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Functional and Neural Organization underlying Face and Facial Expression Perception

A Dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Cognitive Science

by

Stephen Hugh McCullough

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2010
The Dissertation of Stephen Hugh McCullough is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Co-Chair

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University of California, San Diego

2010
To my parents and grandparents
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Chapter 2 of this dissertation, in full, is a preprint version of the material as it appears in Journal of Deaf Studies and Deaf Education, 2(4), pp. 212-22, McCullough, Stephen and Emmorey, Karen, Oxford University Press, 1997. The dissertation author was the primary investigator and author of this paper.

Chapter 3 of this dissertation, in full, has been prepared for publication of the material as it appears in Cognition. McCullough, Stephen and Emmorey, Karen. The dissertation author was the primary investigator and author of this paper.
Chapter 4 of this dissertation, in full, is a preprint version of the material as it appears in Cognitive Brain Research, 22(2), pp. 193-203, McCullough, Stephen; Emmorey, Karen; and Sereno, Martin, Elsevier 2005. The dissertation author was the primary investigator and author of this paper.
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ABSTRACT OF THE DISSERTATION

Functional and Neural Organization underlying Face and Facial Expression Perception

by

Stephen Hugh McCullough

Doctor of Philosophy in Cognitive Science

University of California, San Diego, 2010

Professor Martin Sereno, Chair
Professor Karen Emmorey, Co-Chair

Users of American Sign Language (ASL) must recognize certain non-affective facial expressions as linguistic markers that signal distinct lexical and syntactic structures. When perceiving visual linguistic input, ASL signers must be able to quickly identify and discriminate between different linguistic and affective facial expressions in order to process and interpret signed sentences. Thus, signers have a very different perceptual and cognitive experience with the human face compared to nonsigners. This dissertation examines, in three separate studies, how experience with American Sign Language leads to changes in the processing and neural organization for the perception of faces and facial expressions.
Study 1 examines face processing in Deaf signers and hearing nonsigners and revealed that these groups do not differ in face recognition or gestalt face processing ability; however, ASL signers exhibit a superior ability to detect subtle differences in local facial features.

Study 2 examines whether affective facial expression categorical perception (CP) also extends to ASL facial expressions, and whether lifelong experience with ASL affects CP for affective facial expressions. Deaf signers and hearing nonsigners performed ABX discrimination and identification tasks on morphed affective and linguistic facial expression continua. Significant CP effects were observed in hearing nonsigners for both affective and linguistic facial expressions. Deaf signers, however, showed a significant CP effect only for linguistic facial expressions.

Study 3 examines facial expression perception using functional magnetic resonance imaging (fMRI) and found that activation within the superior temporal sulcus (STS) for emotional expressions was right lateralized for hearing nonsigners and bilateral for deaf signers. In contrast, activation within STS for linguistic facial expressions was left lateralized only for signers and only when linguistic facial expressions co-occurred with verbs. Within the fusiform gyrus (FG), activation was left lateralized for ASL signers for both expression types, whereas activation was bilateral for both expression types for nonsigners.

Taken together, the results demonstrate that linguistic processing of facial expressions leads to specific changes in the processing of and neural organization for human faces and facial expressions.
CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Face and facial expression recognition is essential in everyday living, particularly in the context of social interaction. With a brief glance of a face, one can easily derive a wealth of information about the person’s age, sex, race, identity, intention, and emotional state. What is even more remarkable is that face and facial expression processing--the encoding, analysis, and classification of complex multidimensional information--is always done instantaneously and effortlessly. Sensitivity to faces and facial expression also emerges very early in human development. These distinctive attributes led some to argue that face and facial expression perception, like language, may be innate, modular, and domain specific (Kendrick & Baldwin, 1987; Desimone, 1991).

For signers of American Sign Language (ASL), they must also recognize certain non-affective facial expressions as linguistic markers that signal distinct lexical and syntactic structures such as relative clauses, questions, conditionals, adverbials, and topics (Baker, 1980; Reilly, McIntire, & Bellugi, 1990). Moreover, when perceiving visual linguistic input, ASL signers must also be able to quickly identify and discriminate between different linguistic and affective facial expressions in order to process and interpret signed sentences. Thus, signers have a very different perceptual and cognitive experience with the human face compared to nonsigners. Investigating face and facial expression perception in Deaf and hearing signers provides us a unique opportunity to
examine how human brain recognizes, organizes, and processes different cognitive functions that come in view from the same surface form (i.e., facial features).

1.2 Literature Review

Affective facial expressions

Facial expressions alone can convey rich information about a person’s mood, current emotional state, and intention. Human facial muscles are fully capable of expressing innumerable combinations of facial expressions, yet only few are clearly associated with specific emotional states. Cross-cultural studies in the past few decades have suggested that only six basic affective facial expressions (happiness, sadness, angry, disgust, surprise, and fear) are universal and innate (Darwin, 1872; Ekman & Friesen, 1971; Ekman 1973; Izard, 1994). Desimone (1991) suggested that the evolution of these affective facial expressions is complemented with a co-evolving innate perceptual system that may be specially attuned to the faces and specific categories of facial expressions.

The argument for the co-evolving perceptual system emerges from a multitude of behavioral and neurological studies that consistently find a right hemisphere supremacy for perception of affective facial expressions. Neurological studies with unilateral brain-damaged subjects have shown that recognition of emotional facial expressions was more impaired in right hemisphere damaged (RHD) subjects (Cicone, Wapner, & Gardner, 1980; DeKosky, Heilman, Bowers, & Valenstein, 1980; Kolb, Milner, & Taylor, 1983; Mandal, Asthana, & Maitra 1998). Damage to the right frontal lobe was found to cause severe impairments in the judgment of facial expressions, but not in the ability to identify faces. A unilateral lesion in the right temporal lobe alone was found to be sufficient to
impair the ability to recognize different affective facial expressions (Bowers, Bauer, Coslett, & Heilman, 1985; Rapcsak, Comer, & Rubens, 1993). A large neurological study undertaken by Adolphs, Damasio, Tranel and Damasio (1996) with thirty-seven unilateral brain-damaged subjects has reported that lesions in the right hemisphere were significantly correlated to recognition impairments of five basic emotional facial expressions. Left hemisphere damaged subjects, on the other hand, did not exhibit any significant impairment in the recognition of affective facial expressions. The double dissociation observed in Adolphs et al. (1996) study provides a strong evidence for hemispheric specialization underlying the affective facial expression processing. Moreover, other neurological studies using intraoperative cell stimulating and recording with human patients prior to their neurosurgery have reported that the right temporal lobe contains neural systems that responded specifically to facial expressions. (Ojemann, Ojemann, & Lettich, 1992). The neurological findings were very compelling; however, there are limitations in how inferences can be made from these findings because the brains of the patients were already different to begin with.

However, the neurological findings were subsequently corroborated with functional magnetic resonance imaging (fMRI) studies on facial expression perception. fMRI is a non-invasive neuroimaging technique that allows us to study neural activity in-vivo while normal subjects perform various mental tasks. Several fMRI studies have reported that viewing the eye gaze and mouth movements strongly activated the human superior temporal sulcus (STS) region (Haxby, Hoffman, & Gobbini, 2000; Puce, Allison, Bentin, Gore, and McCarthy, 1998). Furthermore, these studies also have revealed that the neural circuitry underlying the perception of dynamical face (i.e.,
moving eyes or mouth), is partially independent of the neural system that underlies the perception of static facial information, such as person identity or gender (Damasio & Damasio, 1994; Haxby, Hoffman, & Gobbini, 2000; Young, 1998). Haxby (2002) hypothesized that STS plays an important role in processing the changeable aspects of face, such as eye gaze (Hoffman & Haxby, 2002), mouth configuration (Puce et al., 1998), and facial expression (Haxby et al., 2000). Converging evidence from these neuroimaging findings strongly suggests that the STS region in the right hemisphere contains the neural system that is specially attuned to dynamical facial expressions.

Neuroimaging studies also found another important brain region that typically becomes strongly activated during face processing: fusiform gyrus. Sergent, Ohta, and MacDonald (1992), using positron emission tomography (PET), found strong neural activation within the fusiform gyrus in both hemispheres during face processing. This seminal study has been successfully replicated many times across different tasks and imaging techniques (Haxby, et al, 1994; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore,& Allison 1997). Kanwisher et al. (1997) suggested that fusiform gyrus is a special area that is innate and specialized for face processing. This area is now commonly known as fusiform face area (FFA). Moreover, Haxby et al. (2000) also suggest that FFA is primarily responsible for processing invariant aspects of face, such as identity or gender.

Although many neuroimaging studies have shed light on the neural activity within the STS and fusiform gyrus regions during face processing tasks, these regions remain relatively unknown in the breadth of their functional domains. Additional neuroimaging research focusing on different types of facial expression or parts of face is needed to
reveal and map the breadth and depth of cognitive processes these regions encompass. For example, the STS region in left hemisphere may respond more strongly to a particular class of facial expressions such as linguistic facial expressions.

*Linguistic facial expressions*

American Sign Language is a visuo-spatial language used by Deaf people in America and English-speaking parts of Canada. Although the surface form of ASL is markedly different from spoken languages, the linguistic structure (e.g., lexicon, morphology, grammar) of ASL is equally expressive and complex (Baker & Padden, 1978; Klima & Bellugi, 1979).

A unique and modality specific aspect of the grammar of ASL and other signed languages is the use of face as a linguistic marker. Distinct facial expressions serve to signal different lexical and syntactic structures, such as relative clauses, questions, conditionals, adverbials, and topics (Baker & Cokley, 1980; Reilly, McIntire, & Bellugi, 1990). Linguistic facial expressions differ from affective expressions in their scope and in the combinatorial use of facial muscles (Reilly et al., 1990). Linguistic facial expressions have a clear onset and offset, and are coordinated with specific parts of the signed sentence. These expressions are critical for interpreting the syntactic structure of many ASL sentences. Shown below are two examples of how ASL sentences can be syntactically differentiated by linguistic facial expressions alone. The first sentence is signed with raised eyebrows that start at 'TODAY' and end immediately after the sign 'SNOW'. With the raised eyebrows, the signed sentence is a conditional sentence.
However, without the linguistic facial expression, the identical signed sentence becomes a conjoined sentence.

1. TODAY SNOW TRIP CANCEL

“If it snow today, the trip will be cancelled”

2. TODAY SNOW TRIP CANCEL

“It’s snowing today; the trip is cancelled”

Linguistic facial expressions also operate as adverbials that modify the meaning of the predicates. Two ASL sentences may have exactly the same predicate but differ only in the facial adverbials that co-occur with the verb phrase. For example, the facial expression "mm" (lips pressed together and protruded) indicates an action done effortlessly; whereas the facial expression "th" (tongue protrudes between the teeth) means "awkwardly" or "carelessly").

1. LAST YEAR MY C-P-A TAX FIGURE-OUT

“Last year my CPA figured out the taxes really smoothly”

2. LAST YEAR MY C-P-A TAX FIGURE-OUT

“Last year my CPA figured out the taxes carelessly”
There are also some facial expressions that only co-occur with specific lexical signs. For example, sign for SOON is always accompanied with a facial expression that resembles act of whistling. Also, signs for emotional states are often, but not always, accompanied with facial expressions representing such states (e.g., smile for HAPPY and so on). These facial expressions do not necessarily reflect signer's actual emotional states.

Since the function of linguistic facial expressions is clearly different from affective facial expressions (i.e., they are part of linguistic representations), it is hypothesized that the neural organization for linguistic facial expressions may be also different from the one that underlies the emotional facial expressions. This hypothesis is predominantly based on what has been learned from research on the neural organization underlying spoken and signed languages.

**Neural organization underlying sign language**

Aphasia studies dating back to the 1860’s have shown that the neural substrates in the left hemisphere are significantly involved in many aspects of language processing in right-handers. Individuals with lesions in the left inferior frontal region (Broca's area) often show deficits in their language production (e.g., slow, effortful, and awkward) and syntactical processing. Individuals with lesions in the posterior superior temporal gyrus region of the left hemisphere (Wernicke's area), on the contrary, often display poor language comprehension, and often produce fluent paraphasic errors and neologisms.

Although ASL differs markedly from spoken languages in many aspects, aphasia research with unilateral brain damaged deaf individuals has shown that the neural
organization for language in Deaf signers is very similar to hearing English speakers (Hickok, Bellugi, & Klima, 1996). Deaf signers with a lesion encompassing the left inferior frontal region produced effortful, halting, and agrammatic sentences (often limited to a few nouns) without displaying any significant impairments to the language comprehension. Like hearing English speakers, Deaf signers with a lesion to the posterior region of the left hemisphere displayed serious deficits in their comprehension of signed sentences (Poizner, Klima, & Bellugi, 1987; Hickok et al. 1996; Corina, 1998).

Neural organization underlying facial expressions in signers.

Research on neural organization underlying affective and linguistic facial expressions in signers is very limited. Majority of research findings came from Corina, Bellugi, and Reilly’s (1998) study with unilateral brain-damaged signers. Their study found a double dissociation between hemispheres and types of facial expression. A left hemisphere damaged signer was found to be significantly impaired in production of linguistic facial expressions (e.g., omissions of required linguistic facial markers); however, her affective facial expression production remained intact. A right hemisphere damaged signer, on the other hand, did not exhibit any emotional facial expression (positive or negative) under various circumstances where a normal deaf person would naturally express emotions on the face, yet her use of linguistic facial markers was clear and appropriate when linguistically required (Corina, Bellugi, & Reilly 1998). Their study provided a tantalizing possibility that the neural system mediating the perception of linguistic facial expressions may be different from the one that underlies the perception of affective facial expressions. However, since Corina et al. (1998) study only
focused on the facial expression production, a study investigating the neural organization underlying facial expression perception is needed.

The principal aim of this dissertation is to investigate, in separate studies, how the experience with ASL affects the functional and neural organization underlying face and facial expression perception in signers. All studies presented in this dissertation were conducted with three overarching questions in mind: How does brain recognize and process affective and linguistic facial expressions? Will the difference in function between affective and linguistic facial expressions produce different hemispheric specializations? Does experience with linguistic facial expressions alter how faces and affective facial expressions are processed?

