

AGE DIFFERENCES IN THE PERCEPTION OF DISCRETE EMOTIONS

by

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Abstract

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Research has suggested that emotion perception declines with age, although there may be a differential change in emotion perception according to emotion type (e.g., happiness and sadness), with the perception of some emotions declining with age and the perception of others remaining relatively stable across the adult lifespan. However, few studies have investigated age-related changes in the perception of discrete emotions across multiple channels of communication. In addition, few studies have included individuals over the age of 80 years. Therefore, in an effort to extend previous work, the current study aims to characterize age differences in the perception of eight discrete emotions (i.e., anger, sadness, fear, disgust, unpleasant surprise, pleasant surprise, happiness, and interest) across facial, prosodic/intonational, and lexical/verbal channels in healthy adults aged 20-89 years.

A total of 117 healthy, right-handed adults, aged 20-89 completed the study. All participants completed a comprehensive screening process, which included measures of cognitive, perceptual, and affective functioning. Following the screening procedures, participants completed emotion perception tasks from the New York Emotion Battery (NYEB; Borod, Welkowitz, & Obler, 1992), as well as nonemotional control tasks. Multiple regression analyses were conducted to examine associations among measures of emotion perception ability, nonemotional control tasks, and age. Age differences were also evaluated among seven age groups using parametric and non-parametric techniques. Finally, correlational and multiple regression analyses were conducted to investigate the relationship among auditory acuity, cognitive function, emotion perception ability, and age.

Results of the study provided evidence of age differences in emotion perception abilities. In general, older adults were less accurate in the perception of emotion across all three channels of communication than were younger participants, but the most pronounced differences were observed in the prosodic channel for fear, happiness, and interest. Furthermore, age was a significant predictor of performance on emotion perception tests, even after controlling for factors such as performance on nonemotional control tasks, auditory acuity, and cognitive functions. Results are discussed in the context of the neuropsychological hypothesis, simulation theory, and common cause theory. This work has important clinical implications, particularly in terms of understanding social functioning in late life.

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Table of Contents

Introduction	1
Research Question	1
Literature Review	2
Emotion Processing	2
Cues to Decoding Discrete Emotions	3
Facial Channel	4
Prosodic Channel	4
Lexical Channel	5
Individual Differences in Emotion Perception	6
Sex	6
Ethnicity	7
Neural Systems for Emotion Perception	8
Neural Basis for Recognizing Emotion from Faces	8
Neural Basis for Recognizing Emotion from Prosody	12
Neural Basis for Recognizing Emotion from the Lexical Channel	12
Hemispheric Asymmetry in Emotion Perception	13
Facial Channel	13
Prosodic Channel	14
Lexical Channel	15
Are There Separate Systems for Recognizing Discrete Emotions?	15
The Aging Brain	17
Age-Related Cognitive Changes	17
Brain Correlates of Aging	18
Structural Changes	18

White Matter	19
Dopamine Functioning	20
Cognitive Neuropsychological Models of Aging	21
Behavioral Approaches to Cognitive Aging	21
Frontal Lobe Hypothesis of Aging	23
Right Hemi-Aging Hypothesis	24
Hemispheric Asymmetry Reduction in Older Adults (HAROLD) Model	25
The Scaffolding Theory of Aging and Cognition	26
Age and Emotion Processing	27
Age and the Experience of Emotion	27
Age and the Perception of Emotion	27
Facial Channel	28
Prosodic Channel	29
Lexical Channel	30
Theoretical Explanations for Age-Related Changes in Emotion Processing	30
The Neuropsychological Hypothesis	31
The Simulation Theory	33
The Common Cause Hypothesis	34
Overview of the Current Project	36
Aims and Hypotheses	37
Aim I	37
Aim II	38
Methods	40
Participants	40
Procedures	40

Screening Measures	41
Experimental Tasks	43
Emotional Tasks	43
Facial Perception	43
Prosodic Perception	44
Lexical Perception	45
Nonemotional Control Tasks	45
Facial Channel	45
Prosodic Channel	46
Lexical Channel	46
Data Analysis	47
Data Inspection	47
Tests of Normality and Homogeneity of Variance	47
Participant Demographics	48
Statistics Specific to Aims and Hypotheses	48
Aim I	48
Aim II	50
Results	53
Data Inspection	53
Tests of Normality and Homogeneity of Variance	53
Demographic Characteristics	55
Aim I	55
Hypothesis I	55
Hypotheses II and III	57
Non-Parametric Analyses	58
Parametric Analyses with Identification Tasks Using WID	59
Parametric Analyses with Identification Tasks Using SID	64

Parametric Analyses with Discrimination Tasks	68
Aim II	69
Hypothesis I	69
Hypothesis II	70
Discussion	72
Summary of Results	72
Age Differences in Emotion Perception	72
Age Differences in the Perception of Discrete Emotions	73
The Effect of Nonemotional Perception on Emotion Perception Ability	76
The Effect of Auditory Acuity and Cognitive Functions on Emotion Perception Ability	77
Correlations Among Variables	77
Multiple Regression Analyses	78
Evaluating Theoretical Explanations	80
The Neuropsychological Hypothesis	80
The Common Cause Hypothesis	81
The Simulation Theory	81
Limitations	82
Directions for Future Research	83
Clinical Implications	85
Conclusions	86
References	147

Tables

Table 1. Screening Measures: Cut-off Scores for Exclusion from Study	88
Table 2. Demographic Characteristics of Sample by Age Group	89
Table 3. One-way ANOVAs and Chi-Squares on Age Group for Participant Demographics	90
Table 4. Descriptive Statistics for Experimental Tasks by Age Group	91
Table 5. Descriptive Statistics for Nonemotional Control Tasks by Age Group	92
Table 6. Multiple Regression with Nonemotional Control Tasks for Facial Identification Task	93
Table 7. Multiple Regression with Nonemotional Control Tasks for Prosodic Identification Task	94
Table 8. Multiple Regression with Nonemotional Control Tasks for Lexical Word Identification Task	94
Table 9. Multiple Regression with Nonemotional Control Tasks for Lexical Sentence Identification Task	95
Table 10. Multiple Regression with Nonemotional Control Tasks for Facial Discrimination Task	95
Table 11. Multiple Regression with Nonemotional Control Tasks for Prosodic Discrimination Task	96
Table 12. Multiple Regression with Nonemotional Control Tasks for Lexical Word Discrimination Task	96
Table 13. Kruskal-Wallis Test for Emotion Identification Tasks, Separately for Each Emotion	97
Table 14. Summary of Mixed-Design Repeated Measures ANOVA with WID for the Lexical Channel	98
Table 15. Summary of Mixed-Design Repeated Measures ANOVA with SID for the Lexical Channel	98
Table 16. Summary of Mixed-Design Repeated Measures ANOVA for Discrimination Tasks	99
Table 17. Spearman's Rho Statistics Among Emotion Perception Tasks and Auditory Acuity Composite Score: Seven Age Groups	100
Table 18. Spearman's Rho Statistics Among Emotion Perception Tasks and Auditory Acuity Composite Score: Four Age Groups	100

