was found ($F_{1,16} = 5.56, p = .031, \eta_{p^2} = .26$) with deaf subjects showing larger response amplitude than hearing subjects for images presented in the center but lower amplitudes than hearing subjects for images presented in the periphery (figure 10). For the 75% morph level this interaction was not significant ($F_{1,16} = .3, p = .59, \eta_{p^2} = .02$). Results for the 100% morph level are not what we would predict based on the
behavioral results in which deaf subjects appeared to show a greater degree of sensitivity to peripherally presented faces compared to hearing subjects. Alone these EEG results perhaps indicate a lesser degree of sensitivity.

Figure 10. Average baseline subtracted amplitudes summed across the first eight harmonics of the oddball frequency (1.2 Hz) for the central condition and first seven harmonics for the periphery condition. Amplitudes are shown deaf and hearing subjects for 100% and 75% morph levels. Error bars show SEM.

Discussion

The present study investigated whether deaf individuals exhibit enhanced face processing abilities in either the central or peripheral visual fields compared to hearing individuals, and further examined whether these differences would be reflected in the neurophysiological responses to these faces, measured using EEG. We found that overall deaf individuals performed better than hearing individuals in the delayed face matching task and this difference was most clearly evident when faces were presented in the periphery rather than centrally. Similar differences in the
neurophysiological responses to these faces were not observed, with both groups showing similar reductions in amplitude for less distinctive identities. Further, deaf subjects showed some indications of larger decreases in response amplitudes for faces presented in the periphery compared to when they were presented centrally, perhaps indicating a reduction in sensitivity whereas the behavioral data suggested an enhancement.

Researchers have tended to argue that neuroimaging studies citing differences in activity between deaf and hearing groups as evidence of enhancements in processing abilities are unreliable unless behavioral data show the same trend (Pavani & Bottari, 2012). In the case of deaf individuals showing greater allocation of attention to the visual periphery, which in turn appears to lead to enhanced processing of motion stimuli, studies have reported both behavioral and neurological differences. For example, several studies have found that deaf subjects perform better in behavioral motion detection tasks (for review see Bavelier et al., 2006) especially in their peripheral visual field (Loke & Song, 1991). Neville, Schmidt, & Kutas (1983) examined group differences at a neurological level, and found that deaf individuals show significantly larger visual evoked potentials in their auditory and visual cortices compared to hearing subjects, implying that there may be a connection between amplitude differences and the behavioral differences. These findings have been replicated and expanded upon by other groups using various methods for recording brain responses, including EEG (Neville & Lawson, 1987), magnetoencephalography (MEG) (Finney, Clementz, Hickok, & Dobkins, 2003), and fMRI (Bavelier, Tomann, Hutton, Mitchell, Corina, Liu, & Neville, 2000; Bavelier, Brozinsky, Tomann, Mitchell, Neville, & Liu, 2001). In the case of face processing abilities of hearing and deaf individuals, attempts to pair behavioral differences between the two groups with
neurological differences had not been made prior to the current study. We did not find the complimentary neurological differences that we had hypothesized, and this discrepancy and its implications are discussed below.

The dissociation between the behavioral results and neurophysiological activity reported in the current study raises the possibility that the two aspects of the investigation may be measuring two different aspects of faces processing. Some evidence for this may be found in the difference between the thresholds found in the behavioral experiment and what could be considered as ‘thresholds’ in the EEG experiment. In the EEG experiment we saw a loss of significant responses at the oddball frequency in the peripheral condition for faces at the 75% morph level, while in the behavioral experiment both groups were able to maintain a high level of accuracy in the peripheral condition for faces that were much more similar in appearance, with mean 80% correct thresholds corresponding to a 48% morph level for the hearing group and 23% morph level for the deaf group. A study by Gentile and Rossion (2014) found that presenting images quickly (at a frequency of 6 Hz) may promote more holistic processing because the stimuli disappear too quickly to allow participants to selectively attend to local features. In the EEG portion of the present study images were similarly presented at a fast rate of 6 Hz, whereas in the behavioral portion test images remained on the screen for 1 s. It is possible that the current EEG experiment may be measuring a different aspect of face processing than our behavioral forced-choice delayed match-to-sample experiment. Likely, our EEG study measures a range of responses associated with the normal face coding and holistic processing, while our behavioral study examines local feature discrimination. The differences between groups in the behavioral experiment but not EEG experiment may indicate that the enhanced face processing abilities seen in some deaf individuals
does not extend beyond simple shape discrimination of local features. Some support for this proposition can be found in McCullough and Emmorey’s (1997) study, in which differences in the face processing abilities of deaf and hearing individuals were assessed using images that only had singular local feature changes. While deaf individuals showed greater discrimination accuracy than hearing subjects for stimuli with local feature changes, the two groups did not differ in performance for Mooney faces which require more holistic processing to be identified as faces (Mooney, 1957).