This dissertation examines and addresses these questions into five separate chapters. This chapter provides a brief review of selected literature on behavioral and neurophysiological studies relevant to this dissertation, and lays out the motivation and rationale for the experimental studies. Chapter 2 reports three different face processing experiments with signers: face recognition, configurational (gestalt) face recognition, and local facial feature discrimination. Chapter 3 examines a categorical perception study of linguistic and affective facial expressions in Deaf signers and hearing nonsigners. Chapter 4 reports an fMRI study investigating the neural organization underlying recognition of linguistic and affective facial expressions in Deaf signers and hearing nonsigners. Chapter 5 briefly summarizes all experimental findings and presents converging conclusions.
CHAPTER 2: FACE PROCESSING BY DEAF ASL SIGNERS: EVIDENCE FOR EXPERTISE IN DISTINGUISHING LOCAL FEATURES

Abstract

Several previous studies have shown that ASL signers are “experts” on at least one test of face processing: the Benton Test of Face Recognition (Benton, Hamsher, Varney, & Spreen, 1983). This test a discrimination task which requires subjects to select a target face from a set of faces shown in profile and/or in shadow. The experiments reported here were designed to discover why ASL signers have superior skill as measured by this test and to investigate whether enhanced performance extends to other aspects of face processing. Experiment 1 indicated that the enhancement in face processing skill does not extend to recognition of faces from memory. Experiment 2 revealed that deaf and hearing subjects do not differ in their gestalt face processing ability; they perform similarly on a closure test of face perception. Finally, experiment 3 suggested that ASL signers do exhibit a superior ability to detect subtle differences in facial features. This superior performance may be linked both to experience discriminating ASL grammatical facial expressions and to experience with lip reading. We conclude that only specific aspects of face processing are enhanced in deaf signers: those skills relevant to detecting local feature configurations which must be generalized over individual faces.
2.1 Introduction

Studies of face processing have shown that face recognition is a highly complex task involving several subsystems that work together in a rapid and effortless fashion (e.g., Sergent, 1984; Tovee & Cohen-Tovee, 1993). Exactly what those components are and how they work together is still not well understood. Some studies indicate that these subsystems are uniquely specialized for face processing (e.g., Yin, 1969; Damasio, A., Tranel, & Damasio, H., 1990; Tanaka & Farah, 1991). However, there are other studies suggesting that face processing may not necessarily involve specialized mechanisms. For example, Diamond and Carey (1986) and Valentine (1988) argue that face processing recruits several general cognitive functions in which extensive perceptual experience with faces plays an important role in the speed and ease involved in the face processing.

The suggestion that face processing may be tied to experience rather than directly to specialized neural mechanisms, led us to examine face processing in deaf people who use American Sign Language (ASL) as their primary means of communication. Several previous studies have shown that ASL signers are “experts” on at least one test of face processing: The Benton Test of Face Recognition (Bellugi, L. O'Grady, Lillo-Martin, M. O'Grady, van Hoek, & Corina, 1990; Bettger, 1992; Bettger, Emmorey, McCullough, & Bellugi, 1996). In the Benton Faces test, subjects match the canonical view of a target face with other views of the same person. The target faces and distractor faces are presented under different orientation and/or lighting conditions (Benton et al., 1983). An example item is given in Figure 2.1. Bettger (1992) and Bettger et al. (1996) found that deaf ASL signers performed significantly better than hearing non-signers on this task. These two studies replicated the same finding using independent groups of deaf and
hearing subjects from the West and East coast of the United States. Moreover, Bettger (1992) found that both deaf and hearing signers were significantly more accurate on this task than hearing non-signers, suggesting that experience with ASL, rather than auditory deprivation, enhanced performance. In line with this hypothesis, Parasnis, Samar, Bettger, and Sathe (1996) found that “oral” deaf (deaf people who do not know sign language) do not exhibit superior performance on the Benton Faces test compared to hearing subjects. Since these subjects were deaf, but had no experience with sign language, Parasnis et al.’s finding again suggests that the superior performance of the deaf subjects is due to their signing experience rather than to effects of deafness. Finally, Bellugi et al. (1990) and Bettger et al. (1996) found that deaf signing children between the ages of six and nine performed significantly better than hearing children on the this test, indicating that the effects of experience with ASL are found as early as six years old.

Figure 2.1  Example stimulus from the Benton Faces test. The model face is the same face as the top left, top middle, and bottom middle face.
Why are deaf and hearing ASL signers superior at the Benton Faces task compared to hearing non-signers? One possibility is that the enhancement is due to the important role of facial expression in the syntax and morphology of American Sign Language (Baker-Shenk, 1983). For example, the syntax of sentences is often determined by different eye and eyebrow movements, e.g., raised eyebrows mark topic constructions; furrowed brows mark wh-questions. Unlike emotional facial expressions, linguistic facial expressions have a clear onset and offset and are coordinated with specific parts of the signed sentence (Reilly, McIntire, & Bellugi, 1990). Linguistic facial expressions also constitute adverbials which appear in predicates and carry specific meanings. Two ASL sentences may have exactly the same verbal predicate and differ only in the facial adverbials which co-occur with the verb phrase. For example, the facial expression “mm” (lips pressed together and protruded) indicates an action done effortlessly; whereas the facial expression “th” (tongue protrudes between the teeth) means “awkwardly” or “carelessly”. These two facial expressions accompanying the same verb (e.g. DRIVE) convey quite different meanings (“drive effortlessly” or “drive carelessly”).

Not only does the face function to convey grammatical morphology, signers also fixate on the face of their addressee rather than on the hands (Siple, 1978). Addressees make eye contact with the signer and pick up manual information through their peripheral vision. The fact that signers focus on the face during sign perception and the fact that facial expressions convey grammatical and lexical distinctions may lead to the enhanced ability of ASL signers to discriminate among the different faces presented in the Benton task. However, the fact that ASL signers are more accurate on the Benton test does not
provide many clues as to what aspects of face processing might be enhanced in this population.

We present three different experiments that attempt to identify the source and scope of enhanced face processing in ASL signers. Experiment 1 investigates memory for faces in a recognition experiment. Note that although the Benton test is called a test of face recognition, it actually taps face discrimination by asking subjects to distinguish among faces that differ in lighting and profile. There is no memory component, as the target and the response choices are presented simultaneously. We therefore wanted to investigate whether the enhanced face discrimination abilities extended to face recognition as well. Experiment 2 investigates whether ASL signers show an enhanced ability to process faces when gestalt or global processing is required. Finally, Experiment 3 explores whether ASL signers encode facial features in memory in a different manner or with a different level of specificity, compared to hearing non-signers.

2.2 Experiment 1: Face Recognition

This study was designed to test whether the expertise effect from ASL exposure found in the previous studies extends to tasks requiring face recognition from memory. We presented deaf and hearing subjects with an adaptation of the Recognition Memory Test for Faces (RMF) which assesses recognition memory for faces after a short delay (Warrington (1984)). In our version of the test, we added time pressure and a reaction time measure.
2.2.1 Method

Subjects.

Twenty-four deaf signers participated in the experiment (mean age = 24 years). Twenty-two subjects had deaf families and learned ASL from birth; two subjects acquired ASL before age nine. All subjects used ASL as their preferred means of communication. All subjects were prelingually deaf with severe to profound hearing loss. Subjects were tested either at Gallaudet University in Washington, D.C. or at the Salk Institute in San Diego, California.

Fifteen hearing subjects also participated in the experiment (mean age = 22 years). These subjects reported no knowledge of a signed language. All hearing subjects were tested at the Salk Institute.

Design and Procedure.

The same basic procedure designed by Warrington (1984) was used, except that the stimuli were presented on videotape rather than index cards, and subjects’ responses were timed. Subjects were first presented with 50 individual faces, one at a time, for three seconds. With each presentation, subjects had to decide whether the person looked “pleasant” or “unpleasant,” circling the appropriate word on an answer sheet. They were not told that a memory test would follow. After viewing all fifty faces, subjects were then given a 2-item forced choice recognition test with a familiar face (one they had seen during the rating task) and a new face they had not seen before (see Figure 2.2 for an example). Subjects pressed a key on the right side of a computer keyboard if the face on the right was familiar, and a key on the left if the face on the left was familiar. They were
told that they had to respond as quickly and as accurately as possible. The forced-choice stimuli appeared on the screen for two seconds with one second of black video between each item. Subjects were required to respond before the next item appeared on the screen. A tone (inaudible to subjects) was aligned with the first frame of each face stimulus. The tone triggered the computer to begin timing. Both time to respond and response key (right/left) were recorded. The recognition memory task always immediately followed the rating task. Instructions were given in ASL for the deaf subjects.

Figure 2.2 Example stimulus from the Warrington (1984) face recognition memory test used in Experiment 1. The face on the right had not been seen by subjects previously.
2.2.2 Results and Discussion

Deaf and hearing subjects did not differ significantly in their ability to recognize faces after a short delay. Mean response times and percent correct are given in Table 2.1. Both groups had very similar error rates (F(1,37) < 1), and deaf and hearing subjects also did not differ in their decision times (F(1,37) < 1). These findings indicate that deaf and hearing subjects are similar in their ability to recognize faces when only a short delay is involved. Our adaptation of the Warrington test appeared to be quite difficult -- both groups scored only 70% correct (50% is chance). One reason for this poor performance may have been that subjects were required to respond in less than two seconds which many found to be difficult.

Table 2.1
Mean Response Time (msec) and Accuracy (Percent Correct) for Face Recognition

<table>
<thead>
<tr>
<th></th>
<th>Response Time (msec)</th>
<th>Accuracy (Percent Correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf</td>
<td>1268 (149)</td>
<td>71.7% (8.5)</td>
</tr>
<tr>
<td>Hearing</td>
<td>1258 (193)</td>
<td>70.9% (8.9)</td>
</tr>
</tbody>
</table>

Note--Values in parentheses indicate standard deviations.

Since it may have been possible that our timed task created performance that was near floor for both groups, we administered the Warrington Faces test in its standardized version to an additional 23 deaf subjects who were either native signers from deaf families (N = 13) or near-native signers acquiring ASL prior to age eight (N = 10). The
mean age for these subjects was 24 years. Subjects were first presented with 50 individual faces on index cards and rated whether the face was “pleasant” or “unpleasant”. Subjects were then presented with the surprise memory task, but the stimuli were presented on index cards rather than video, and subjects could take as long as they wished to make their decision. The deaf subjects scored a mean of 81% correct (s.d. 11.5%) with a raw score of 40.7 (out of 50). The published norms from the Warrington Recognition Memory for Faces test shows that hearing subjects in the age group of 18 - 39 have a raw score of 43.6 or 87% correct. Thus, the deaf ASL signers actually performed worse than the hearing subjects.  

The results of Experiment 1 indicate that the effect of experience with American Sign Language apparently does not extend to recognition of faces. We found no evidence for enhanced performance on tests that required face recognition after a short delay. Thus, the enhanced performance that has been observed on the Benton Faces Test may be linked more strongly to face discrimination processes that are required for that test. In some ways, our results are not surprising because the skills required to interpret facial expression in ASL are more dependent upon discrimination of facial features than recognition of a particular face. Signers must generalize linguistic facial expressions over different faces. For a particular face, they must be able to discriminate between subtle differences in mouth shape and eyebrow height/shape in order to correctly interpret the grammatical morphology. This reasoning and the negative results of Experiment 1 led us to the next two studies which were designed to pinpoint which discrimination

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1One explanation for the poor performance of the deaf subjects may be that the faces were all British men. Our American subjects may have had more difficulty with the recognition task compared to the British norms collected by Warrington (1984).
mechanisms (featural vs. global) might be responsible for the superior performance observed with the Benton Faces Test for ASL signers.

2.3 Experiment 2: Gestalt Face Recognition

This second study investigates whether configurational (gestalt) processing of faces is enhanced in deaf signers as a result of their perceptual experience with ASL grammatical facial expressions. This was done by comparing deaf and hearing subjects' performance on the Mooney Faces Closure Test (Mooney, 1957). This test contains high contrast pictures of human faces of various ages and different genders. Figure 2.3 provides an example face from the Mooney test. Since local facial features are not shown in these high contrast images, subjects must rely on global information derived from the faces to identify and categorize the stimuli into different age and gender groups. That is, before individual features can be identified, recognition of the face must be achieved through the gestalt process of visual closure; correct sorting of the stimuli is taken as evidence that visual closure has been achieved (Vigen, Goebel, & Embree, 1982).
2.3.1 Method

Subjects.

Twenty-four deaf ASL signers participated (mean age = 25 years). Nineteen were native ASL signers who had deaf parents, and five were near-native signers who acquired ASL before age nine. All subjects used ASL as their preferred means of communication. All subjects were prelingually deaf with severe to profound hearing loss. Deaf subjects
were tested at either Gallaudet University in Washington, D.C. or at the Salk Institute in San Diego.

Twenty-four hearing subjects who had no knowledge of sign language also participated (mean age = 24 years). Subjects were tested either at the Salk Institute or at San Diego State University.

Design and Procedure.

Subjects were presented with 51 pictures of human faces in which shadows were rendered in black and highlights in white (see Figure 2.3). For many of the test items, these ambiguous shapes can be perceived as a recognizable face after the first brief glance; others are more difficult. Each picture was presented on a separate page, and subjects were asked to label each picture according to one of four categories: boy (less than 20 years of age); girl (less than 20 years of age); adult man (between 20 - 60 years of age); adult woman (between 20-60 years of age); old man (over 60 years of age), old woman (over 60 years of age). Subjects circled their response on an answer sheet. There was no time limit for the task, and subjects were told to guess if they could not decided which response was correct. Instructions were given in ASL for the deaf subjects.

2.3.2 Results and Discussion

Deaf subjects did not exhibit superior performance compared to hearing subjects on the Mooney Faces Closure task. Mean percent correct for deaf signers was 79% (s.d. = 7%), and hearing subjects scored 82% correct (s.d. = 5%). This difference was marginally significant (F(1,46)= 3.64, p < .07).
This result suggests that when a configurational analysis with a gestalt closure process is required for face identification, deaf signers perform on a par with hearing subjects (or perhaps even slightly worse). The fact that deaf signers were not superior to hearing subjects on the Mooney Faces Closure task suggests that the mechanism(s) responsible for their superior performance on the Benton Faces Test may involve processes related to local facial features rather than to global facial features. Again, such a hypothesis is reasonable given that signers must discriminate among facial expressions that involve individual facial features (e.g., eyebrows) rather than global features (e.g., the overall configuration of facial features within the face). In fact, it may be that an over-reliance on a featural strategy may have led to slightly poorer performance by the deaf subjects.

2.4 Experiment 3: Facial Feature Recognition

This study investigates whether ASL signers exhibit a superior ability to discriminate subtle differences in local facial features. We compared deaf and hearing subjects’ ability to detect changes in facial features within the same face. We hypothesized that since ASL signers must attend to facial features in order to interpret signed sentences, they may perform better than non-signers in detecting differences in facial features after a short delay. In this study, subjects were first presented with a “target” face in the center of a computer screen. After several seconds, two “response” faces were presented side-by-side: one was exactly the same as the target face and the other was also the same face, but one facial feature had been changed (e.g., different eyes, nose, or mouth). Subjects had to indicate which face was the same as the target
face. Correct performance on this task relies on the ability to detect a difference in one facial feature (see Figure 2.4 below).