Table 19. Pearson Correlations Between Emotion Perception Task and Auditory Acuity Composite Score: Seven Age Groups	101
Table 20. Pearson Correlations Between Emotion Perception Task and Auditory Acuity Composite Score: Four Age Groups	101
Table 21. Fisher's Z-Tests Comparing Correlations Between Auditory Acuity and Emotion Perception Tasks: Seven Age Groups	102
Table 22. Fisher's Z-Tests Comparing Correlations Between Auditory Acuity and Emotion Perception Tasks: Four Age Groups	102
Table 23. Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Identification Task	103
Table 24. Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Identification Task	103
Table 25. Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Identification Task	104
Table 26. Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Sentence Identification Task	104
Table 27. Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Discrimination Task	105
Table 28. Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Discrimination Task	105
Table 29. Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Discrimination Task	106

Figures

Figure 1. Main Effect of Age for Identification Tasks with WID for the Lexical Channel	107
Figure 2. Main Effect of Channel for Identification Tasks with WID for the Lexical Channel	108
Figure 3. Main Effect of Emotion for Identification Tasks with WID for the Lexical Channel	109
Figure 4. Channel by Age Group Interaction for Identification Tasks with WID for the Lexical Channel	110
Figure 5. Channel by Emotion Interaction for Identification Tasks with WID for the Lexical Channel	111
Figure 6. Performance of Each Age Group on Identification Tasks with WID for the Lexical Channel (Separately for Each Emotion)	112
Figure 7. Performance on Identification Tasks for Each Age Group by Channel (Separately for Each Emotion)	114
Figure 8. Main Effect of Age for Identification Tasks with SID for the Lexical Channel	116
Figure 9. Main Effect of Channel for Identification Tasks with SID for the Lexical Channel	117
Figure 10. Main Effect of Emotion for Identification Tasks with SID for the Lexical Channel	118
Figure 11. Channel by Emotion Interaction for Identification Tasks with SID for the Lexical Channel	119
Figure 12. Performance of Each Age Group on Identification Tasks with SID for the Lexical Channel (Separately for Each Emotion)	120
Figure 13. Main Effect of Age for Discrimination Tasks	122
Figure 14. Main Effect of Channel for Discrimination Tasks	123

Appendix

Table 1. Shapiro-Wilk Tests of Normality and Levene’s Test of Homogeneity of Variance for Identification Tasks with Total Scores	124
Table 2. Shapiro-Wilk Tests of Normality and Levene’s Test of Homogeneity of Variance for Discrimination Tasks	125
Table 3. Shapiro-Wilk Tests of Normality & Levene’s Test of Homogeneity of Variance for Discrete Emotions – Facial Identification	126
Table 4. Shapiro-Wilk Tests of Normality & Levene’s Test of Homogeneity of Variance for Discrete Emotions – Prosodic Identification	128
Table 5. Shapiro-Wilk Tests of Normality & Levene’s Test of Homogeneity of Variance for Discrete Emotions – Lexical Word Identification	130
Table 6. Shapiro-Wilk Tests of Normality & Levene’s Test of Homogeneity of Variance for Discrete Emotions – Lexical Sentence Identification	132
Table 7. Shapiro-Wilk Tests of Normality & Levene’s Test of Homogeneity of Variance for Nonemotional Control Tasks	134
Table 8. Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Identification Task with Age as a Continuous Variable	136
Table 9. Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Identification Task with Age as a Continuous Variable	136
Table 10. Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Identification Task with Age as a Continuous Variable	137
Table 11. Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Sentence Identification Task with Age as a Continuous Variable	137
Table 12. Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Discrimination Task with Age as a Continuous Variable	138
Table 13. Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Discrimination Task with Age as a Continuous Variable	138
Table 14. Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Discrimination Task with Age as a Continuous Variable	139
Figure 1. Normal and Detrended Normal P-P Plots for Facial Identification	140
Figure 2. Normal and Detrended Normal P-P Plots for Prosodic Identification	141
Figure 3. Normal and Detrended Normal P-P Plots for Lexical Word Identification	142
Figure 4. Normal and Detrended Normal P-P Plots for Lexical Sentence Identification	143

Figure 5. Normal and Detrended Normal P-P Plots for Facial Discrimination	144
Figure 6. Normal and Detrended Normal P-P Plots for Prosodic Discrimination	145
Figure 7. Normal and Detrended Normal P-P Plots for Lexical Word Discrimination	146

Introduction

Research Question

The ability to accurately perceive and interpret subtle, often implicit, emotional cues enables us to better understand other people, and is therefore vital for successful social interactions. Difficulties in emotion recognition have been associated with social function impairment, including poor interpersonal relationships (Carton, Kessler, & Pape, 1999), increased psychopathology (Keltner & Kring, 1998), and decreased social competence (Shimokawa et al., 2001), factors that have an adverse affect on overall life satisfaction (Berg, Hassing, McClearn, & Johansson, 2006; Miller & Chan, 2008). Successful social interactions are particularly important for older adults, as loneliness and social isolation have negative implications for both physical and cognitive health (Cacioppo & Hawkley, 2009; Hawthorne, 2008; Wilson et al., 2007). Therefore, it is important for us to understand how emotion processing changes as a function of age.

It has been argued that aspects of emotion processing, such as emotion regulation, remain intact or are even enhanced in later life (Mather & Carstensen, 2005). In contrast, research examining the ability to recognize and identify emotions as a function of normal aging has demonstrated that, in general, emotion perception ability declines with increasing age (e.g., Moreno, Borod, Welkowitz, & Alpert, 1993), although there may be a differential change in emotion perception according to emotion type (e.g., happiness, sadness, anger, fear, disgust, or surprise), with the perception of some emotions declining with age and the perception of other emotions remaining relatively stable across the life span (e.g., Allen & Brosgole, 1993; Calder et al., 2003; Malatesta, Izard, Culver, & Nicolich, 1987; Schaffer, Wisniewski, Dahdah, & Froming, 2009). These findings are in line with research proposing that the recognition of discrete emotions is modulated by separate neural substrates (e.g., amygdala associated with fear, and the insula and basal ganglia associated with disgust), each substrate with its own age-related changes.

Although these studies of discrete emotions provide interesting results, very few measure emotion perception in multiple channels of communication, such as the facial, prosodic/intonational, or lexical (i.e., language content) channels (cf. Brosgole & Weisman, 1995; Ruffman, Sullivan, & Dittrich, 2009; Schaffer et al., 2009). Furthermore, previous research is often restricted to individuals under the age of 70 and has not included members of the “oldest-old,” a group which includes individuals aged 85 and older (Blazer, 2000). Given the extensive age-related changes in the brain occurring in late life, it would be interesting and relevant to examine the pattern of change in individuals in the 9th decade of life.

Therefore, in an effort to extend previous work, the current project systematically examined changes in the perception of discrete emotions across facial, prosodic/intonational, and lexical channels in individuals between the ages of 20 and 89. A total of 117 healthy, right-handed adults between the ages of 20-89 completed the identification and discrimination tasks from the New York Emotion Battery (NYEB; Borod et al., 1992b; Borod, Tabert, Santschi, & Strauss, 2000), a comprehensive battery of tests examining the perception, expression, and experience of emotion across three channels of communication (i.e., facial, prosodic/intonational, and lexical channels). The primary aim of the project was to characterize age-related changes in discrete emotions as a function of age. It was hypothesized that accuracy in the perception of discrete emotions in each channel would show a differential pattern of change with age, paralleling age-related changes that have been observed in the structure and function of the brain.