If we assume that we are correct in our assessment that the two aspects of the present study may be measuring different aspects of face processing, we must now consider what this means for the area and the extent to which deaf individuals possess enhanced face processing abilities. As previously mentioned, researchers have tended to dismiss neurological differences when they cannot be linked to observable behavioral differences. However in the current study we have reason to believe that the results from our neurophysiological measures may actually better reflect ‘true’ face processing. That is, one of the hallmarks of face processing compared to the processing of other objects that an observer does not have significant expertise with (Gauthier et al., 1999; 2000), is holistic processing (Tanaka & Farah, 1993). In addition to the fast presentation rate of the images in the EEG portion of the present study, the images varied in size on each trial, similar to previous studies using the same paradigm (Dzhelyova & Rossion, 2014). That significant responses at the oddball frequency can still be observed with these size changes suggests that the effect may be associated with higher-order processing of the images at a stage where complete representations of the facial identities are being constructed. Without these size variations, the oddball frequency could simply reflect local angular differences between local features of different identities that would likely be identifiable at a
retinotopic level. For these reasons we suggest that our EEG results may be a better indication of what could be considered more specific face processing than our behavioral results, and that the behavioral differences may be driven by neurological processes that are partially separate from the stages of initial face encoding.

Another factor potentially contributing to the discrepancy in results between the behavioral and EEG experiments in the present study is the role of attention. Behavioral and neuroimaging studies indicate that deaf individuals may exhibit an increased allocation of attention to the periphery and differences in performance between groups are most clearly seen under conditions with high attentional demands (Bavelier, Dye, & Hauser, 2006; Hauthal, Neumann, & Schweinberger, 2012; Loke & Song, 1991; Lomber et al., 2010, Neville & Lawson, 1987; Scott, Karns, Dow, Stevens, & Neville, 2014). The design of our EEG experiment required participants to attend to a central fixation cross (i.e. pressing the spacebar when the cross briefly changed into a square), whereas in the behavioral task they were instructed to specifically attend to the faces. By not explicitly directing subjects to attempt to discriminate between the baseline and oddball images in the EEG experiment we may not have fostered the optimal conditions for differences in neurophysiological responses to be observed. Future experiments may benefit from including a task in the periphery that induces a higher attentional demand in those locations.

If our EEG results indeed reflect responses associated with face coding, this raises the question of what the greater reduction in oddball amplitude for the 100% morph level faces when presented in the periphery compared to centrally seen in the deaf group compared to the hearing group means in regards to the face processing abilities of deaf individuals. One possible explanation is that deaf individuals might be more susceptible to face distortion effects induced by fast-paced presentation of
faces, especially in the visual periphery. Tangen and colleagues (2011) found that when faces are cycled at a steady rate, they appear caricatured and highly deformed. The ‘flashed face distortion effect’ is most evident at 4-5 Hz presentation rate and for faces that deviate from the others in the set on a particular dimension. While the effect reported by Tangen et al. (2011) appears to arise from differences in the physical characteristics between different identities, during pilot testing we observed similar effects for the size changes on each trial between the images forming the baseline. That is, the size changes appeared more extreme in the peripheries making it harder to determine the same identity was being repeated during the baseline. It is possible that deaf subjects experienced a greater distortion effect for these size changes resulting in a less defined sequence of baseline images contrasting with the oddball image. However such an interpretation is highly speculative and further testing would be required to confirm this conclusion.

In the present study we found that overall deaf participants were more accurate than hearing participants in a face matching task, with the effect being mainly driven by a significant difference between the two groups in the peripheral condition. Similar differences in the neurophysiological responses to these faces were not observed, with deaf subjects even showing some indications of reduced sensitivity to peripherally presented face stimuli, whereas the behavioral data suggested an enhancement. We suggest that this discrepancy may be due to differences in the task demands between the two aspects of the study, with the behavioral experiment reflecting more local feature discrimination, while the EEG experiment may reflect more holistic face coding. The behavioral face advantage shown in previous studies and replicated in our own does not appear to correlate with a difference in the neurophysiological responses associated with the stage of encoding measured here. A future expansion upon the
current study could be to use shorter presentation times in the behavioral experiment in an attempt to force participants to rely on more holistic processing.
References