We predicted that not all changes in facial features would be equally well-detected by deaf and hearing subjects. Deaf subjects may be better at detecting alterations of the eyes because they focus on the eyes during sign perception (Siple, 1978), and in addition, changes in eye configuration (e.g., raised eyebrows, squinted eyes, furrowed brows) convey various syntactic distinctions. Very little linguistic information is conveyed by movements of the nose -- wrinkling the nose conveys pragmatic information, such as indicating approval or agreement with the speaker. Given this limited use, we predict that deaf and hearing subjects will not differ in their ability to detect alternations of the nose. Finally, many adverbial and adjectival distinctions (e.g., manner of motion, size of object) are conveyed by different configurations of the mouth (e.g., raising one side of the mouth indicates recency or immediacy; pursed lips indicate small size). Therefore, we predict that deaf signers may be more accurate than hearing subjects at detecting alterations of the mouth.

2.4.1 Method

Subjects.

Thirty deaf subjects participated in the experiment (mean age = 23 years). Twenty-four were native signers with deaf parents, and six learned sign language prior to age 6. All subjects preferred ASL as their primary means of communication, and all were prelingually deaf with severe to profound hearing loss. Subjects were tested either
at the Salk Institute, at Gallaudet University in Washington, D. C., or at California State University, Northridge.

Thirty hearing subjects who had no knowledge of ASL also participated (mean age = 20 years). Hearing subjects were tested at the Salk Institute and were undergraduate students from the University of California, San Diego.

**Stimuli.**

Sixty faces from Warrington’s (1984) Recognition Memory Test were scanned into a Macintosh computer. These faces were then each electronically copied and three different facial features were altered separately: eyes, nose, and mouth. This created a total of 120 face stimuli: 60 intact faces, 20 faces with altered eyes, 20 with altered nose, and 20 with altered mouth. All alterations were done by replacing a specific area with the same feature from another face. Each feature was used only once. The features were also similar in overall shape, size, and gaze direction; for example, if an original face had a somewhat incomplete smile or eyes that looked to the left, the altered image would have a similar incomplete smile or eyes that looked in the same direction.

**Apparatus.**

Stimuli were first digitized using Omnimedia scanner at 300 dpi resolution, then they were altered systematically using the Adobe Photoshop software. Macintosh IIx, Apple 13" grayscale display, and PsyScope software were used for presentation and data collection.

**Design.**

There were two presentations on each trial. The first presentation showed a 5"x3.5" picture of a target face for 750 milliseconds at the center of the screen. Thirty
altered faces (10 eyes, 10 nose, and 10 mouth) and 30 Original faces were selected randomly out of a pool of 120 faces to be used as the target face in each of the trials. There was a seven second delay before the response stimulus was presented. The response stimulus consisted of two wallet sized (3" x 2.5") pictures of both the original target face and an altered face placed equidistant from the center of the screen. For the response presentation, both target and altered faces were randomly placed to either the left or right. The response stimulus remained on the screen until the subject responded. An example stimuli set is shown in Figure 2.4.
Figure 2.4  Example stimuli set from Experiment 3. The altered face has different eyes than the target face.
Procedure.

Subjects were instructed to look at a fixation point at the center of the screen at the beginning of each trial, and when ready, press the space bar to start a trial. Subjects were told that in each of the trials, there would be a presentation of a face which they needed to remember. Then, after a delay, they would have to decide which of two pictures matched the target face. They completed three practice trials to become familiarized with the computer keyboard and the experiment. During those practice trials, subjects got immediate feedback, informing them whether they were correct or not. Subjects did not receive feedback during the test trials.

2.4.2 Results and Discussion

Response time and percent correct were analyzed separately with a two-way ANOVA. The design of the ANOVA was 2 Groups (deaf, hearing) X 3 Facial feature alternations (eyes, nose, mouth). Response times and accuracy are given in Table 2.2.2

Accuracy. Overall, deaf subjects were significantly more accurate than hearing subjects (F(1,57) = 4.74, p < .05). There was also a significant main effect of facial feature alteration (F(2,114) = 14.15, p < .001), indicating that some feature alterations were easier to detect than others. Detecting a difference in the nose was more difficult than detecting an alteration in either the eyes (t(57) = 5.37, p < .001) or the mouth (t(57) = 3.62, p < .001). Detecting an alteration in the eyes was not significantly different from

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2One deaf subject had extremely long response times (over 10 seconds per trial) and was therefore eliminated from the analysis.
detecting an alteration of the mouth ($t(57) = 1.26$, ns.). Finally, the interaction between subject group and facial feature type was not significant ($F(2, 114) = 2.23$, ns.). However, planned comparisons revealed that the deaf subjects were significantly more accurate than hearing subjects in detecting an alteration of the mouth ($t(57) = 3.95$, $p < .001$), but the groups did not differ significantly in their ability to detect eye alterations ($t(57) = 1.09$, ns.) or nose alterations ($t < 1$).

Table 2.2

Accuracy (percent correct) and Mean Response Time (msec) for Detecting Feature Alterations

<table>
<thead>
<tr>
<th></th>
<th>Eyes</th>
<th>Facial Feature Altered</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nose</td>
<td>Mouth</td>
</tr>
<tr>
<td>Deaf</td>
<td>71.2%</td>
<td>60.5%</td>
<td>71.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(13.8)</td>
<td>(11.5)</td>
<td>(7.1)</td>
<td></td>
</tr>
<tr>
<td>Hearing</td>
<td>68.0%</td>
<td>60.3%</td>
<td>63.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(9.4)</td>
<td>(11.1)</td>
<td>(8.1)</td>
<td></td>
</tr>
<tr>
<td>Hearing Signers</td>
<td>77.5%</td>
<td>55.0%</td>
<td>61.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8.2)</td>
<td>(11.5)</td>
<td>(8.8)</td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaf</td>
<td>2965 (1102)</td>
<td>3692 (1500)</td>
<td>3044 (1065)</td>
<td></td>
</tr>
<tr>
<td>Hearing</td>
<td>3074 (1494)</td>
<td>3374 (1396)</td>
<td>3047 (1286)</td>
<td></td>
</tr>
<tr>
<td>Hearing Signers</td>
<td>3189 (1007)</td>
<td>3720 (1304)</td>
<td>3315 (1095)</td>
<td></td>
</tr>
</tbody>
</table>

Note--Values in parentheses indicate standard deviations.

Response Times. There was no main effect of subject group with the response time data ($F(1,57) = .043$, ns.). This result indicates that the difference in accuracy
between deaf and hearing subjects was not due to a speed-accuracy trade-off. There was a significant main effect of type of feature alteration ($F(2,114) = 25.25, p < .001$). Patterning like the accuracy data, response times for detecting alterations of the nose were significantly longer than for detecting alterations of the eyes ($t(57) = 5.37, p < .001$) or mouth ($t(57) = 3.62, p < .001$). Response times did not differ for detecting differences in the eyes compared to the mouth ($t(57) = 1.26, \text{ns.}$). Finally, there was a significant interaction between subject group and type of feature alteration ($F(2,114) = 3.78, p < .05$). Inspection of the means suggests that the interaction is due to the fact that deaf subjects responded slightly faster than hearing subjects when detecting differences in the eyes, but deaf subjects were slower than hearing subjects when detecting differences in the nose. However, both of these comparisons failed to reach significance.

There are at least two explanations for why deaf subjects were more accurate than hearing subjects in detecting alterations of the mouth. One possibility is that this difference is an effect of language experience. As noted above, adverbials are often expressed by different configurations of the mouth. Practice distinguishing and identifying different mouth configurations may lead to deaf signers superior ability to detect a difference between the mouth in the target face and that of the response face. However, it is also possible that the deaf subjects' extensive training in lip-reading might lead to the specific ability to detect changes in mouth configuration between the target and response faces.
To investigate these two possibilities we tested ten hearing subjects who were native signers. These subjects had deaf parents and learned ASL as their first language. Thus, like the deaf subjects, they have had extensive experience interpreting grammatical facial expressions in ASL. Unlike the deaf subjects, however, they did not receive training in lip reading. If the superiority we observed in ability to detect differences in mouth configuration were due to lip reading ability, then the hearing signers should pattern like the hearing non-signers, performing poorly compared to the deaf subjects. On the other hand, if the difference in detection skill is due to experience discriminating ASL facial expressions, then the hearing and deaf signers should pattern together, exhibiting superior performance compared to hearing non-signers.

Hearing Signers

Ten hearing signers were tested either at California State University, Northridge or at the Salk Institute (mean age = 37 years). All used ASL daily as part of their employment as interpreters or in daily interaction with their deaf family and friends. The accuracy and response time means for these subjects are given in Table 2.2. Planned comparisons revealed that the hearing signers were significantly more accurate than hearing non-signers at detecting differences in the eyes (t(1,38) = 2.84, p < .01), and they were not significantly different than deaf signers (t(1,37) = 1.36, ns.). There were no differences between groups for face stimuli that differed in the nose feature. Finally, hearing signers were significantly less accurate than deaf signers for faces that differed in the mouth feature (t(1,57) = 3.73, p < .001), and did not differ from hearing non-signers (t

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3One hearing signer was actually first exposed to Signed Exact English.
< 1, ns.). The subject groups did not differ in response time (F(2,66) < 1), and there was no interaction between subject group and feature type for response time (F(4, 132) = 1.84, ns.).

The results from hearing subjects who were native ASL signers suggest that the superior ability of deaf subjects to detect changes in the mouth of the target and response faces appears to stem from the experience of deaf subjects with lip reading, rather than their experience with ASL facial expressions. Deaf subjects were more accurate when the mouth was altered compared to both hearing signers and hearing non-signers. However, the pattern of results with hearing signers also suggests that experience with ASL can lead to an enhanced ability to detect changes in the eyes. Hearing signers were significantly more accurate than hearing non-signers in this condition, and they did not differ significantly from deaf signers. The deaf signers were also more accurate than hearing non-signers in detecting differences in the eyes, but the difference failed to reach significance. Overall, the results suggest that experience with either lip reading or with interpreting ASL facial expressions can lead to an enhanced ability to detect differences in relevant facial features.

2.5 General Discussion

The specific goal of these experiments was to discover whether the enhanced performance on the Benton Faces test by ASL signers was a general enhancement in face processing ability or whether the enhanced performance is specific to those aspects of face processing most relevant to the Benton Faces test (face discrimination). Experiment 1 revealed that deaf signers and hearing non-signers did not differ in their ability to
recognize faces after a short delay. This negative finding is consistent with the hypothesis that signers may be more accurate in their ability to identify and discriminate among different faces, rather than in their ability to recognize a particular face from memory. The results of experiment 2 showed that deaf signers were not better at identifying faces when gestalt processing is required. This result is consistent with the hypothesis that signers are particularly adept at processing featural aspects of faces because they must identify grammatical facial expressions that differ in the configuration of internal facial features rather than in the global configuration of the face. Finally, experiment 3 provided positive evidence for this hypothesis. Overall, deaf signers were significantly more accurate than hearing non-signers in discriminating between faces that were identical except for a change in a single facial feature: the eyes, nose, or mouth. When the performance of hearing signers was compared to both deaf signers and hearing non-signers, the pattern that emerged suggested that both experience with ASL and experience with lip reading might lead to the enhanced ability to identify differences in facial features. Specifically, experience with ASL may lead to an enhanced ability to detect differences in eye configuration; whereas experience with lip reading might lead to a superior ability to detect differences in mouth shape. Deaf and hearing subjects did not differ in their ability to detect alterations of the nose. This is predicted because ASL grammatical facial expressions do not involve the nose, and the nose is also not relevant for lip reading skills.

The combined results of these experiments suggest that ASL signers are not enhanced in all aspects of face processing. Specifically, deaf signers and hearing non-signers do not differ in their ability to recognize faces from memory or in their gestalt
face processing abilities. Enhancement of face processing skill appears to be most strongly tied to the ability to discriminate among faces that are very similar (as in the Benton Faces test) and to recognize subtle changes in specific facial features (as in experiment 3). These skills are most closely tied to recognizing and interpreting linguistic facial expression in ASL. To identify and categorize ASL facial expressions, signers need not recognize the person. Rather, signers must rely on featural (rather than global) processing of the face in order to identify specific facial expressions. The gestalt aspect of the face does not change with different facial expressions. Ability to generalize over individual faces and to focus on a specific local features rather than the global configuration of the face are characteristic of lip reading as well. Thus, the results suggest that only specific aspects of face processing are enhanced in deaf signers: those skills relevant to interpreting subtle differences in local feature configurations which must be generalized over individual faces.

2.6 Acknowledgement

Chapter 2 of this dissertation, in full, is a preprint version of the material as it appears in Journal of Deaf Studies and Deaf Education, 2(4), pp. 212-22, McCullough, Stephen and Emmorey, Karen, Oxford University Press, 1997. The dissertation author was the primary investigator and author of this paper.
CHAPTER 3: CATEGORICAL PERCEPTION OF AFFECTIVE AND LINGUISTIC FACIAL EXPRESSIONS

Abstract

Affective facial expressions (AFE), like color hues and speech sounds, are categorically perceived (Etcoff & Magee, 1992; De Gelder et al., 1997). Less clear is whether affective facial expression categorical perception (CP) also extends to learned American Sign Language (ASL) facial expressions, and whether lifelong experience with ASL facial expressions affects the CP for affective facial expressions. These questions were investigated in Deaf ASL signers—a linguistic population for whom the use of facial expressions is required for language production and comprehension. In two separate CP experiments (face only and face with sign), Deaf signers and hearing nonsigners performed ABX discrimination and identification tasks on morphed affective and linguistic facial expression continua. All facial expression continua were created by morphing the end-point photo exemplars into 11 images changing linearly from one facial expression to another. All original photo exemplars for affective and linguistic facial expressions were produced by Facial coding system (FACS) certified models. Significant CP effects were observed in hearing nonsigners for both affective and linguistic facial expressions. Deaf signers, however, showed a significant CP effect only for linguistic facial expressions. Subsequent analyses indicated that the order of presentation significantly affected signers’ reaction time performance for affective facial
expressions only. For signers, viewing linguistic facial expression first, slowed the reaction times for affective facial expression. Hearing nonsigners’ CP performance in both experiments suggests that facial expression categorical perception does extend to other types of facial expressions. Furthermore, the results also suggest that, similar to the CP for speech sounds, Deaf signers’ CP performance for affective facial expressions can be influenced by language experience.