Literature Review

Emotion processing. Broadly speaking, emotion processing can be defined as a biologically based state comprising multiple components, including expression, perception, cognitive appraisal, subjective experience, physiological arousal, and goal-directed activity (Borod, 1993; Plutchik, 1984). Much of the previous research examining age-related changes in emotion processing has focused on the experience of emotion and the role of cognitive appraisal in emotion regulation (e.g., Mather & Carstensen, 2005; Ochsner & Gross, 2005). However, for

the purpose of this review and the current project, the focus was primarily upon emotion perception, which can be defined as the “processing, appreciation, or comprehension of the emotional aspect of a stimulus” (Borod, 1992, p. 340). Emotions are perceived via several different communication channels, including (but not limited to) the facial, prosodic (i.e., vocal intonation), and lexical (i.e., speech content) channels (Borod, 1992).

At the most basic level, emotion can be subdivided into discrete emotions (e.g., happiness, sadness, anger, fear, surprise, and disgust) and dimensions (e.g., valence). There is widespread evidence indicating that a number of discrete emotions are perceived and expressed in a similar fashion throughout the world (e.g., Ekman, 1992, 1994; Ekman, Sorenson, & Friesen, 1969; Elfenbein & Ambady, 2002; Galati, Scherer, & Ricci-Bitti, 1997; Izard, 1994; Sauter, Eisner, Ekman, & Scott, 2010; cf. Naab & Russell, 2007; Russell, 1994). Accordingly, these emotions have been described as “basic” or fundamental emotions. The specific emotions attributed to this list varies (Ortony & Turner, 1990), but most researchers seem to agree that basic emotions include fear, anger, sadness, disgust, happiness, and surprise, as these are the emotions that are readily identified in other cultures. An argument has also been made for the inclusion of contempt (Izard, 1977b; Tomkins, 1984) and interest (Izard, 1971), although these additions are more controversial. Basic emotions have been identified by both literate and non-literate cultures (Ekman et al., 1969; Sauter et al., 2010) in both the facial (Ekman et al., 1969; Elfenbein & Ambady, 2002) and prosodic (Pell, Monetta, Paulmann, & Kotz, 2009; Sauter et al., 2010; Scherer, Banse, & Wallbott, 2001) channels.

Cues to decoding discrete emotions. Ekman (1992) has argued that an important characteristic of basic emotions is that they each have distinctive universal signals. Unless emotions can be recognized consistently from their associated expressions, they would not serve any adaptive value as a communication device (Ekman, 1992). Consequently, a considerable body of research has explored the cues used to express and perceive emotions. The following section will provide a brief overview of this literature, including research involving facial, prosodic, or lexical channels.

Facial channel. In an effort to understand the cues that signal discrete emotions in the facial channel, a number of techniques have been developed for the quantification of discrete movement changes associated with emotion expressions in the face. Two of the most well known techniques are the Maximally Discriminative Movement Coding System (MAX; Izard, 1983) and the Facial Action Coding System (FACS; Ekman, 1980; Ekman & Friesen, 1977). In order to create these objective, quantifiable systems, facial expressions are broken down into discrete movement changes, which are each anatomically separable and visually distinguishable. These action units work in combination to create recognizable facial expressions. Each emotion is represented by a distinct combination of facial musculature. This research greatly increased our knowledge of how facial expressions are produced and provided solid evidence for the existence of basic universal expressions.

Interesting work investigating the cues to discrete emotions has also examined how we *perceive* facial expressions (e.g., Aviezer et al., 2008; Calder, Young, Keane, & Dean, 2000b). For instance, Calder and colleagues (2000b) have demonstrated that some emotions are recognized more accurately from information in the bottom half of the face (i.e., mouth region), whereas other emotions are more readily recognizable from information in the top half (i.e., eyes region). Specifically, participants were shown pictures of facial expressions that had been divided into top and bottom segments, and participants' accuracy rates and reaction times for identifying the emotion expressed were compared. Results of this study demonstrated that anger, fear, and sadness were more recognizable from the top half of the face and that happiness and disgust were more recognizable from the bottom half. Surprise was recognized equally well from the top and bottom half (Calder et al., 2000b).

Prosodic channel. The vocal channel is also rich in information, as demonstrated by the abundance of research examining the vocal communication of emotion. This research suggests that physiological changes associated with the experience of emotion affect respiration, articulation, and phonation in ways that produce perceivable prosodic cues (Scherer, 1986). The cues that appear to be most helpful for identifying emotions are measures of fundamental

frequency (perceived as pitch), intensity or loudness, timbre (measures of phonation and articulation), and time-related measures, such as speech rate, pausing, and phrase-duration (Johnstone & Scherer, 2000; Juslin & Laukka, 2001; Scherer, 1986).

Accuracy rates for recognizing emotion from prosody are consistently found to be significantly higher than chance, ranging from 55-65% correct (Banse & Scherer, 1996; Johnstone & Scherer, 2000; Juslin & Laukka, 2001). These accuracy rates have led researchers to argue that acoustic cues combine to form relatively distinct patterns that enable the differentiation of discrete emotions – an auditory equivalent for action units in facial expressions (for reviews, see Banse & Scherer, 1996; Belin, Fecteau, & Bédard, 2004; Pittam & Scherer, 1993). Scientists have been somewhat successful in identifying these patterns. For example, *happiness* is characterized by higher and more variable pitch (fundamental frequency), increased volume (intensity), and accelerated speech rate for more intensely felt emotion (Johnstone & Scherer, 2000). In contrast, *sadness* is characterized by lower and less variable pitch (cf. Banse & Scherer, 1996 [increased FO range]), as well as decreased intensity (Johnstone & Scherer, 2000). Findings concerning speech rate in sadness are inconsistent, which may be due to the varied potency of the emotion expressed (Banse & Scherer, 1996; Pittam & Scherer, 1993; Scherer, 1986). However, there remains considerable overlap between the cues used for many emotions. For instance, like happiness, *anger* and *fear* are generally characterized by higher and more variable pitch, increased volume, and accelerated speech rate, which leaves researchers perplexed that they have been unable to pinpoint more discriminating acoustic profiles (Banse & Scherer, 1996). Some have suggested that this may be because there have not been enough vocal cues studied (Juslin & Laukka, 2001; Pittam & Scherer, 1993), whereas others argue that accuracy rates are impeded by the labeling system for emotions (Scherer, 1986).

Lexical channel. In contrast to the facial and prosodic channels, psychologists have studied very little about the cues for decoding discrete emotions in the lexical channel, although computer scientists and linguists have analyzed rules for emotional language and created

complex lexicons of emotional words. One estimate suggests that there are at least 2,000 words for emotion in the English language (Wallace, 1973). However, many of these words represent the same larger category of basic emotions. For instance, rage, fury, and wrath are all words used to describe feelings of anger. Existing research examining how these words are categorized as discrete emotions has pointed towards arousal, frequency, and valence as important contributors to the perception of emotional verbal content (Nakic, Smith, Busis, Vythilingam, & Blair, 2006; Scott, O'Donnell, Leuthold, & Sereno, 2009).

Individual differences in emotion perception. Research investigating individual differences in emotion perception has identified various demographic characteristics that are associated with the ability to identify emotional stimuli. In particular, there is evidence that demographic variables, such as sex and ethnicity, can affect the ability to recognize emotions. This research will be briefly reviewed below.

Sex. Sex differences in emotion perception are commonly reported. Women are generally reported to perform better on emotion perception tasks than are men (Campbell et al., 2002; Hall, 1978; Hampson, van Anders, & Mullin, 2006; Montagne, Kessels, Frigerio, de Haan, & Perrett, 2005; Scholten, Aleman, Montagne, & Kahn, 2005; Thayer & Johnsen, 2000), although some studies have not found any sex differences (Rahman, Wilson, & Abrahams, 2004). Most of this research has been conducted in the facial channel, although there is evidence to suggest that sex differences are also found in the prosodic (Hall, 1978) and lexical (Grunwald et al., 1999) channels.

Some studies suggest that the female advantage is particularly prevalent for the recognition of negative emotions, such as fear, sadness, anger, and disgust (Campbell et al., 2002; Montagne et al., 2005; Scholten et al., 2005). However, the only positive emotion assessed in these studies was happiness, and ceiling effects were prevalent. Furthermore, research examining sex differences in discrete emotions has been limited to the facial channel, and, therefore, it is not clear whether or not emotion-dependent differences are observed across

multiple channels of communication. Clearly, further research is needed to more fully characterize sex differences in discrete emotions.

Ethnicity. In addition to research indicating sex differences in emotion perception, there is also evidence suggesting that ethnicity may influence emotion perception accuracy. Specifically, support from both the facial and prosodic channels indicates that emotions are recognized more accurately when the expresser and the perceiver are members of the same cultural, ethnic, and/or national group, a finding that has become known as the “in-group advantage” (Elfenbein & Ambady, 2002; Markham & Wang, 1996; Scherer et al., 2001; Wickline, Bailey, & Nowicki, 2009; cf. Beaupré & Hess, 2005).

There are a number of potential reasons why individuals might be more accurate at recognizing emotions expressed by members of their own cultural, racial, or ethnic group. One explanation is that individuals are able to use more efficient modes of processing when judging emotion expressions of in-group members, due to factors such as familiarity with facial morphology and increased motivation to decode expressions by in-group members (Wickline et al., 2009). This theory relates to the “own-race bias,” the observation that people tend to recognize and remember faces of their own race more accurately than faces of other races (Malpass & Kravitz, 1969; Meissner & Brigham, 2001).

An alternative hypothesis, called the *dialect theory of emotion recognition*, suggests that subtle differences exist in cultural representations of nonverbal emotional cues, and that these differences are learned, similar to an accent or dialect of language (Elfenbein & Ambady, 2002, 2003; Elfenbein, Beaupré, Levesque, & Hess, 2007). This hypothesis predicts that greater discrepancies in emotion recognition will exist when the expresser and the perceiver are from culturally dissimilar groups. Furthermore, as emotional “dialects” can be learned, it would also predict that exposure to a dissimilar culture should improve an individual’s ability to recognize the emotions of a member of that cultural group. Supporting this theory is research showing a positive correlation between the amount of time spent in a new country and performance on emotion recognition tasks (Wickline, 2006).

Neural systems for emotion perception. Over the past 20 years, a growing body of lesion and neuroimaging studies has begun the complex task of characterizing the brain circuitry that mediates emotion communication (for reviews, see Adolphs, 2002a, 2002b; Davidson & Irwin, 1999; Tamietto & de Gelder, 2010). The following section will provide a brief overview of this literature, including a discussion of the key structures implicated in emotion perception in the facial, prosodic, and lexical channels, as well as a review of hemispheric asymmetry for emotion perception.

Neural basis for recognizing emotion from faces. Perhaps more than any other channel of communication, the face provides a wealth of social and emotional information (e.g., Borod, Koff, Lorch, & Nicholas, 1985). Therefore, it is not surprising that the brain has developed a highly complex, specialized network for viewing, recognizing, and interpreting facial expressions of emotion (Haxby, Hoffman, & Gobbini, 2000). Research suggests that aspects of this network, including knowledge of the structure of the face, may be in place at birth (Morton & Johnson, 1991) and that the network continues to develop into a specialized system through continued exposure to faces (Leppanen & Nelson, 2009; Nelson, 2001). This specialized network consists of a number of structures, including the fusiform gyrus, the superior temporal sulcus, the amygdala, the prefrontal cortex, and areas related to components of the somatosensory cortices (for reviews, see Adolphs, 2002a; Haxby et al., 2000; Tamietto & de Gelder, 2010). Salient contributions of each of these structures are reviewed below.

It has been suggested that localized subregions of the *fusiform gyrus* are selectively engaged during face perception (Grill-Spector, Sayres, & Ress, 2006; Kanwisher & Yovel, 2006), particularly the right middle region of the gyrus (Rossion et al., 2003). This area has been coined the “fusiform face area,” although other investigators have suggested that the region is not limited to face perception, but rather responds when discriminating among members of categories that we have expertise in viewing (e.g., bird watchers discriminating among birds; Gauthier, Skudlarski, Gore, & Anderson, 2000). Neuroimaging research has implicated the

fusiform gyrus in more static or invariant aspects of facial structure that code facial identity (e.g., Barton, Press, Keenan, & O'Connor, 2002; Haxby et al., 2000; Rossion et al., 2003).

The *superior temporal sulcus* (STS) has been posited as another key structure for face perception (Haxby et al., 2000; Hoffman & Haxby, 2000; Turk-Browne, Norman-Haignere, & McCarthy, 2010). While the fusiform face area has been associated with static or invariant aspects of the face, the STS appears to be involved in the perception of changeable or dynamic aspects of faces (Haxby et al., 2000; Hoffman & Haxby, 2000), including the direction of eye gaze (Pelphrey, Viola, & McCarthy, 2004) and mouth movements (Puce, Allison, Bentin, Gore, & McCarthy, 1998), that can be used in inferring someone's emotional state. The STS is well situated to participate in the emotional neural network: It receives input from the inferior occipital gyri (Haxby et al., 2000) and has reciprocal connections with the amygdala, another critical structure for emotional communication (Allison, Puce, & McCarthy, 2000).

In addition, a large body of animal and discrete lesion studies highlights the ubiquitous and complex role of the *amygdala* in emotion processing (for reviews, see Adolphs, 2002a, 2002b; Calder, Lawrence, & Young, 2001). These observations are not surprising, given the structure's widespread connections throughout the brain, including connections with cortical sensory regions (visual, auditory, somatosensory, gustatory, and olfactory), thalamus, hippocampus, hypothalamus, anterior cingulate and orbitofrontal cortex (LeDoux, 2000, 2007). Observations from human lesion studies have demonstrated that individuals with bilateral amygdala damage have impairments in recognizing negative emotions (particularly fear), despite intact face perception (Adolphs, Tranel, Damasio, & Damasio, 1995; Adolphs et al., 1999; Calder et al., 1996; Schmolck & Squire, 2001; Scott et al., 1997). Individuals with unilateral lesions also experience impairments, although to a lesser extent than those with bilateral lesions (Adolphs, Tranel, & Damasio, 2001; Anderson, Spencer, Fulbright, & Phelps, 2000). These observations are corroborated by results of neuroimaging studies, which show that the amygdala is activated in response to viewing faces with fearful expressions (Morris et al., 1998).