3.1 Introduction

In his book *The expression of the emotions in the man and animals*, Charles Darwin (1872) astutely noted that Laura Bridgman, a woman who was deaf and blind since birth, was able to express spontaneously a wide range of affective facial expressions that she was never able to observe in others. This case was one of the arguments Darwin put forth in support of the evolutionary underpinnings of facial expressions in humans. Since then, an extensive body of research, including two notable cross-cultural studies by Ekman and others (Ekman & Friesen 1971; Ekman et al. 1987, Ekman, 1994), has provided empirical support for the evolutionary basis of affective facial expression production. Yet, the origin and development of neural mechanism that underlies facial expression perception is still not well understood. The ease and speed in the perception and categorization of facial expressions suggest the engagement of a highly specialized system or systems. Is the ability to perceive and categorize facial expressions innate? If so, is this ability limited to affective facial expressions? Can the perception of affective facial expressions be modified by the experience? If so, how and to what extent? These are important cognitive neuroscience questions that this study attempts to elucidate by
investigating categorical perception for facial expressions in Deaf users of American Sign Language signers—a population for whom the use of facial expressions are required for language production and comprehension.

Categorical perception (CP) is a psychophysical phenomenon that manifests itself when a uniform and continuous change in a continuum of perceptual stimuli is perceived as discontinuous variations. More specifically, the perceptual stimuli are seen as qualitatively similar within categories and different across categories. An example of categorical perception is the hue demarcations in the rainbow spectrum. Humans with normal vision perceive discrete color categories within a continuum of uniform linear changes of light wavelengths (Bornstein & Korda, 1984). The difference between green and yellow hues are more easily perceived than the different hues of yellow, even if the change distances in the wavelength frequencies between the green-yellow and yellow-yellow hues were exactly the same. This phenomenon is a result of compression (differences among stimuli in the same category are minimized) and expansion (stimuli differences among categories are exaggerated) in the perceived stimuli relative to a perceptual baseline (Livingston, Andrews, & Harnad, 1998). The compression and expansion effects reduce the continuous perceptual stimuli into simple, relevant, and manageable chunks for further cognitive processing and concept formation.

Investigations of the CP phenomenon in various perceptual and cognitive domains had provided insights into the development of neural mechanisms underlying different cognitive processes. For example, our understanding of cognitive development in speech perception continues to evolve through a large body of CP studies involving voice-onset time (VOT). VOT studies have shown that English listeners have a sharp phoneme
boundary between /ba/ and /pa/ sounds which differ primarily in the onset time of laryngeal vibration (Liberman, et al. 1957; Eimas, Miller, Jusczyk, and Vigorito, 1971). Moreover, other speech CP studies have shown that six-month-old infants can easily discern speech sound boundaries from other languages not spoken by their families; for example, infants from Japanese speaking families can distinguish /l/ and /r/ sounds which are difficult for adult speakers of Japanese to distinguish (however, when they reach 1 year of age this ability diminishes) (Eimas, 1975). How did the adult Japanese speakers “lose” the ability to distinguish the /l/ and /r/ sounds? Bates et al. (1999) points out that the decline of ability to discern phonemic contrasts that are not in one’s native language neatly coincides with the first signs of word comprehension, suggesting that language learning can result in low-level perceptual changes. Iverson et al. (2003), using a multidimensional scaling, analyzed the perception of phonemic contrast by Japanese, German, and American native speakers and found that the perceptual sensitivities formed under one’s language neatly correspond to the differences among group’s perceptual salience of within- and between English /r/ and /l/ categories.

A CP investigation with American Sign Language (ASL) handshapes has shown that auditory perception is not the only sensory modality that language experience can have significant effect. (Emmorey, McCullough, & Brentari, 2003). Using computer generated continua of ASL hand configurations, we found that experience with sign language led Deaf ASL signers, but not hearing nonsigners, to exhibit CP effects for visually presented phonologically contrastive handshapes (see Brentari, 1998, for discussion on sign language phonology). Since categorical perception occurred only for specific learned hand configurations, the study shows that CP effects can be induced by
learning a language in a different modality, and that they emerged independently of low-
level perceptual contours or sensitivities.

Similar high-level CP effects have been observed for face perception, Beale and Keil (1995). Participants in this study exhibited CP effects for morphed familiar faces (e.g., John F. Kennedy morphed into Bill Clinton), but not for unfamiliar faces, strongly suggesting that the CP effects, again, are not confined to the low-level perception, but also occur at the other levels mediating face perception. Since CP effects occur readily at different levels of face processing, do they exist for facial expression perception as well?

*Categorical Perception for Facial Expression*

Several facial expression CP studies have shown that affective facial expressions are perceived categorically but only if presented in upright orientation (Calder et al. 1996 Etcoff & Magee 1992; de Gelder et al. 1997). Campbell et al. (1999) undertook a study to find out if CP effects for affective facial expression also extend to learned facial actions. They examined whether Deaf signers, hearing signers, and hearing nonsigners exhibited similar CP effects for syntactic facial expressions (Yes-No/Wh–question) in British Sign Language (BSL) and their affective facial expression counterparts (Surprised/Puzzled). Syntactic facial expressions are specific linguistic facial expressions that signal grammatical contrasts. Their statistical analysis revealed no CP effects for BSL facial expressions in all three groups. However, when participants from each group were analyzed individually, 20% of the nonsigners, 50% of the Deaf signers, and 58% of the hearing signers demonstrated CP effects for BSL syntactic facial expressions. Campbell et al. 1999) suggested that CP effects for BSL expressions may be present but
weak for both signers and nonsigners. In contrast, all groups in the same study showed
definite CP effects for surprised-puzzled facial expressions.

Campbell et al. (1999), however, acknowledged several possible methodological
issues in their study. First, the groups differed significantly in the age at which BSL was
acquired. The mean age of BSL acquisition was 19.75 years for the hearing signers and
6.63 years for the Deaf signers. Language acquisition studies have shown that the age
when language was acquired is critical and has lifelong impact signer’s language
proficiency (Mayberry, 1993). Second, only six images were used to create the stimuli
continua (two originals and four intermediates). With such large steps between the
endpoints, the category boundaries and CP effects observed are somewhat suspect.

*Facial expressions in American Sign Language*

The present study addresses the methodological issues discussed above while
investigating whether the categorical perception of affective facial expressions also
extends to linguistic facial expressions from American Sign Language (ASL). ASL is
wholly distinct sign language from BSL (they are mutually unintelligible). However,
ASL, like BSL, uses distinct facial expressions to signal grammatical contrasts such as
Wh-Questions (WH-Q), Yes–No questions, conditional clauses, as well as adverbials
(Baker-Shenk, 1983; Liddell, 1980; Reilly, McIntire, & Bellugi, 1990a). These linguistic
facial expressions differ from affective expressions in their scope, timing and in the facial
muscles that are used (Reilly, McIntire, & Bellugi, 1990b). Linguistic facial expressions
have a clear onset and offset and are highly coordinated with specific parts of the signed
sentence. These expressions are critical for interpreting the syntactic structure of many
ASL sentences. For example, Wh-Questions and wh-phrases are accompanied by a
furrowed brow, which must be timed to co-occur with the manually produced clause. Syntactic scope is indicated by the location and duration of the facial expression. In addition, yes/no questions are distinguished from declarative sentences by raised eyebrows, which must be timed with the onset of the question.

ASL signers, naturally, also use their face to convey affective information. Thus, when perceiving visual linguistic input, signers must be able to quickly discriminate and process different linguistic and affective facial expressions concurrently to understand the signed sentences. ASL signers, as a result, have a very different perceptual and cognitive experience with the human face compared to nonsigners. Indeed, behavioral studies have suggested that this experience leads to specific enhancements in their face processing abilities. ASL signers (both deaf and hearing) performed significantly better than nonsigners at memorizing faces (Arnold & Murray, 1998), discriminating faces under different spatial orientations and lighting conditions (Bettger, et al., 1997), and discriminating local facial features (McCullough & Emmorey, 1997). Given the differences observed in Deaf and hearing signers for face perception, it is likely that ASL signers have different internal representations for facial expressions due to their unique experience with human faces.

Using computer morphing software, we conducted two experiments investigating categorical perception for facial expressions by Deaf signers and hearing nonsigners. We hypothesized that both groups would exhibit categorical perception for affective facial expressions, and that only Deaf signers would exhibit a CP effect for linguistic facial expressions. However, if hearing group has also demonstrates a CP effect for linguistic facial expressions, it will suggest that ASL facial expressions originate from natural
categories of facial expression, perhaps based on affective or social facial displays. Finally, if both groups fail to demonstrate a CP effect for linguistic facial expressions, it will strongly suggest that affective facial perception may be innate and domain specific.

3.2 Experiment 1

Wh-Q/Yes-No questions and Angry/Disgust facial expressions

3.2.1 Method

Participants

Seventeen Deaf native signers (four males, thirteen females, mean age = 23 years) and seventeen hearing nonsigners (five males, twelve females, mean age = 20 years) participated. All of the Deaf native signers had Deaf parents and learned ASL from birth. All were prelingually deaf and used ASL as their preferred means of communication. All hearing participants had never been exposed to ASL prior to the study. All participants were tested either at Gallaudet University in Washington, D.C. or at the Salk Institute for Biological Studies in San Diego, California.

Materials

Black and white photographs, depicting two affective facial expressions (angry, disgust) and two linguistic facial expressions (Wh-Question (Wh-Q), Yes–No Question) were produced by a model who is certified in the Facial Action Coding System (FACS) (Ekman & Friesen, 1978). These photographs were then used as the endpoints for creating and morphing the facial expression continua (see Figures 3.1 and 3.2). The affective facial expressions Angry and Disgust were chosen because both share similar
overall musculature changes, and the angry expression engages furrowed brows, similar to the linguistic expression marking Wh-Question. The linguistic facial expressions (Figure 3.2) are normally expressed with manual signs; however, they were presented as head without upper body for purpose of replication and extension of previous studies.

Figure 3.1 Illustration of morphed affective (Angry / Disgust) facial expression continuum.

Figure 3.2 Illustration of morphed linguistic (Wh–Q / Yes-No Question) facial expression continuum.
Morphing procedure. VideoFusion™ software was used to produce 11 steps of equal spaced succession of morphed images between the original image endpoints. The protocol for setting the image control points was done in a manner nearly identical to the procedure described in Beale and Keil (1995). A total of 240 control points were positioned manually onto the endpoint images for the linguistic facial expressions, and approximately the same number was used for the affective facial expressions. Anatomical landmarks (e.g., corners of mouth or eyes) were used as locations for control point placements. See Beale and Keil (1995) for details concerning control point placements and morphing procedures.

Procedure

Two different tasks, discrimination and identification, were used to determine whether participants demonstrated CP effects for a specific continuum, and the overall task design was identical to Beale and Keil (1995). Instructions and stimuli were presented on an Apple PowerMac with a 17-inch monitor using PsyScope software (Cohen, MacWhinney, Flatt & Provost, 1993). The presentation order of linguistic and affective continua was counterbalanced across participants. The discrimination task (an “ABX” matching to sample paradigm) was always presented before the identification task. Instructions and practice trials were given before each task.

On each trial, participants were shown three images successively. The first two images (A and B) were always two steps apart along the linear continuum (e.g., 1-3, 5-7) and were displayed for 750 ms each. The third image (X) was always identical to the first or second image and was displayed for 1 second. A one second inter-stimulus
interval (ISI) consisting of a blank white screen separated consecutive stimuli. Participants pressed either the ‘A’ or ‘B’ key on the computer keyboard to indicate whether the third image was similar to the first image (A) or the second image (B). All nine two-step pairings of the 11 images were presented in each of four orders (ABA, ABB, BAA, BAB) resulting in 36 combinations. Each combination was presented twice to each participant, and the resulting 72 trials were fully randomized within each continuum. These methods (i.e., a relatively long ISI and two step size) were chosen to maximize the probability of obtaining categorical perception effects for the discrimination task.

The identification task consisted of a binary forced-choice categorization. Before participants performed the identification task for each continuum, they were first shown two endpoint images labeled with the number 1 or 2. On each trial, participants were presented with a single image randomly selected from the eleven image continuum and were asked to decide quickly which one of the pair (image number 1 or 2) most closely resembled the target image. For example, participants pressed the ‘1’ key if the target image most resembled the ‘angry’ facial expression and the ‘2’ key if it most resembled the ‘disgust’ facial expression. Stimuli were presented for 750 ms followed by a white blank screen, and each image was presented eight times, resulting in 88 randomly ordered trials for each continuum. In the linguistic facial expression continuum, the endpoint images numbered 1 and 2 were recognized by all signers as linguistic facial expressions. Hearing nonsigners had no difficulty in recognizing the difference between the end point facial expressions; however, these expressions carried no grammatical or linguistic meaning for them.
The sigmoidal curve, a “S” shape in the labeling percentage for the right image endpoint—in the identification task data was then used to predict performance on the discrimination task. Following Beale and Keil (1995), we assessed whether the stimuli within a continuum were perceived categorically by defining the category boundary as the region that yielded labeling percentages between 33 % and 66 % on the identification task. An image that yielded the score within those upper and lower percentages was identified as the category boundary. If two images yielded scores that fell within those upper and lower percentages, then the category boundary was defined by the image that had the peak mean response time for category labeling. If the stimuli along a continuum were perceived categorically, peak accuracy would be expected in the discrimination task for the two-step pair that straddles the boundary. Planned comparisons were performed on the accuracy scores at the predicted peaks. That is, for each continuum, the mean accuracy for the pair that straddled the boundary was contrasted with the mean accuracy on all the other pairs combined.

In addition to the planned comparisons of accuracy scores, participants’ response times in both discrimination and identification tasks were analyzed using repeated design analysis of variance with three factors: Group (deaf signers, hearing nonsigners), facial expression (affective, linguistic), and order of conditions.

3.2.2 Results

Assessment of categorical perception performance. In the identification task, Deaf signers and hearing nonsigners demonstrated categorical boundaries—a sigmoidal shift in category labeling--for both affective (Angry/Disgust) and linguistic (Wh-Q/Yes-
No Question) facial expression continua (see top of Figures 3.3 and 3.4). In the
discrimination task, hearing nonsigners, as expected, showed a CP effect for affective
expressions ($F(1,144) = 8.22, p < .005$) (Figure 3.4a), but surprisingly Deaf signers did
not ($F(1,144) = 1.59, \text{n.s.}$) (Figure 3.3a). Also to our surprise, both hearing and Deaf
participants showed a CP effect for the linguistic expressions, ($F(1,144) = 9.84, p < .005$
and $F (1,144) = 10.88, p < .005$), respectively (See bottom of Figure 3.3 and 3.4).
Figure 3.3  Experiment 1 *Deaf participants.*  *Top:* Mean response percentages for the identification tasks: percentage “disgust” responses in the (Angry/Disgust) continuum and percentage “Yes-No” responses in the Wh-Q – Yes-No Question continuum. The horizontal lines indicate 33 % and 66 % boundaries.  *Bottom:* Means of accuracy responses in the discrimination tasks; the vertical lines indicate the predicted peaks in accuracy.
Figure 3.4 Experiment 1 *Hearing participants*. Top: Mean response percentages for the identification tasks: percentage “disgust” responses in the (Angry/Disgust) continuum and percentage “Yes-No Question” responses in the WH-Q – Yes-No Question continuum. The horizontal lines indicate 33 % and 66 % boundaries. Bottom: Means of accuracy responses in the discrimination tasks; the vertical lines indicate the predicted peaks in accuracy.

**Discrimination task response times.** A repeated measure ANOVA showed no overall group difference, $F(1,30) = (F < 1)$. Affective facial expressions were responded more slowly than linguistic facial expressions, $(F(1, 30) = 27.70, p < .0001)$. There was no group difference in response times for linguistic facial expressions, but Deaf group
was significantly slower for affective facial expressions, (F(1,30) = 8.02, p < .01). Deaf participants responded significantly slower to affective expressions when linguistic expressions were presented first (but not when affective expressions were presented first), whereas hearing participants were unaffected by initial presentation of linguistic expressions, (F(1,30) = 9.77, p < .005).

**Identification task response times.** The response time pattern for the identification task was parallel to the discrimination task. There was no overall group difference, (F(1,30) = 2.39, n.s.). Affective facial expressions were categorized significantly slower, (F(1,30) = 13.172, p = .001). There was no group difference in response times for linguistic facial expressions; Deaf group, again, was significantly slower for affective facial expressions (F(1,30) = 30.73, p < .0001). A three-way interaction between group, facial expressions, and presentation order showed that the hearing group categorized facial expressions similarly, regardless the order of presentation. In contrast, the Deaf group performed close to the hearing group for affective facial expressions only when those facial expressions were presented first; however, they performed significantly slower if affective expressions were presented *after* linguistic facial expressions (F(1,30) = 8.417, p < .001).

### 3.3.3 Discussion

We predicted that both Deaf signers and hearing nonsigners would exhibit categorical perception for the affective facial expression continuum, and that only Deaf signers would exhibit a CP effect for the linguistic facial expression continuum. The
results, however, were somewhat unexpected and suggested a more complex interplay among the mechanisms involved in affective and linguistic facial expression perception. We explore this interaction below, discussing the results for affective and linguistic facial expressions separately.

**Affective Facial Expressions**

Both hearing nonsigners and Deaf signers, as predicted, exhibited a sigmoidal shift in the identification task for the affective facial expression continuum. The sigmoidal curves observed in this experiment are similar to the curves observed in the previous affective facial expression CP studies (Etcoff & Magee, 1992; de Gelder et al. 1997). As expected, hearing nonsigners showed a CP effect (see bottom Figure 3.4a) for affective facial expressions in their discrimination task performance; however, Deaf signers did not show a clear CP effect for the same facial expression continuum (see bottom Figure 3.3a). The absence of a CP effect is surprising, given Deaf signers and hearing nonsigners have reasonably similar experience with affective facial expressions.

We propose that the observed difference may be due to signers’ unique experience with ASL. More specifically, ASL exposure during a critical period in early development may have significantly altered Deaf signers’ internal representations for affective facial expressions. In a longitudinal analysis of affective and linguistic facial expression development in young Deaf children, Reilly, McIntire, and Bellugi (1990) found that Deaf 1-year-olds did not differ significantly from their hearing peers in achieving developmental milestones for the interpretation and expression of affective states. However, in the early stages of Deaf children’s sign language acquisition, lexical
signs for emotions were often accompanied by very specific facial expressions as if both the sign and facial expression were unified into a gestalt (i.e., sad facial expression with manual sign SAD). When these children reached approximately age two and one-half, their signs and facial expressions bifurcated, resulting in often uncoordinated and asynchronous production of facial expressions and signs. It was not until after affective facial expressions were successfully de-contextualized from signs and incorporated into the linguistic system that facial expressions began to be tightly coordinated with signs or sentences again. However, now the affective facial expressions accompanying lexical signs for emotions are controlled independently and can be selectively omitted.

It is plausible that during this critical developmental transition, the internal representation of affective facial expressions may be altered in the same way that the internal representation of speech sounds can be modified by linguistic experience as shown in the speech perception studies (Eimas, 1975, Iversion et al. 2003). The internal change in facial expression representations during early development may also explain why Deaf BSL signers demonstrated CP effects for affective facial expressions in the Campbell et al. (1999) study. Unlike the Deaf ASL signers in our study who were exposed to ASL from birth, the Deaf British participants in Campbell et al. (1999) study acquired sign language at a much later age. Their internal affective facial expression representations, thus, may not have been significantly affected by sign language exposure like it was for the Deaf ASL signers.

*Linguistic Facial Expressions.* Deaf signers and hearing nonsigners demonstrated sigmoidal performance in the identification task for linguistic facial expression continuum, and both groups also demonstrated CP effects for the linguistic continuum.
The Deaf group’s CP performance was expected given their linguistic experience; however, hearing participants’ CP effect for supposedly ‘unfamiliar’ facial expressions suggests that the linguistic knowledge of ASL facial expressions ‘Wh-Q’ and ‘Yes-No Question’ is not required for categorical perception.

There are two plausible explanations for the hearing nonsigners’ unexpected CP performance for ASL facial expressions. First, the linguistic facial expressions shown in Figure 3.2 may be encoded and processed as affective facial expressions (e.g., Yes-No Question as surprised; Wh-Q as angry). Second, the linguistic facial expressions used in this study may be part of very common non-linguistic, social facial displays that have been learned. For example, raised eyebrows indicate openness to communicative interaction for English speakers (Pyers & Emmorey, 2005). In either case, the results of Experiment 1 lend support to Campbell’s (1999) conclusion that the CP effects for facial expressions are not necessarily limited to the universal affective facial expressions, i.e., Happiness, Sadness, Anger, Surprise, Disgust, and Fear (Ekman & Friesen, 1971).

Presentation order effects

Overall, Deaf signers responded more slowly than hearing nonsigners for affective facial expressions only; however, response time statistics revealed that the signers’ performance in both identification and discrimination tasks was contingent upon presentation order. Specifically, Deaf signers’ response times for affective facial expression were similar to hearing nonsigners when affective facial expressions were presented first; however, their responses were slower when the affective continuum was presented after the linguistic continuum. Hearing nonsigners’ response times, on the other hand, remained unaffected by the presentation order of conditions. The fact that
antecedent exposure to linguistic facial expressions within the experiment affected signers’, but not nonsigners’, response times to the affective facial expressions lends plausibility to the our hypothesis that signers’ linguistic experience can alter how affective facial expressions are processed.

Experiment 1 design, however, had two shortcomings that may have affected the results. First, the facial expressions were presented with just the face, but linguistic facial expressions are normally expressed with manual signs. Thus, viewing linguistic facial expressions alone without accompanying signs was a highly atypical experience for Deaf signers. It is plausible that those experimentally constrained images may have affected the CP and response time performance among signers for both types of facial expressions. Second, as previously explained, the linguistic facial expressions used in Experiment 1 may have been viewed by hearing nonsigners as affective facial expressions. Specifically, the Wh-Q facial expression shares features with the universal expression of anger (furrowed brows), while the Yes-no question expression surprise and social openness (raised eyebrows).

A second experiment, therefore, was conducted with new affective and linguistic facial expression continua and presented the facial expressions in the context of a manual sign. Adverbial facial expressions were chosen for the linguistic continuum because they are less likely to be viewed by hearing nonsigners as part of affective facial expressions. In addition, the linguistic expressions were presented in the context of a manual sign in order to make the stimuli more ecologically valid for Deaf signers. The MM adverbial expression (meaning “effortlessly”) and TH expression (meaning “carelessly”) were selected from a large set of ASL adverbial facial expressions because these expressions
have little resemblance to universal affective facial expressions. For the affective continua, the positive and negative expressions *happy* and *sad* were chosen as endpoints. These expressions were selected specifically to investigate whether the absence of a CP effect that we observed for Deaf signers also holds for a more salient and contrasting continuum of affective facial expressions.

### 3.3 Experiment 2

MM/TH adverbial expressions and Happy/Sad affective facial expressions

#### 3.3.1 Method

**Participants**

Twenty Deaf signers (eight males, twelve females, mean age = 26 years) and twenty-four hearing nonsigners (thirteen males, eleven females, mean age = 20.5 years) participated. All of the Deaf native signers had Deaf parents and learned ASL from birth. All were prelingually deaf and used ASL as their preferred means of communication. All hearing nonsigners had never been exposed to ASL prior to the study. Participants were tested either at Gallaudet University in Washington, D.C. or at the Salk Institute for Biological Studies in San Diego, California.

**Materials**

The endpoint images, which show face and upper body, were selected from a digital videotape in which a FACS certified sign model was instructed to produce either affective (happy or sad) or linguistic facial signals (the adverbials MM “effortlessly” or
TH “carelessly”) while producing the sign for “write” (see Figures 3.5 and 3.6). The endpoint images for the linguistic continuum were reviewed and selected by a native ASL signer as representing the best prototype for each adverbial expression. The morphing procedure performed on the selected images was identical to Experiment 1.

Figure 3.5 Illustration of morphed affective (Happy/Sad) facial expression continuum.

Figure 3.6 Illustration of morphed linguistic (MM / TH) facial expression continuum.
Procedure

The procedure was identical to Experiment 1.

3.3.2 Results

Assessment of categorical perception performance. In the identification task, Deaf signers and hearing nonsigners, again, demonstrated sigmoidal shift for both linguistic (MM/TH) and affective (Happy/Sad) facial expression continua (see top Figures 3.7 and 3.8). The category boundaries for the discrimination tasks were determined by the same method described in Experiment 1. Both hearing nonsigners and Deaf signers exhibited a CP effect for adverbial linguistic expressions (F(1,207) = 12.60, p < .001 and F(1,171) = 11.88, p < .001), respectively. However, as in Experiment 1, only hearing nonsigners showed a CP effect for affective expressions, ( F(1,207) = 5.68, p < .05) (See bottom Figures 3.7 and 3.8).
Figure 3.7  Experiment 2  *Deaf participants.*  *Top:* Mean response percentages for the identification tasks: percentage “Sad” responses in the (Happy/Sad) continuum and percentage “TH” responses in the (MM/TH) continuum. The horizontal lines indicate 33 % and 66 % boundaries.  *Bottom:* Means of accuracy responses in the discrimination tasks; the vertical lines indicate the predicted peaks in accuracy.
Figure 3.8  Experiment 2 Hearing participants.  Top: Mean response percentages for the identification tasks: percentage “Sad” responses in the (Happy/Sad) continuum and percentage “TH” responses in the (MM/TH) continuum. The horizontal lines indicate 33 % and 66 % boundaries. Bottom: Means of accuracy responses in the discrimination tasks; the vertical lines indicate the predicted peaks in accuracy.

Discrimination task response times. A repeated measure ANOVA showed a pattern of results similar to Experiment 1. There was no group difference in the discrimination task reaction times (F(1, 40) = n.s.). However, across the groups, affective continuum was discriminated more slowly (F(1,40) = 21.79, p <.0001). There was also a significant interaction between group and facial expression type. Deaf signers were
significantly slower than hearing nonsigners for affective facial expression, \(F(1,40) = 15.60, p < .001\). Finally, there was a three-way interaction between group, facial expression type, and presentation order \(F(1,40) = 4.50, p < .05\). Deaf signers discriminated the affective facial expressions more slowly when they were presented after linguistic facial expressions.

**Identification task response times.** As in Experiment 1, the reaction time pattern for the identification task was parallel to the discrimination task. There was no significant group difference in reaction time for identification task, \(F(1,40) = 1.15, \text{n.s.}\). Affective facial expressions, again, were categorized more slowly, \(F(1,40) = 4.9, p < .05\). The interaction of group and facial expression showed that Deaf group responded more slowly than hearing group for affective facial expressions \(F(1,40) = 25.83, p = .0001\). The pattern of results from the three-way interaction of group, facial expression, and presentation order again was similar to Experiment 1. The Deaf group, as in the Experiment 1, was significantly slower to categorize affective expressions when they were presented after linguistic facial expressions \(F(1,40) = 12.39, p < .005\).

### 3.3.3 Discussion

As in Experiment 1, Deaf signers did not exhibit a CP effect for affective facial expressions, even though the affective facial expression stimuli in Experiment 2 were more salient and contrastive (happy versus sad). Both groups categorized the affective stimuli similarly (see top Figure 3.7 and 3.8), but only the hearing group showed evidence of a CP effect (see bottom Figure 3.8). Also replicating the results of Experiment 1, both groups exhibited CP effects for ASL linguistic expressions, and there
was a significant effect of presentation order on response time performance. Specifically, presentation of ASL linguistic facial expressions slowed response time to affective expressions for Deaf signers. Hearing nonsigners, like in the Experiment 1, were unaffected by the presentation order.

3.5 General Discussion

The fact that hearing nonsigners exhibited discontinuous perceptual boundaries for linguistic facial expressions demonstrates that non-affective unfamiliar facial expressions can be perceptually categorized. Previous face and facial expression CP studies have suggested that familiarity with face stimuli is necessary for CP to occur. For example, CP effects were observed for the Kennedy-Clinton face continuum but not for a continuum with unfamiliar faces as the endpoints (Beale & Keil, 1995). The hearing participants in Experiments 1 and 2, however, were never familiarized with the linguistic facial expressions before they performed the discrimination task. Why did they show CP effect for supposedly unfamiliar facial expressions?

The CP effects observed for hearing nonsigners for unfamiliar linguistic facial expressions could be used to argue for the existence of an innate perceptual mechanism for discrimination of any type of upright facial expression (Campbell et al., 1999). However, we offer a different explanation. Linguistic facial expressions may have roots in the social facial displays which may have been recognized by hearing nonsigners, despite our best efforts to minimize their resemblance to affective facial expressions. Ekman (1979) reports a large number of facial expressions that are normally generated during everyday conversations that are not associated with affective categories. It is
possible that some of the linguistic facial expressions used in signed language originated from social facial displays but have been systematized and re-utilized to serve linguistic functions.