These studies, which suggest a disproportionate amygdalar response to negative stimuli, have led researchers to conclude that the amygdala is principally involved in threat detection. However, subsequent research indicates that the amygdala also responds to some, but not all, facial expressions of happiness (e.g., Juruena et al., 2010; Somerville, Kim, Johnstone, Alexander, & Whalen, 2004), which has led researchers to suggest that the amygdala may play a more general role in recognizing emotion regardless of valence (Breiter et al., 1996; Costafreda, Brammer, David, & Fu, 2008; Sergerie, Chochol, & Armony, 2008). Based on this evidence, it has been argued that the amygdala is involved with the perceptual coding of emotionally significant events (Anderson & Phelps, 2001).

The amygdala is also activated in response to masked (i.e., non-conscious) emotional stimuli (Juruena et al., 2010; Whalen et al., 1998) and in response to facial expressions in individuals with blindsight (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999; Morris, de Gelder, Weiskrantz, & Dolan, 2001), suggesting that the amygdala may also play a role in the initial, rapid perceptual processing of emotional stimuli. This processing likely takes place via a subcortical pathway, including the superior colliculus and the pulvinar, which receives input directly from the retina (Costafreda et al., 2008; Tamietto & de Gelder, 2010; Vuilleumier, 2005), enabling a quick visual analysis.

Furthermore, Adolphs (2002a) has noted that activation of the amygdala in response to facial expressions appears to depend on whether the stimuli are passively or actively viewed: *Passive* viewing of stimuli results in increased activation in the amygdala, whereas *active* viewing (i.e., tasks requiring the participant to label emotions) results in decreased activation. Adolphs (2002a) attributes these contradictory findings to the amygdala's inhibition by the frontal cortex during active viewing tasks.

Another region involved in emotion processing is the *orbitofrontal cortex* (OFC). The OFC is perhaps best known for its role in cognitive appraisal (Ochsner & Gross, 2005) and emotion regulation (for a review, see Davidson, Putnam, & Larson, 2000). The OFC has direct connections to the amygdala and appears to be involved in inhibiting physiological responses

elicited by amygdala stimulation (Phillips, Drevets, Rauch, & Lane, 2003). However, evidence suggests that this region may also play a role in the recognition of emotion, particularly for highly arousing emotions such as fear and anger (Adolphs, 2002b). For instance, damage to the OFC can cause impairments in the recognition of emotion from facial expressions (Hornak, Rolls, & Wade, 1996), as can transient interruptions to the region from transcranial magnetic stimulation (TMS; Harmer, Thilo, Rothwell, & Goodwin, 2001). PET studies analyzing activation during emotion recognition tasks also show increased activity in the OFC, which corroborates observations from lesion studies. Finally, indirect evidence for the involvement of the OFC in emotion recognition comes from studies that demonstrate impaired emotion recognition in individuals with frontal variant frontotemporal dementia (Keane, Calder, Hodges, & Young, 2002; Lavenex, Pasquier, Lebert, Petit, & der Linden, 1999). Contrary to the amygdala, which is often activated in passive viewing paradigms, the OFC may be activated in cognitive tasks requiring the explicit identification of emotion (Adolphs, 2002a; Nakamura et al., 1999).

In addition to the structures outlined above, evidence suggests that the network involved in emotion recognition includes portions of the right *parietal lobe* that process somatosensory information, including the right somatosensory cortex, right insula, and the anterior supramarginal gyrus. Using three-dimensional lesion mapping, Adolphs and colleagues (2000) demonstrated that damage to these regions resulted in impaired facial emotion recognition. These same regions of the parietal lobe have been implicated in the mirror neuron system (Rizzolatti, Fogassi, & Gallese, 2001; Singer et al., 2004), suggesting that the recognition of emotion may rely on internal simulations of an emotional expression. In other words, in order to understand what another person is feeling, we may need to simulate the emotion expression ourselves, in order to literally feel what they are feeling (Adolphs, 2003). The parietal lobe appears to be particularly important for processing noxious and unpleasant stimuli (Benuzzi, Lui, Duzzi, Nichelli, & Porro, 2008), including expressions of disgust (Murphy, Nimmo-Smith, & Lawrence, 2003; Phillips et al., 1998; Phillips et al., 1997; Wicker et al., 2003).

Neural basis for recognizing emotion from prosody. Although the voice is one of the primary channels of emotion communication, vocal expressions of emotion have not received as much attention from social neuroscientists as have facial expressions. Nevertheless, recent neuroimaging studies have begun to delineate a complex distributed network devoted to the recognition of emotion in the prosodic channel. Schirmer and Kotz (2006) have proposed a model for vocal emotional comprehension that includes several sub-processes that are each differentially represented in the brain. They propose that emotion recognition begins bilaterally in the primary auditory cortex and superior temporal gyrus, where relevant acoustic features, such as frequency and amplitude, are encoded. The emotional features of the vocal stimuli are integrated at the level of the right superior temporal sulcus before advancing to cortical areas, including the right prefrontal cortex, where the information is evaluated for meaning and goal relevance (Schirmer & Kotz, 2006).

This basic model has received some support in the literature: Neuroimaging studies using PET and fMRI to measure activation in response to affective speech stimuli generally show activation in the right temporal lobe and the right inferior prefrontal cortex (Buchanan et al., 2000; Ethofer et al., 2009; George et al., 1996; Grandjean et al., 2005; Morris, Scott, & Dolan, 1999). Yet, evidence from other neuroimaging studies suggest that neural processing of vocal information may have a more complex, distributed network, which includes structures such as the amygdala and parietal lobe (Morris et al., 1999; Wildgruber, Pihan, Ackermann, Erb, & Grodd, 2002). Additional research is needed within this modality to better delineate the neural networks involved.

Neural basis for recognizing emotion from the lexical channel. As with the facial and prosodic channels, recognition of lexical content, such as emotional words and sentences, is associated with widely distributed activations. Processing of lexical content appears to be associated with activations in the bilateral inferior frontal gyrus (Nakic et al., 2006; Price, 2000), amygdala (Maddock, Garrett, & Buonocore, 2003; Nakic et al., 2006; Tabert et al., 2001), and the posterior cingulate gyrus (Kuchinke et al., 2005; Maddock et al., 2003). The

basal ganglia and insula may also be implicated, although this finding is not as well supported (Lewis, Critchley, Rotshtein, & Dolan, 2007). It is not clear whether the network for processing lexical verbal content is distinct from networks devoted to processing emotional stimuli in other channels of communication.