Cross-linguistic studies of linguistic facial expressions lend some support to this hypothesis (Zeshan, 2004; Janzen and Schaffer, 2002). Facial expressions that mark linguistic distinctions are often similar or even identical across signed languages; however, the same facial expression does not necessarily represent the same meaning cross-linguistically (Zeshan, 2004). The use of highly similar facial expressions across signed languages suggests that these facial markers may originate from non-affective social facial displays adopted from the surrounding hearing communities. The abstraction and conventionalization of linguistic facial markers from social facial displays can occur through repetition, ritualization, and obligatoriness (Janzen & Shaffer, 2002). Furthermore, a small subset of highly similar linguistic facial markers from the wide range of possible facial expressions suggests that those expressions have undergone a highly selective conventionalization process. If a facial expression cannot be easily perceived and/or expressed under different environmental conditions (e.g., a rapid succession of facial expressions or in low light), it will be less likely to be repeated, conventionalized, and adopted as an obligatory facial expression. Given the nature of conventionalization processes, facial expressions selected as linguistic markers must be inherently salient and easy to categorize. Therefore, the CP effects observed for hearing nonsigners for linguistic facial markers may be due to properties inherent to the conventionalized facial expressions.
Deaf signers, as predicted, showed significant CP effects for linguistic facial expressions in both experiments, but they consistently showed no CP effects for affective facial expressions. We hypothesize that Deaf signers’ experience with linguistic facial expressions accounts for this pattern of results. Specifically, we propose that initially viewing linguistic facial expressions led to different attentional and perceptual strategies that subsequently affected the perception of affective expression continua. The order of presentation effect observed in Deaf signers’ response times for affective facial expressions seem to lend support our hypothesis. Deaf signers did not perform differently from hearing nonsigners for the affective continuum when affective facial expressions were presented first; however, they performed significantly slower on the same affective continuum after performing the tasks with linguistic facial expressions (See Figure 3.9).
Figure 3.9  Each histogram bar in the top and bottom panels shows reaction time (in milliseconds) for specific facial expression continua viewed by each group in a particular presentation order. The group labeled with “Affective First” discriminated the affective facial expression continua before discriminating the linguistic facial expression continua. The group labeled with “Linguistic First” discriminated the linguistic facial expression continua before discriminating the affective facial expression continua. The asterisk
indicates a significant three way interaction between group, facial expression, and presentation order.

Effects of presentation order on facial expression processing have been observed in other studies. Corina (1989) conducted a tachistoscopic hemifield study with affective and linguistic facial expressions presented to Deaf signers and hearing nonsigners. When affective facial expressions were presented first, Deaf signers showed a left visual field advantage (right hemisphere) for both types of expressions; however, when linguistic facial expressions were presented before affective facial expression, signers showed a right visual field advantage (left hemisphere) for linguistic facial expression and no hemispheric advantage for affective facial expression. Order effects were not observed for hearing nonsigners. As in the present study, Corina (1989) found that viewing linguistic facial expressions affected the perception of affective facial expressions for signers.

Why does performing a discrimination or perceptual task with linguistic facial expressions affect the performance of signers, but not nonsigners, on affective facial expressions? We suggest that such order effects stem from the different contribution of local and global involvement in the processing of different types of facial expressions. Linguistic facial expressions differ from affective facial expressions in many respects but one salient difference is that linguistic facial features are expressed independently from each other. For example, it is possible to produce combinations of Yes-No or WH-Q (changes in eyebrows) with MM or TH (changes in mouth feature) to convey eight grammatically distinct meanings using only one identical manual sign WRITE (e.g., MM
alone ("write effortlessly"), WH-Q alone ("what did you write?")], MM + WH-Q ("what did you write effortlessly?"), and so on). In order to isolate and comprehend the linguistic meaning of an ASL sentence, signers must quickly recognize and integrate various individual facial features.

In addition, it appears that substantial experience in processing linguistic facial expressions can lead to significant changes in the local face processing mechanism in general. Our previous research has shown that both Deaf and hearing signers perform significantly better than nonsigners on the local facial feature discrimination (McCullough & Emmorey, 1997) and on the Benton Faces Tasks which involves the discrimination of faces under different conditions of lighting and shadow (Bettger, Emmorey, McCullough, 1997). However, signers and nonsigners did not differ in the gestalt processing of faces, as assessed by the Mooney Closure Test or in their ability to simply recognize faces after a short delay (Mooney, 1957, McCullough & Emmorey, 1997). Thus, signers appear to only exhibit enhanced performance on tasks that require greater attention to componential facial features. Attention to such local facial features is required during every day language processing for signers.

How might this difference in the local facial feature processing impact the perception of affective facial expressions? Previous studies have shown that componential and holistic processing are not independent and can influence each other. Tanaka and Sengco (1997) propose that the internal representation of a face is composed of highly interdependent componential and holistic information, such that a change in one type of face information affects another. Since Deaf signers must attend and recognize local facial expressions for linguistic information, their holistic facial perception may be
altered by disproportionate attention to the componential facial features. The difference in signers’ attention to local facial features may lead to a different warping in the similarity space for facial expressions, compressing and expanding the facial features along various dimensions (for an extended description of warping and similarity space, see Livingston, et al. 1998). This does not mean that Deaf signers have impaired affective facial recognition—they perform similarly to hearing controls in affective facial expression recognition and categorization (Goldstein, Sexton, & Feldman, 1996, 2000). Moreover, the effect seems to be fluid and transitory, as the order effects have shown. When affective facial expressions are presented first, the performance of Deaf signers parallels that of hearing nonsigners in both the Corina (1989) study and in our study.

In conclusion, the evidence from two experiments suggest that facial expression categorical perception is not limited to universal emotion categories, but readily extend to other types of facial expressions, and that exposure to linguistic facial expression categories can significantly alter categorical perception for affective facial expression.

3.6 Acknowledgement

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CHAPTER 4: NEURAL ORGANIZATION FOR RECOGNITION OF GRAMMATICAL AND EMOTIONAL FACIAL EXPRESSIONS IN DEAF ASL SIGNERS AND HEARING NONSIGNERS

Abstract

Recognition of emotional facial expressions is universal for all humans, but signed language users must also recognize certain non-affective facial expressions as linguistic markers. FMRI was used to investigate the neural systems underlying recognition of these functionally distinct expressions, comparing deaf ASL signers and hearing nonsigners. Within the superior temporal sulcus (STS), activation for emotional expressions was right lateralized for the hearing group and bilateral for the deaf group. In contrast, activation within STS for linguistic facial expressions was left lateralized only for signers and only when linguistic facial expressions co-occurred with verbs. Within the fusiform gyrus (FG), activation was left lateralized for ASL signers for both expression types, whereas activation was bilateral for both expression types for nonsigners. We propose that left lateralization in FG may be due to continuous analysis of local facial features during on-line sign language processing. The results indicate that function in part drives the lateralization of neural systems that process human facial expressions.
4.1 Introduction

Recognition of facial expressions of emotion is a crucial communication skill relevant for both human and non-human primates. Sensitivity to emotional facial expressions occurs very early in development, and the neural circuitry underlying facial affect recognition is partially independent of neural systems that underlie recognition of other information from faces, such as person identity or gender (Damasio & Damasio, 1994; Haxby, Hoffman, & Gobbini, 2000; Young, 1998). Humans have clearly evolved an ability to quickly recognize emotional and socially relevant facial expressions, and this ability appears to be processed by a distributed neural circuitry, generally lateralized to the right hemisphere [Borod, Kent, Koff, & Martin, 1988; Narumoto, Sadato, Fukui, & Yonekura, 2001; Schmitt, Hartje, & Willmes, 1997]. We investigate the plasticity and functional organization of this neural circuitry by studying facial expressions that do not convey emotional or social-regulatory information, namely the linguistic facial expressions produced by users of American Sign Language (ASL).

A unique and modality specific aspect of the grammar of ASL and other signed languages is the use of the face as a linguistic marker. Distinct facial expressions serve to signal different lexical and syntactic structures, such as relative clauses, questions, conditionals, adverbials, and topics (Baker & Cokley, 1980; Reilly, McIntire, & Bellugi, 1990). Linguistic facial expressions differ from emotional expressions in their scope and timing and in the facial muscles that are used (Reilly et al., 1990). Linguistic facial expressions have a clear onset and offset, and are coordinated with specific parts of the signed sentence. These expressions are critical for interpreting the syntactic structure of many ASL sentences. For example, restrictive relative clauses are indicated by raised
eyebrows, a slightly lifted upper lip, and a backward tilt of the head. When this combination of head and facial features occurs, the co-occurring lexical items are interpreted as constituting a relative clause (Liddell, 1980). Facial behaviors also constitute adverbials that appear in predicates and carry various specific meanings. For example, the facial expression glossed as MM (lips pressed together and protruded) indicates an action done effortlessly, whereas the facial expression TH (tongue protrudes slightly) means “carelessly” (see Figure 4.1A). These two facial expressions accompanying the same verb (e.g. DRIVE) convey quite different meanings (“drive effortlessly” or “drive carelessly”).

Figure 4.1 Illustration of (A) ASL linguistic facial expressions and (B) emotional facial expressions used in the ‘face only’ condition. The labels under the linguistic expressions identify distinct facial adverbials (see text for details).
Of course, deaf signers also use their face to convey emotional information. When perceiving visual linguistic input, ASL signers must be able to quickly identify and discriminate between different linguistic and affective facial expressions in order to process and interpret signed sentences. Thus, signers have a very different perceptual and cognitive experience with the human face compared to nonsigners. This experience appears to result in specific enhancements in face processing. Several studies have found that both hearing and deaf signers perform significantly better than nonsigners in distinguishing among similar faces (e.g., the Benton Faces Test), in identifying emotional facial expressions, and in discriminating local facial features (Arnold & Murray, 1998; Bettger, Emmorey, McCullough, & Bellugi, 1997; Goldstein & Feldman, 1996; Goldstein, Sexton, & Feldman, 2000; McCullough & Emmorey, 1997). It is possible that ASL signers exhibit a somewhat different neural representation for face perception due to their unique experience with human faces.

Recently, it has been argued that cognitively distinct aspects of face perception are mediated by distinct neural representations (Haxby et al., 2000). We hypothesize that the laterality of these representations can be influenced by the function of the expression conveyed by the face. Linguistic facial expressions are predicted to robustly engage left hemisphere structures only for deaf signers, whereas perception of emotional expressions is predicted to be lateralized to the right hemisphere for both signers and nonsigners.

An early hemifield study by Corina (1989) found distinct visual field asymmetries for deaf ASL signers when recognizing linguistic and emotional facial expressions, compared to hearing nonsigners. The visual field effects were contingent upon the order of stimulus presentation. Both emotional and linguistic facial expressions produced
significant left visual field (right hemisphere) asymmetries when emotional facial expressions were presented first. In contrast, when deaf signers viewed the linguistic expressions first, no significant visual field asymmetries were observed. Although suggestive, the results do not provide support for a dominant role of the left hemisphere in recognizing linguistic facial expressions. A right visual field (left hemisphere) advantage was not observed for linguistic facial expressions.

Nonetheless, data from lesion studies indicate that damage to the left hemisphere impairs signers’ ability to produce ASL linguistic facial expressions (Corina, Bellugi, & Reilly, 1999; Kegl & Poizner, 1997). In contrast, damage to the right hemisphere impairs the ability to produce emotional facial expressions, but leaves intact the ability to produce linguistic facial expressions (Corina et al., 1999). With respect to perception, a recent study by Atkinson et al. (2004) examined the comprehension of non-manual markers of negation in British Sign Language (BSL) by signers with left- or right-hemisphere damage. Non-manual negation in BSL is marked by a linguistic facial expression and an accompanying headshake. Right hemisphere-damaged signers were impaired in comprehending non-manual negation, in contrast to left-hemisphere damaged signers who were unimpaired. However, a negative headshake is obligatory for grammatical negation in BSL, and recognition of a headshake is distinct from the recognition of the linguistic facial expressions because 1) a headshake can be used non-linguistically to signal a negative response and 2) a headshake can occur without signing, unlike grammatical facial expressions which are bound to the manual signs and do not occur in isolation. Thus, the neural organization for the recognition of linguistic facial expressions may differ from that for the recognition of headshakes marking negation.
With the advent of functional neural imaging, we can now study the brain regions involved in the perception of linguistic and emotional facial expressions in intact deaf signers with much greater anatomical precision than is possible with lesion studies.

Neuroimaging results with hearing subjects indicate that the superior temporal sulcus (STS) is critically involved in processing changeable aspects of the face, such as eye gaze (Hoffman & Haxby, 2002), mouth configuration (Puce, Allison, Bentin, Gore, & McCarthy, 1998), and facial expression (Haxby et al., 2000). Furthermore, attention to emotional facial expression can modulate activity within the right superior temporal sulcus (Narumoto et al., 2001). We predict that attention to linguistic facial expressions will produce greater activity within the left STS for deaf signers than for hearing nonsigners.

In addition, recognition of facial expressions may modulate activity within the face-responsive areas within inferior temporal cortex. In particular, the fusiform gyrus has been identified as crucial to the perception of faces and as particularly critical to perceiving invariant properties of faces, such as gender or identity (Haxby et al., 2000; Kanwisher, McDermott, & Chun, 1997). Activation within the fusiform gyrus in response to faces may be bilateral but is often lateralized to the right hemisphere. We hypothesize that the linguistic content of ASL facial expressions for deaf signers will modulate activity within the fusiform gyrus, shifting activation to the left hemisphere. In contrast, we hypothesize that hearing nonsigners will treat the unfamiliar ASL linguistic expressions as conveying social or affective information, even though these expressions are unique and non-identical to canonical affective expressions (Reilly et al., 1990).
Thus, activation in the fusiform gyrus is expected to be bilateral or more lateralized to the right hemisphere for hearing subjects with no knowledge of ASL.

In our study, subjects viewed static facial expressions performed by different models who produced either emotional expressions or linguistic expressions (adverbials indicating manner and/or aspect) with or without accompanying ASL verbs. Subjects made same/different judgments to two sequentially presented facial expressions, blocked by expression type. This target task alternated with a control task in which subjects made same/different judgments regarding gender (the models produced neutral expressions with or without verbs). Figure 4.1 provides examples of the ‘face only’ condition, and Figure 4.2 provides examples from the ‘face with verb’ condition. In this latter condition, models produced ASL verbs with either linguistic, neutral, or emotional facial expression. The ‘face only’ condition was included because most previous face processing studies presented isolated face stimuli. Although emotional facial expressions can be produced without an accompanying manual sign, ASL linguistic facial expressions are bound morphemes (like –ing in English) that must co-occur with a manually produced sign. Therefore, we included a second ‘face with verb’ condition in order to present the linguistic facial expressions in a more natural linguistic context.
Figure 4.2 Illustration of facial expressions produced with ASL verbs, used in the ‘face with verb’ condition.

4.2 Materials and methods

Participants

Ten deaf native signers (five male, five female, mean age = 29.4 ± 6 years) and ten hearing nonsigners (five male, five female, mean age = 24.2 ± 6 years) participated in the experiment. All of the deaf native signers had deaf parents and learned ASL from birth. All were prelingually deaf with severe to profound hearing loss (90 db or greater) and used ASL as their preferred means of communication. Hearing nonsigners had never been exposed to ASL. All subjects had attended college (an average of 5.1 and 3.8 years of college education for deaf and hearing subjects, respectively). No subject had a history of neurological or psychiatric illness, and none had taken any psychotropic medication within six months prior to the study. All subjects were right-handed and had normal or corrected-to-normal vision. All subjects signed an informed written consent approved by the Salk Institute Institutional Review Board.
**Materials**

The static facial expression stimuli used in the study were selected from digital videos of facial expressions generated by sign models who were certified ASL interpreters or ASL interpreters in training. None of the sign models were later found to be familiar to the subjects. All sign models were videotaped wearing the same dark clothing with a light blue background. During the videotaping the sign models were instructed to generate a neutral facial expression, six emotional, and six adverbial facial expressions while signing ten different verbs: WRITE, DRIVE, READ, BICYCLE, SIGN, STUDY, RUN, CARRY, DISCUSS, and OPEN. These verbs were selected because they can be used naturally in conjunction with all of the emotional and linguistic facial expressions. The adverbial facial expressions were: MM (meaning “effortlessly”), CS (“recently”), TH (“carelessly”), INTENSE, PUFF (“a great deal” or “a large amount”), and PS (“smoothly”) (see Figure 4.1A). The emotional facial expressions were: happy, sad, anger, disgust, surprise, and fear (see Figure 4.1B). Eye gaze was generally straight ahead, but occasionally gaze was directed to the side or downward. However, direction of gaze was balanced across conditions.

All static facial expressions were selected from digital videos using the following criteria. A still image for an emotional facial expression was selected if the image frame was at the peak of the expression and if the expression met the appropriate Facial Action Coding System (FACS) criteria, as assessed by a certified FACS coder (Ekman & Friesen, 1978). Static images of linguistic facial expressions were screened and selected by a native ASL signer based on how accurately and clearly each expression conveyed the ASL facial adverb.
These emotional, linguistic, and neutral facial expression images were cropped to show only the head of sign model for the ‘face only’ condition. For the ‘face with verb’ condition, the stimuli were cropped to show the head and upper body of the sign model producing an ASL verb (see Figure 4.2). All of the verbs were instantly recognizable from these still images.

An LCD video projector and PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) running on an Apple PowerBook were used to back-project the stimuli onto a translucent screen placed inside the scanner. The stimuli were viewed at a visual angle subtending 10° horizontally and vertically with an adjustable 45° mirror.

Procedure

The experimental task was to decide whether two sequentially presented facial expressions (produced by different sign models) were the same or different. The control (baseline) task was to decide whether two sequentially presented sign models (producing neutral facial expressions) were the same or different gender. For all tasks, subjects pressed a “yes” response button for same judgments and a “no” response button for different judgments. Response accuracy during the fMRI sessions was recorded using PsyScope software (Cohen et al. 1993). The ‘face only’ and ‘face with verb’ conditions were blocked and counter-balanced across subjects.

For each condition, subjects participated in two repeated sets of three runs: emotional-control, linguistic-control, and alternating blocks of emotional and linguistic expressions. Both sets contained the same run order, but the stimuli in each run were presented in a different order. Each run consisted of eight 32-second blocks alternating between experimental and control blocks. Each trial in the experimental block presented
a pair of facial expression stimuli, each presented for 850 ms with a 500 ms ISI. At the start of each block, either the words 'facial expression' or the word 'gender' was presented for one second to inform subjects of the upcoming task. Each run lasted four minutes and sixteen seconds. All stimuli pairs in the experimental blocks showed different individuals expressing either the same or different facial expressions. Each trial in the control block showed different individuals with neutral facial expressions only. All blocks were approximately equal in the number of males/females and experimental blocks contained approximately equal numbers of facial expressions in each of the six categories.

Data acquisition, processing, and analysis

Both structural MRI and fMRI scans were performed using a 1.5 Tesla Siemens MRI scanner with a whole head coil. Head movement was minimized by using cushioned supports placed around subject’s head and neck within the whole head coil. Two structural MR images were acquired for each subject prior to the fMRI scans (T1-weighted MPRAGE with TR = 11.4, TE = 4.4, FOV 256, and 10° flip angle; voxel dimensions: 1 X 1 X 1mm). These T1-weighted images were averaged post hoc using AFNI (Analysis of Functional NeuroImages) (Cox, 1996) to create a single high quality anatomical data set for registration and spatial normalization to the atlas of Talairach and Tournoux (1988). Each subject’s anatomical dataset in the Talairach atlas was used to delineate the region of interest (ROI) boundaries for the superior temporal sulcus (STS) and the fusiform gyrus (FG) in both hemispheres. We defined the superior temporal sulcus ROI as the area encompassing the upper and lower bank of STS, extending from the temporo-occipital line to the posterior part of temporal pole. The fusiform gyrus was
defined as the area bounded by the anterior and posterior transverse collateral sulcus, medial occipito-temporal sulcus, and the lateral occipito-temporal sulcus.

For all functional scans, T2*-weighted interleaved multi-slice gradient-echo echo-planar imaging (TR = 4 s, TE = 44 ms, FOV 192, flip angle 90°, 64 x 64 matrix) was used to acquire 24 contiguous, 5 mm thick coronal slices extending from occipital lobe to mid-frontal lobe with voxel dimension of 3 x 3 x 5 (mm). The fMRI time-series data were pre-processed and analyzed with AFNI in several steps in order to acquire voxel numbers from the ROIs for analysis. The first two volumes (acquired prior to equilibrium magnetization) from each scan were discarded. All scans were corrected for head motion using an iterative least-squares procedure that aligns all volumes to the reference volume (the third volume of the first functional scan acquired immediately after the last structural MRI scan). All volumes were then spatially smoothed with a 5 mm FWHM Gaussian kernel prior to the analysis.

The significance level for each voxel was calculated using Pearson product-moment correlation coefficient for cross-correlation of hemodynamically convolved reference waveform with the measured fMRI time-series for each voxel. A combination of AlphaSim (Ward, 2000) and AFNI’s 3dclust was used to derive numbers of statistically significant activated voxels from the regions of interest (superior temporal sulcus and fusiform gyrus) for subsequent ROI analyses, while minimizing the probability of random Type-1 errors due to large number of comparisons and spatial correlations resulting from gaussian smoothing. AlphaSim calculates the probability of occurrence of a cluster made up of specific number of smoothed neighboring voxels with a given P value through Monte Carlo simulations (see Ward, 1997, for details). Based on
AlphaSim calculations, only clusters of 7 voxels (315 mm$^3$) or greater with voxel-wise significance level of $p \leq .001$ within the ROIs were used for statistical analysis of extent of activation.

In addition to the ROI analysis using individual data, we acquired group-level z-maps for each condition. This was done by normalizing all raw individual functional scans, which were then spatially converted into the Talairach atlas. The talairached individual scans were then concatenated before analysis with 3dDeconvolve (part of the AFNI package). For clarity, only neural activations within the ROI being discussed are shown in the figures.

### 4.3 Results

**Behavioral results**

All subjects performed the tasks without difficulty. Separate two-factor ANOVAs (2: subject group X 2: facial expression type) were conducted on the accuracy data for the ‘face only’ and the ‘face with verb’ conditions. For the ‘face only’ condition, there were no significant main effects of group or facial expression type and no interaction between subject group and facial expression ($F<1$). For the emotional expressions, deaf and hearing subjects were equally accurate (81.8% and 80.6%, respectively). Importantly, deaf and hearing subjects were also equally accurate with the linguistic facial expressions (79.6% and 79.1%, respectively). Thus, any group differences in activation are unlikely to be due to differences in task difficulty for the two groups. Similarly, for the ‘face with verb’ condition, there were no main effects of group or facial expression type, and no interaction ($F<1$). For the emotional expressions,
hearing subjects were slightly more accurate than deaf subjects (85.3% and 83.8%, respectively), but this difference was not significant. For the linguistic expressions, deaf subjects were slightly more accurate than hearing subjects (85.4% and 81.6%, respectively), but again, this difference was not significant. Thus, the behavioral data indicate that task difficulty did not contribute to the differences in neural activity observed between the groups.

Imaging results

A mixed-design ANOVA was conducted separately for each ROI for each stimulus condition, using extent of activation with voxel-wise probability ≥ .001 as the dependent measure. The mixed-design ANOVA consisted of one between group factor (subject group: deaf, hearing) and two within group factors: hemisphere (left, right) and facial expression type (emotional, linguistic). Activation patterns for the ‘face only’ and ‘face with verb’ conditions were analyzed separately. These analyses were based on results from the runs in which facial expressions alternated with the control condition. In the final section, we report on the results from the runs in which alternating emotional and linguistic facial expressions were presented.

Face Only Condition

Superior Temporal Sulcus. The pattern of neural activation in STS did not differ significantly for deaf and hearing subjects in the ‘face only’ condition. There were no main effects of subject group (F < 1) or of facial expression type (F < 1). Activation was bilateral, with no significant main effect of hemisphere (F < 1). Although no interactions were significant, planned comparisons revealed significantly greater right- than left-
hemisphere activation for emotional facial expressions for the hearing subjects (F(1, 9) = 8.90, p < .02). No other hemispheric differences were significant.

Fusiform Gyrus. There were no significant main effects of subject group or of facial expression type. However, the ANOVA revealed a significant interaction between subject group and cerebral hemisphere (F(1,18) = 5.45, p < .05). For deaf signers, activation within the fusiform gyrus was significantly left-lateralized for emotional facial expressions (F(1,9) = 5.38, p < .05), but the pattern of left-lateralization did not reach significance for linguistic facial expressions. For hearing subjects, activation in FG was consistently bilateral. There were no significant differences between activation in the left versus right hemisphere (F < 1 for both linguistic and emotional facial expressions).

To demonstrate the correspondence between the MR response and task performance and to illustrate the strength of the left-right hemispheric differences in Blood Oxygen Level Dependent (BOLD) signal, we calculated the percent signal change in MR response across time in the left and right hemispheres for each group. This calculation was performed using the following steps: 1) for each individual, all MR response time-series within an ROI were normalized and averaged into an ROI time-series for each condition. 2) All ROI time-series were then averaged for each group for each condition and for each ROI. Figure 4.3 illustrates the group difference in neural activation and percent signal change across time-series in the fusiform gyrus for the emotional facial expressions in the ‘face only’ condition.
Finally, Table 4.1 provides the Talairach coordinates, the mean volumes of activation, and the maximum z scores for activation extents for each ROI for the ‘face only’ condition.

Figure 4.3 Illustration of activation in the fusiform gyrus for emotional facial expressions in the ‘face only’ condition. The bottom graphs show normalized MR response from left (yellow) and right (cyan) ROIs averaged across subjects. For graph clarity, the final ROI time-series were smoothed using three-step moving average.
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Face with Verb Condition

Superior Temporal Sulcus. As in the ‘face only’ condition, there were no main effects of subject group (F < 1) or of facial expression type (F < 1). However, the interaction between hemisphere and group approached significance (F(1,18) = 4.86, p = .059). Planned comparisons showed that when presented with linguistic facial expressions produced with a verb, deaf subjects exhibited significantly more activation in the left than right hemisphere (F(1,9) = 6.82, p < .05). In contrast, hearing subjects exhibited no differences in hemispheric activation for linguistic expressions (F(1,9) = 2.12, p = .187). Figure 4.4 illustrates the group difference in neural activation and percent signal change in STS for the linguistic facial expressions in the ‘face with verb’ condition.

Figure 4.4 Illustration of activation in the superior temporal sulcus for linguistic facial expressions in the ‘face with verb’ condition. The bottom graphs show normalized MR
response from left (yellow) and right (cyan) ROIs averaged across subjects. For graph clarity, the final ROI time-series were smoothed using three-step moving average.

For emotional facial expressions produced with an ASL verb, deaf subjects exhibited bilateral activation (F<1); whereas, hearing subjects exhibited a trend for more right-lateralized activation (F(1,9) = 3.70, p = .08).

Fusiform Gyrus. The pattern of results for the ‘face with verb’ condition was similar to the ‘face only’ condition. There were no significant main effects of group, facial expression, or hemisphere. Planned comparisons revealed that Deaf subjects exhibited a strong trend for more activation in the left than right fusiform gyrus for both linguistic facial expressions (F(1,9) = 3.97, p = .07) and emotional facial expressions (F(1,9) = 4.67, p = .05). In contrast, activation was bilateral for hearing subjects for both types of facial expressions (F < 1 for all contrasts). Table 4.2 provides the Talairach coordinates, the mean volumes of activation, and the maximum z scores for activation extents for each ROI for the ‘face with verb condition.’
## Table 2. Brain regions regions activated in the 'face with verb' condition

### Emotional Facial Expressions

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<tr>
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### Linguistic Facial Expressions

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Finally, to more clearly illustrate the pattern of hemispheric differences, we calculated a lateralization index based on the group means for the number of activated voxels thresholded above \( p < .001 \) in the STS and FG ROIs in each hemisphere. A lateralization index (LI) for each ROI was computed according to the formula \( LI = \frac{Vol_R - Vol_L}{Vol_R + Vol_L} \), where \( Vol_L \) and \( Vol_R \) represent the mean numbers of activated voxels in the left and right hemispheres. The laterality indices are graphed in Figure 4.5 and are based on the mean volumes of activation shown in Tables 4.1 and 4.2. Figure 4.5 thus provides a visual illustration of the group differences in hemispheric bias across tasks and conditions. Positive and negative index values represent rightward and leftward bias, respectively.

Figure 4.5  Lateralization index for total number of voxels in left versus right in the STS (A) and in the fusiform gyrus (B). The index is calculated using the group means from Tables 4.1 and 4.2.

*Alternating blocks of emotional and linguistic facial expressions.*

For runs consisting of alternating emotional and linguistic blocks, the percentage of signal change in the individual datasets was found to be weak. The partial correlation
coefficient calculated for the ROIs from each run failed to rise above the pre-determined threshold required to prevent false positives. Thus, we could not perform ANOVA analyses for those datasets. However, z-maps acquired from the correlation coefficient analysis of concatenated datasets from the ‘face with verb’ condition across subjects in each group showed neural activity in the right middle temporal gyrus in both groups for emotional facial expressions block. Activation in the left STS and lateral occipital temporal gyrus was found for linguistic facial expressions in deaf subjects only.

4.4 Discussion

Overall, our results revealed consistent activation in face-related neural regions for the recognition of both emotional and linguistic facial expressions for deaf and hearing subjects. Thus, the neural organization underlying facial expression recognition is relatively robust since these regions are engaged in processing all types of facial information, including linguistic facial expressions. However, the lateralization of activation within these face-related neural regions appears to be functionally driven and malleable.

Superior temporal sulcus

Presentation of emotional facial expressions resulted in right-lateralized activation within the superior temporal sulcus (STS) for the hearing group (see Figure 4.5A). This result is consistent with previous research indicating greater right hemisphere involvement in processing emotional information (Haxby et al., 2000, Narumoto et al., 2001). In addition, the pattern of right hemisphere lateralization was relatively unchanged when emotional expressions were presented with non-meaningful manual
postures, i.e. ASL verbs (see Figure 4.2). Thus, for hearing subjects, simply viewing the hands and arm does not modulate the pattern of right-lateralized activity within STS when perceiving emotional facial expressions.