Hemispheric asymmetry in emotion perception. Investigators have argued that the right hemisphere plays a critically important role in emotional processing in right-handed individuals, regardless of valence (Borod, Koff, & Caron, 1983; Bryden & Ley, 1983; Buck, 1984; for a review, see Savage, Borod, & Ramig, 2011). Although it is not entirely clear why the right hemisphere might be dominant for emotion, Borod and colleagues (Borod, 1992, 1996; Borod, Bloom, & Santschi-Haywood, 1998a) have suggested that the neuroanatomical structure of the right hemisphere makes it better suited than the left hemisphere for handling the multimodal integration necessary for emotional processing (Borod, 1996; Goldberg & Costa, 1981; Semmes, 1968). Specifically, according to Borod and colleagues (e.g., Borod et al., 1998a), as compared to the left hemisphere, the right hemisphere has more widespread interlobular organization (Egelko et al., 1988), greater neural interconnectivity among regions (Gur et al., 1980; Thatcher, Krause, & Hrybyk, 1986; Tucker, Roth, & Bair, 1986), more overlapping axonal interconnectivity (Woodward, 1988), and more horizontal axonal connectivity (Springer & Deutsch, 1981; Woodward, 1988). Furthermore, the right hemisphere is thought to control functions such as pattern perception, visuospatial organization, and visual imagery processing, which are necessary for the perception of emotion (Borod, 1992).

Facial channel. In the facial channel, support for the right-hemisphere hypothesis can be garnered from studies of individuals with unilateral brain damage (for reviews of this literature, see Borod, 1992; Borod, Bloom, Brickman, Nakhutina, & Curko, 2002; Borod et al., 1998b; Demaree, Everhart, Youngstrom, & Harrison, 2005; Savage et al., 2011), from studies of individuals who have undergone a corpus callosotomy to sever the corpus collosum (i.e., "split-brain" patients; Benowitz, 1983; cf. Stone, Nisenson, Eliassen, & Gazzaniga, 1996) and from studies conducted while individuals were undergoing the intracarotid sodium amytal procedure,

often referred to as the Wada Test (Ahern et al., 1991; Wada & Rasmussen, 1960). Research investigating the laterality of facial perception has also been extended to healthy controls, using paradigms such as tachistoscopic viewing (e.g., Landis, Assal, & Perret, 1979; Ley & Bryden, 1979; McKeever & Dixon, 1981; Suberi & McKeever, 1977) and free-field viewing tasks such as the presentation of “chimeric” faces (e.g., Christman & Hackworth, 1993; Luh, Rueckert, & Levy, 1991; Moreno, Borod, Welkowitz, & Alpert, 1990). Studies using these paradigms have generally shown that individuals discriminate among emotional expressions more accurately when the information is presented in the left visual field than when the information is presented to the right visual field. As the right hemisphere predominantly processes stimuli viewed in the left visual field, these findings provide support for the right-hemisphere hypothesis.

Contrary to the many findings from behavioral studies, evidence for the right hemisphere hypothesis from functional imaging studies has been equivocal. Some studies using evoked response potentials (ERP) have shown greater right hemisphere activity during the processing of facial emotion, as compared to activity in the left hemisphere (Kestenbaum & Nelson, 1992; Laurian, Bader, Lanares, & Oros, 1991; Vanderploeg, Brown, & Marsh, 1987). Similar results have been reported in some studies using functional magnetic resonance imaging (fMRI), with some studies reporting greater activation in regions of the right hemisphere when processing facial emotion stimuli, as compared to non-emotional facial stimuli (e.g., Narumoto, Okada, Sadato, Fukui, & Yonekura, 2001; Sato & Aoki, 2006). However, results from recent meta-analyses on the functional neuroanatomy of emotion failed to find support for the right-hemisphere hypothesis (Murphy et al., 2003; Wager, Phan, Liberzon, & Taylor, 2003). Taken together, results from the behavioral and neuroimaging studies suggest that while the right hemisphere may be necessary for engaging in emotion recognition, it is not sufficient for these processes (Savage et al., 2011).

Prosodic channel. Traditionally, the left hemisphere has been associated with language functions. However, evidence from lesion studies has suggested that the right hemisphere may also be involved with some aspects of language, particularly in the mediation of emotional

language. Patients with right hemisphere damage (RHD) show impairment in the perception of prosody as compared to left hemisphere damage (LHD) participants or normal controls (for reviews, see Borod et al., 2002; Demaree et al., 2005; Snow, 2000). This work has been further substantiated by studies using the dichotic listening paradigm, which have shown a left ear (i.e., right hemisphere) advantage in the perception and interpretation of emotional utterances (e.g., Borod, Zgaljardic, Tabert, & Koff, 2001; Erhan, Borod, Tenke, & Bruder, 1998; Rodway & Schepman, 2007). Finally, support for the right hemisphere hypothesis can be found from functional neuroimaging studies in the prosodic channel (e.g., George et al., 1996; Pihan, Altenmüller, & Ackermann, 1997; Wildgruber et al., 2002).

Lexical channel. Relatively little attention has been given to the lexical channel, as compared to the facial and prosodic channels. However, existing studies do provide some indication of a right-hemisphere bias in the processing of emotional language. Patients with RHD are generally impaired on tasks requiring the identification of lexical emotional stimuli as compared to patients with LHD or healthy controls (Borod, Andelman, Obler, Tweedy, & Welkowitz, 1992a; Borod et al., 1998b; Cicero et al., 1999; Zgaljardic, Borod, & Sliwinski, 2002).

Are there separate systems for recognizing discrete emotions? While the information reviewed above implies a unified system for the perception of emotion, there is accumulating evidence that the perception of each discrete emotion may be modulated by a dissociable neural system, although aspects of those systems may overlap to some extent (e.g., Adolphs, Damasio, Tranel, & Damasio, 1996). The strongest evidence supporting this point comes from studies demonstrating the disproportional involvement of the amygdala in processing facial expressions of *fear* (Calder et al., 2001). Involvement of the amygdala has been demonstrated in studies of fear conditioning in animals (for a review, see Phelps & LeDoux, 2005). In humans, Adolphs and colleagues initially demonstrated impairment of fear recognition secondary to bilateral lesions of the amygdala with patient S.M. (Adolphs, Tranel, Damasio, & Damasio, 1994), and subsequent lesion studies have replicated their finding (Adolphs et al., 1995; Adolphs et al., 1999; Calder et al., 1996; Schmolck & Squire, 2001; Scott et

al., 1997). Furthermore, fMRI and PET studies have demonstrated that the amygdala is preferentially activated during tasks in which healthy volunteers view facial expressions of fear (Breiter et al., 1996; Murphy et al., 2003; Phillips et al., 1998; Whalen et al., 2001), even when the stimuli are not consciously perceived (i.e., masked; Phillips et al., 2004; Whalen et al., 1998).

The only other emotion for which there is strong evidence of a distinct network is *disgust* (Calder et al., 2001; Phillips et al., 1998; Phillips et al., 1997). Specifically, functional imaging studies point towards the involvement of the anterior insula and the basal ganglia in the recognition of disgust from facial expressions (Murphy et al., 2003; Phillips et al., 1998; Phillips et al., 1997; Wicker et al., 2003), vocal cues (Phillips et al., 1998), and odors (Wicker et al., 2003). These findings parallel observations of impaired recognition of disgust in Huntington's disease (Kipps, Duggins, McCusker, & Calder, 2007; Sprengelmeyer et al., 1996; Wang, Hoosain, Yang, Meng, & Wang, 2003), Wilson's disease (Wang et al., 2003), and Parkinson's disease (Suzuki, Hoshino, Shigemasu, & Kawamura, 2006), three neurological disorders associated with pathological changes in the basal ganglia. Furthermore, a selective impairment in disgust recognition was also found in cases of pre-clinical Huntington's disease (Gray, Young, Barker, Curtis, & Gibson, 1997; Hennenlotter et al., 2004). Finally, further evidence comes from case studies showing selective impairment in the recognition of disgust secondary to lesions in the putamen, globus pallidus, and anterior insula (Adolphs, Tranel, & Damasio, 2003; Calder, Keane, Manes, Antoun, & Young, 2000a).

Comparatively less research has investigated the neural response to *anger*. A recent meta-analysis of PET and fMRI studies of human emotion indicated that tasks involving the recognition of anger were most associated with activity in the OFC, suggesting that this region may be specialized for the processing of anger (Murphy et al., 2003). This finding should be interpreted with caution, given the small number of studies contributing to the analysis ($n = 5$). However, as the authors of the meta-analysis point out, a specific role for the OFC in anger is

consistent with case studies demonstrating an association between focal lateral OFC lesions and aggression (Blair & Cipolotti, 2000; Brower & Price, 2001), which makes the results of the meta-analysis stronger.

It is less clear whether other emotions, such as *sadness* or *happiness*,¹ show a similar degree of neural segregation. The amygdala may play a role in processing both sadness (Blair, Morris, Frith, Perrett, & Dolan, 1999; Schmolck & Squire, 2001) and happiness (Juruena et al., 2010; Somerville et al., 2004). However, results of the aforementioned meta-analysis did not indicate the presence of a distinct neural network for these emotions (Murphy et al., 2003). Once again, relatively few studies contributed to the analyses for these emotions (sadness: $n = 3$; happiness: $n = 6$) and, therefore, further research is needed before definitive statements regarding the neural circuitry of these emotions can be made.

The aging brain. The focus of the proposed project is on understanding age-related changes in emotion processing, but it may be helpful to understand these changes within the broader context of cognitive aging. Therefore, the next section will present a review of relevant findings in aging literature, with a brief overview of age-related changes in cognition and the brain, as well as a discussion of cognitive neuropsychological models of aging. Subsequent sections will take an in-depth look at age-related changes in emotion processing.

Age-related cognitive changes. A wealth of neuropsychological literature has been devoted to characterizing changes in cognition that occur with age (Glisky, 2007; Schaie & Willis, 2011). Overall, research has demonstrated a general pattern of age-related decline in many areas of cognition beginning in early adulthood (Salthouse, 2004), although there is a

¹ Neuroscientists have begun the process of identifying the neuroanatomy of happiness, but work in this area is still in the early stages. At the current time, the only evidence for the neural underpinnings of happiness is indirect, coming from studies of pleasure, reward, and addiction (for a review, see Kringelbach & Berridge, 2009). Furthermore, to our knowledge, there is no research investigating the neural mechanisms of the *perception* of happiness. Therefore, research on the brain regions involved in the emotion of happiness is not included in the discussion of dissociable networks for discrete emotions.

considerable amount of variability among individuals regarding the extent of the decline (Lindenberger & von Oertzen, 2006). Common observations with age include slowed reaction times (e.g., Verhaeghen & Salthouse, 1997), difficulty learning new information (e.g., Grady & Craik, 2000), decreased working memory capacity (e.g., Bopp & Verhaeghen, 2005; Light & Anderson, 1985), susceptibility to distraction (e.g., Healey, Campbell, & Hasher, 2008), and reduced inhibitory control (e.g., Hasher, Zacks, & May, 1999; Lustig, Hasher, & Zacks, 2007). Visual and auditory perception also decline with age due to physiological changes in both primary sensory pathways and higher order processes (e.g., Clinard, Tremblay, & Krishnan, 2010; Faubert, 2002). Despite evidence of pervasive cognitive decline with age, a few areas of cognition appear to be largely protected from age. For instance, implicit memory and semantic memory remain relatively stable in normal aging (e.g., Glisky, 2007; Isingrini, Vazou, & Leroy, 1995), as well as aspects of verbal ability (e.g., vocabulary [e.g., Verhaeghen, 2003]).

Brain correlates of aging. Given the widespread cognitive changes observed in aging, it is not surprising that age-related changes are also observed in brain structure and function.

Structural changes. Research has demonstrated widespread structural changes in the brain as a function of age (Good et al., 2001; Raz et al., 1997; for a review, see Raz & Rodrigue, 2006). Evidence from post-mortem (Miller, Alston, & Corsellis, 1980) and *in vivo* studies (Brickman et al., 2008; Courchesne et al., 2000; Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003) indicates age-related reductions in brain weight and cerebral volume. Further, age-dependent increases are also observed in the relative volume of cerebrospinal fluid and the volume of the cerebral ventricles (Brickman et al., 2008; LeMay, 1984; Raz, 2000).

Despite these seemingly global changes, age-associated atrophy does not seem to occur in a uniform manner, which suggests that some cortical regions are more vulnerable to the

effects of aging than are others.² *In vivo* neuroimaging analyses suggest that the impact of aging is greatest in the prefrontal cortex (Jernigan et al., 2001; Raz et al., 1997; West, 1996), particularly in the lateral and orbital regions (Tisserand et al., 2002). Accelerated age-related atrophy is also observed in the parietal lobe and, to a somewhat lesser extent, the temporal lobe (Good et al., 2001; Grieve, Clark, Williams, Peduto, & Gordon, 2005; Raz, 2000; Resnick et al., 2003). In contrast, longitudinal and cross-sectional studies suggest that areas such as the primary visual and primary somatosensory cortices are largely spared from the negative impact of aging (Grieve et al., 2005; Raz, 2000; Raz et al., 1997; Resnick et al., 2003).

Studies examining patterns of brain change in subcortical areas remain equivocal; Overall, regions of the limbic system, including the hippocampus and amygdala, appear to be relatively unaffected by age, declining only at a moderate rate, if at all (Good et al., 2001; Grieve et al., 2005; Raz et al., 1997; Sullivan, Marsh, Mathalon, Lim, & Pfefferbaum, 1994; Zimmerman et al., 2006), although some studies have noted significant atrophy in the hippocampus (Allen, Bruss, Brown, & Damasio, 2005; Jernigan et al., 2001). It is also unclear whether or not the basal ganglia demonstrate age-related losses, with some studies indicating little age-related change (Good et al., 2001; Raz et al., 1997) and others showing moderate decline (Grieve et al., 2005; Gunning-Dixon, Head, McQuain, Acker, & Raz, 1998).