For the deaf group, activation in STS was bilateral for emotional facial expressions in both the ‘face only’ and the ‘face with verb’ conditions. A possible explanation for bilateral processing of emotional facial expressions by deaf signers is that emotional facial expressions can occur as non-manual components of lexical signs denoting emotional states, e.g., the signs ANGRY, SAD, DISGUST, HAPPY are most often (but not always) produced with the corresponding emotional facial expression. In addition, emotional facial expressions are often produced during “role shifted” discourse in which the affect of someone other than the signer is depicted. Deaf signers may show bilateral activation for emotional expressions within STS because for this group, linguistic processing involves the detection of emotional facial expressions during narrative discourse, as well as during lexical processing.

However, when linguistic facial expressions were accompanied by an ASL verb, deaf signers exhibited significant left-lateralized activation within STS (see Figures 4.4 and 4.5A). The control condition also presented still images of models producing ASL verbs but with neutral facial expressions. Thus, activation associated with the verbs themselves was factored out. It was the combination of adverbial facial expressions with ASL verbs that shifted processing to the left hemisphere for deaf signers. Furthermore, this shift in hemispheric lateralization did not occur when linguistic facial expressions were presented in isolation (the ‘face only’ condition). For deaf signers, adverbial facial expressions presented without a manual verb are recognizable but incomplete because
these expressions constitute bound morphemes. An English analogy would be presenting speakers with bound suffixes such as \textit{-ing} or \textit{-ness}. Thus, linguistic facial expressions significantly engage left STS only when these expressions occur within their obligatory linguistic context.

Unlike the deaf group, hearing signers exhibited bilateral activation within STS for ASL facial expressions in both the ‘face only’ and in the ‘face with verb’ conditions. Although the hearing group means suggests right lateralized activation for ASL facial expressions (see Figure 4.5A and Tables 4.1 and 4.2), there was a large variance in laterality patterns across hearing subjects, which led to the lack of statistical significance. The variability might be due to some hearing subjects interpreting ASL expressions as conveying affective or socially relevant information, while other subjects may have treated the expressions as unfamiliar facial gestures.

\textit{Fusiform Gyrus}

The fact that any activation within the fusiform gyrus was observed at all is significant because neutral faces were used as the control condition. Thus, the observed activation within the fusiform is not due to the processing of faces \textit{per se}. Apparently, the fusiform remains part of the distributed neural circuitry mediating the recognition of facial expressions, despite its hypothesized role in processing invariant aspects of faces [17]. Whether the observed fusiform activation reflects top-down modulation of face processing or early visual face processing will require further investigation.

For hearing subjects, activation within the fusiform gyrus was bilateral for all conditions (see Figures 4.3 and 4.5B). In contrast, activation within the fusiform gyrus
was left-lateralized or biased toward the left hemisphere for deaf subjects for all conditions (see Figures 4.3 and 4.5B). Unlike activation within the STS, activation within the fusiform gyrus was unaffected by the presence of an ASL verb for deaf signers. This result indicates that activation within the fusiform gyrus is not modulated by the recognition of the linguistic content of the stimulus. For both subject groups, fusiform activation may primarily reflect the early analysis of facial features, regardless of the function of the facial expression (emotional vs. linguistic) or the linguistic/gesture context (i.e., ‘face only’ vs. ‘face with verb’).

The fact that deaf subjects exhibited left-lateralized activation within the fusiform gyrus for emotional expressions is somewhat surprising. One possible explanation is that the nature of the processing required for linguistic facial expressions shifts the activation to the left hemisphere for emotional expressions as well. Several studies have suggested that local and global face processing are mediated in the left and right fusiform gyrus respectively (Hillger & Koenig, 1991; Rossion, Dricot, Devolder, Bodart, & Crommelinck, 2000). Recognition of linguistic facial expressions requires identification of local facial features, and we propose that left lateralization within the fusiform may arise from the life-long and constant neural activity associated with local facial feature processing for deaf signers.

In contrast to linguistic facial expressions, emotional facial expression categories are determined by global and configurational processing of facial features--with the possible exception of the ‘happy’ facial expression (Adolphs, 2002). Categories of linguistic facial expressions, on the other hand, are differentiated only by local changes to a single feature (e.g. mouth) or to specific groups of facial features (e.g. the two
eyebrows). In the case of adverbial facial expressions, specific meanings are carried solely by different configurations of the mouth feature. That is, any changes associated with other individual facial features or the global configuration of facial features will not affect the adverbial meaning expressed by the mouth alone. Unlike emotional facial expressions which can be differently combined to create subordinate categories of specific emotional facial expressions (e.g., fearful surprise or happy surprise), linguistic facial expressions articulated with the same facial feature (e.g. mouth) cannot be combined and do not have any subordinate categories. In addition, emotional facial expressions can vary in strength, conveying different meanings (e.g., ‘rage’ versus ‘irritation’, with respect to the emotional category “angry”). In contrast, a difference in strength or intensity of the adverbial expression ‘MM’ does not convey any additional information. Variation in the intensity of adverbial expressions across individuals is not interpreted as variation in the intensity of the verbal modification; rather, such variation in expression is treated as phonetic variation that does not convey meaningful information. Thus, processing linguistic facial expressions requires categorical identification and detection of local facial feature configurations.

Crucially, behavioral evidence indicates that ASL signers (both deaf and hearing) excel at discriminating local facial features compared to nonsigners. McCullough and Emmorey (1997) found that ASL signers were significantly more accurate than hearing nonsigners in discriminating between faces that were identical except for a change in a single facial feature. These behavioral data indicate that extended experience with featural processing of facial expressions affects how ASL signers process faces in general.
We propose that monitoring and processing both linguistic and emotional facial expressions during everyday sign language conversation may induce a constant competition between local and global processing for attentional resources. Perception of emotional facial expressions is nearly automatic but is still not spared from attentional competition (Pessoa, McKenna, Gutierrez, & Ungerleider. 2002). Furthermore, since linguistic facial expressions are very brief and change frequently compared to emotional facial expressions, we suggest that processing linguistic facial expressions draws more attentional resources to local facial feature processing and keeps these processes engaged constantly. The continual difference in the attentional resources allocated to local versus global processing during life-long exposure to ASL may lead to changes in the efficiency and lateralization of activity within the fusiform gyrus for native signers.

Indeed, such changes in hemispheric lateralization of neural activation have been observed for perception of non-linguistic visual motion in deaf and hearing native signers (Bavelier et al., 2001; Bavelier et al., 2000; Neville & Lawson, 1987). MT/MST activation in response to peripheral visual motion stimuli was found to be left-lateralized for native signers when compared to hearing non-signer controls (Bavelier et al., 2001). This lateralization pattern is also argued to result from life-long exposure to sign language (Bavelier et al., 2001; Neville & Lawson, 1987).

In conclusion, our study has shown that the neural regions associated with general facial expression recognition are consistent, predictable, and robust. Neural activation was consistently found in the STS and FG regions across both deaf and hearing subjects. In addition, the results support the hypothesis that the right hemisphere is dominant for recognition of emotional facial expressions. The results also show that the neural
representation underlying facial expression recognition can be modulated. The leftward asymmetry observed in the STS region for facial expressions presented within a linguistic context implies a strong language dominance for left hemisphere processing regardless of the form in which that linguistic information is encoded. In addition, the left FG activation observed in signers when viewing either emotional or linguistic facial expressions suggests that long-term experience with sign language may affect the neural representation underlying early visual processing of faces. Future research with hearing native signers exposed to ASL from birth by their deaf parents will help determine whether the changes in neural organization for facial expression recognition are due to auditory deprivation or to linguistic experience, as we propose. In addition, research with signers who acquired ASL in adulthood or late childhood will determine the developmental plasticity of face-related neural regions within the brain.

4.5 Acknowledgement

Chapter 4 of this dissertation, in full, is a preprint version of the material as it appears in Cognitive Brain Research, 22(2), pp. 193-203, McCullough, Stephen; Emmorey, Karen; and Sereno, Martin, Elsevier 2005. The dissertation author was the primary investigator and author of this paper.
CHAPTER 5: GENERAL CONCLUSIONS

Converging evidence from the behavioral and neuroimaging studies reported in the earlier chapters clearly substantiates that experience with signed language has a significant effect on behavioral performance and neural organization underlying face and facial expression perception. Particularly, the experimental findings reveal that the changes were very specific and closely tied to recognizing and interpreting linguistic facial expressions in ASL. This chapter summarizes these experimental findings and provides the answers to the three overarching questions raised in the first chapter. The questions were: how does brain recognize and process affective and linguistic expressions? Will the difference in function underlying affective and linguistic facial expressions produce different hemispheric specializations? Does experience with linguistic facial expressions alter how faces or affective expressions are processed?

5.1 Summary of Experimental Findings.

Experimental studies in the Chapter 2 report that signers, when compared with hearing nonsigners, did not exhibit any enhanced performance in recognizing unfamiliar faces from memory or in the configurational (gestalt) processing of faces. However, only signers (Deaf and hearing) have demonstrated an enhanced performance in the discrimination of local facial features. The enhancements observed were confined only to the eyes and mouth facial features. These findings suggest that the enhancements may be closely tied to recognizing and interpreting linguistic facial expression in ASL. To
identify and categorize ASL facial expressions, signers do not need to recognize the person. Rather, signers must recognize changes in local facial features of person’s face in order to identify specific facial expressions. Ability to generalize over individual faces and to focus on a specific local features rather than the global configuration of the face are characteristic of lip reading as well. Thus, the results suggest that only specific aspects of face processing are enhanced in signers: those skills relevant to interpreting subtle differences in local feature configurations, which must be generalized over individual faces.

Experimental studies in the Chapter 3 reveal that hearing nonsigners have categorical perception effects for both affective and linguistic facial expression continua. Deaf signers, in contrast, exhibited a significant CP effect only for linguistic facial expression continuum. Furthermore, the same experimental results also reveal that Deaf signers discriminated affective facial expressions more slowly after they discriminated linguistic facial expressions. Hearing nonsigners, on the other hand, were unaffected by the presentation order of conditions. The results from the Deaf group strongly suggest that exposure to linguistic facial expression categories can significantly alter the processing underlying the categorical perception for affective facial expressions. Finally, the experimental findings from Chapter 3 also reveal that facial expression categorical perception is not limited to universal emotion categories, but readily extends to other types of facial expressions.

Chapter 4 reports an fMRI study, investigating the neural organization underlying facial expression perception. The neuroimaging findings presented in the Chapter 4 show that a life-long exposure to signed language has a significant effect on the neural activity
within the superior temporal sulcus (STS) when viewing facial expressions. As predicted, nonsigners viewing the affective facial expressions showed increased neural activation in the STS within the right hemisphere. Signers, on the other hand, showed bilateral STS activation when viewing the same facial expressions. Moreover, only signers demonstrated a strong left lateralized STS activity when viewing the linguistic facial expressions presented with signed verbs. Crucially, the left-lateralized activity was not observed when signers viewed the affective facial expressions presented with the identical signed verbs. Furthermore, the same study also reports that the neural activation in the fusiform gyrus (FG) was left lateralized for ASL signers for both expression types across all conditions, whereas nonsigners continually show bilateral activation for both expression types across the same conditions.

5.2 General Conclusions

How does brain recognize and process the affective and linguistic expressions?

Both types of facial expressions are recognized and processed in the superior temporal sulcus and fusiform gyrus regions in both hemispheres. Although Deaf signers have a very different perceptual and cognitive experience with the human face compared to nonsigners, the fMRI results clearly show virtually identical loci of neural systems involved in the face and facial expression perception (i.e., STS and fusiform gyrus in each hemisphere). The fMRI findings discussed in this dissertation are in a complete agreement with the previous neuroimaging findings mentioned in the literature review (Haxby, 1999; Haxby et al. 2000, Ojemann et al. 1992; Puce et al., 1998, Sergent et al. 1992, Kanwisher et al. 1997). Highly consistent neural activities observed in the STS
and fusiform gyrus regions across diverse individuals and populations strongly suggest that these neural substrates are specially attuned for face and facial expression processing. Moreover, the results reported in the chapter 4 also substantiate Haxby’s (1999) hypothesis that the fusiform gyrus is specially attuned to the invariant aspects of face (e.g., identity, gender, etc.), and that the STS is separately attuned to the changeable aspect of faces (i.e. facial expressions). The fMRI study in Chapter 4 reveal that the neural activity in the STS regions varied when Deaf signers and hearing nonsigners viewed different types of changeable facial expressions, whereas the neural activity in the fusiform gyrus regions remained the same across all conditions.

*Will the difference in function between affective and linguistic facial expressions produce different hemispheric specializations?*

The findings from the Chapter 4 confirm that facial expressions serving different functions are processed differently in the brain regions. Chapter 4 of this dissertation shows several clear examples of how the organization of neural activity are changed and driven by the function of stimuli. The lateralization of neural activity for adverbial facial expressions depends on whether the facial expressions were presented in the ‘face only’ and ‘face with sign’ conditions. It is important to keep in mind that the adverbial facial expressions shown in both conditions were *identical*. However, in the ‘face only’ condition, the adverbial facial expressions, which are bound morphemes, do not perform their linguistic function fully without the accompanying verbs. An English analogy would be presenting speakers with bound suffixes such as *-ing* or *-ness*. Thus, as result these facial expressions do not significantly engage left STS as they normally do when
they were presented with signed verbs. When adverbial facial expressions are presented with signed verbs they serve their linguistic function fully, and as a result they are processed primarily in the left STS. The affective facial expressions presented with signed verbs do not serve linguistic function, therefore did not significantly activate the left STS. The experimental outcomes observed in the Chapter 4 confirm that facial expressions are processed differently in different hemispheres depending on the function the facial expressions serve.

*Does experience with linguistic facial expressions alter how faces or affective facial expressions are processed?*

Converging evidence from all findings presented in this dissertation has clearly demonstrated that experience with sign language does affect signers’ perception for face and facial expressions. The effects are also found to be very specific and related to detecting the changes in the local facial features during linguistic processing. Two examples of the observed effects are A) signers performed significantly better than nonsigners in local facial feature discrimination, and B) their brain showed strong left-lateralized neural activity in the fusiform gyrus for all types of facial expressions. Both effects indicate that signers rely more on local feature processing when viewing faces or facial expressions when compared with nonsigners. Moreover, the greater reliance on the local facial feature processing may be the reason for the absence of signers’ categorical perception for the affective facial expressions, which are normally perceived globally.
REFERENCES


of the human amygdala during visual processing of facial expression. *Neuron, 17*(5).


Pyers, J.E. & Emmorey, K (2005). The eyebrows have it: Evidence for the activation of two grammars in ASL-English bilinguals. YYY