White matter. As part of characterizing age-related structural changes in the brain, neuroimaging studies have focused more specifically on understanding the relationship between age and white matter (for a review, see Gunning-Dixon, Brickman, Cheng, & Alexopoulos, 2009). Research has demonstrated age-associated reductions in white, particularly in the prefrontal cortex (e.g., Raz et al., 2005; Salat, Kaye, & Janowsky, 1999), as well as an increase in

² It should be noted that, although relatively consistent patterns are observed, there is a tremendous amount of variability in terms of the magnitude of age-related changes reported among different brain regions. Some of this variation is likely due to methodological factors, such as the definition of the regions of interest and sampling differences (for a review, see Raz, 2005).

the number and severity of white matter hyperintensities (Brickman et al., 2008; Raz, 2000). Studies using diffusion tensor imaging (DTI) have confirmed that white matter is vulnerable to aging (Brickman et al., in press; Kochunov et al., 2012). Furthermore, research has indicated that age-related changes in white matter are associated with worsening cognitive performance on measures of memory and executive functioning (Brickman et al., in press; Brickman et al., 2006, 2009).

Although it is not clear whether age has a more significant impact on gray or white matter, neuroimaging studies have suggested a distinction between age-related changes in gray and white matter: Overall, gray matter volume decreases in a more or less linear fashion throughout the lifespan whereas white matter volume peaks around age 50 before a precipitous decline after around age 60 or 70 (Allen et al., 2005; Jernigan et al., 2001).

Dopamine functioning. Evidence for age-related changes in the structure of the brain are also found at the cellular level, particularly in the dopamine system (Raz et al., 1997). Studies indicate a decrease in the number of dopaminergic receptors (Volkow et al., 1996; Yang et al., 2003), transporters (Volkow, 1994), and presynaptic vesicles (Frey et al., 1996) with increasing age (for a review, see Kaasinen & Rinne, 2002). Research has also demonstrated an association between deficient dopaminergic modulation and cognitive deficits. For example, reduced D2 receptor density was associated with slower response times in older rats (MacRae, Spirduso, & Wilcox, 1988). In addition, work in older monkeys has shown that a D1 agonist, which facilitates dopaminergic modulation, reduces working memory deficits. Furthermore, work in humans has demonstrated that age-related decreases in D2 receptor binding are associated with cognitive deficits on tasks measuring executive functions (i.e., mental flexibility and response inhibition; Volkow et al., 1998), processing speed (Backman et al., 2000), and episodic memory (Backman et al., 2000).

Li and colleagues (2001) have proposed that naturally-occurring age-related loss of dopaminergic receptors may account for many of the cognitive deficits observed in normal aging. Specifically, they suggest that age-related changes in dopaminergic neuromodulation

lead to a decrease in the distinctiveness of neural representations of events and contexts, creating an excess of “neural noise.” Further, they argue that an increase in neural noise is responsible for age-related deficits in working memory, processing speed, and inhibition. Recent computational models simulating the effects of age-related attenuation of dopaminergic modulation (Li, Lindenberger, & Frensch, 2000; Li & Sikström, 2002) provide statistical support for the hypothesis.

Cognitive neuropsychological models of aging. With the advent of advanced neuropsychological and neuroimaging techniques, the focus of cognitive aging research has been extended to understanding the cause of age-related declines in cognitive functions. The following section will review relevant theories of cognitive aging, including behavioral approaches focusing on inefficient cognitive processes, as well as approaches focusing on age-related changes in brain structure.

Behavioral approaches to cognitive aging. Several researchers in the field of cognitive aging have focused on general cognitive indicators, such as working memory capacity, processing speed, inhibitory function, and sensory functions, which may mediate age-related variance in cognition. For instance, Salthouse has made a convincing argument that not only does the time needed to process information increase with age (Salthouse, 1992; Schaie, 1989), but that a large proportion of the age-related variation in cognition can be accounted for by measures of processing speed (Salthouse, 1994).

Along the same lines, Baltes and Lindenberger (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994) have proposed that measures of sensory functions may represent a basic indicator of neural integrity. This hypothesis, often referred to as the “common cause hypothesis,” stems from work demonstrating that the association between sensory acuity and performance on cognitive tests increases with age, and, in fact, sensory measures account for a large proportion of age-related variance in cognitive function (Baltes & Lindenberger, 1997; Dulay & Murphy, 2002; Lindenberger & Baltes, 1994). Robust correlations are also observed between cognition and an array of non-cognitive functions in old age, including balance

(Lindenberger & Baltes, 1994), respiratory functioning (Christensen, Mackinnon, Korten, & Jorm, 2001), grip strength (Christensen et al., 2001), and lower limb strength (Anstey, Lord, & Williams, 1997). Baltes and Lindenberger (1997) argue that the dedifferentiation, or enhanced correlation, between cognitive and non-cognitive processes in old age is a reflection of the deteriorating physiological integrity of the aging brain. As such, they propose the existence of an underlying “common factor” that simultaneously reduces performance in both cognitive and sensory functions.

Other researchers have focused on aspects of executive function that may account for age-related changes in cognitive function. For instance, it has been argued that decreases in working memory are the driving force behind age-related decrements in performance (Park et al., 2002; Park et al., 1996). Park and colleagues used structural equation models to show that working memory accounts for substantial age-related variance on tasks of cognition (Park et al., 1996). The authors conclude that working memory represents a fundamental mechanism that, along with processing speed, may mediate age-related variation in cognition.

Taking a different approach, Hasher and Zacks (1988) argue that declines in cognitive ability are rooted in age-related deficits in inhibitory functions, such as controlling the focus of attention, disregarding irrelevant information, and suppressing inappropriate responses (for a review, see Lustig et al., 2007). Specifically, older adults are unable to delete irrelevant information from working memory and, as a result, experience slowed processing speed and reduced working memory capacity. The authors provide a myriad of evidence from behavioral studies to support this view (Lustig et al., 2007; May, Hasher, & Kane, 1999; Rowe, Hasher, & Turcotte, 2010; Rowe, Valderrama, Hasher, & Lenartowicz, 2006). For example, Lustig and colleagues (2006) asked participants to determine whether letter strings were the same or different under conditions of high and low distraction. In the high distraction condition, 24 stimulus pairs were presented simultaneously, whereas in the low distraction condition, stimulus pairs were presented individually on the screen. Older adults completed the task more

quickly in the low distraction condition than in the high distraction condition, but no such benefit was observed in younger adults.

Frontal lobe hypothesis of aging. Rather than focusing on inefficiencies in cognitive processes, other researchers have turned to age-related changes in the structure of the brain as an approach to explaining cognitive decline in aging. A prominent theory that takes this approach is the frontal lobe hypothesis, which is centered on observations that the prefrontal cortex is particularly vulnerable to the adverse effects of aging (Dempster, 1992; Moscovitch & Winocur, 1992; West, 1996). As part of this theory, it is hypothesized that cognitive functions supported by the prefrontal cortex will be particularly vulnerable to the effects of age, declining at an earlier age and at a greater rate than functions supported by non-frontal regions. Evidence supporting this hypothesis comes from neuroimaging studies indicating both structural (e.g., Jernigan et al., 2001; Raz et al., 1997) and functional (e.g., Jonides et al., 2000; Langenecker & Nielson, 2003) changes in the frontal lobe with increasing age. Additional evidence comes from behavioral studies indicating decline in functions mediated by the frontal lobe such as inhibitory processes (e.g., Andrés, Guerrini, Phillips, & Perfect, 2008; Bedard et al., 2002), working memory (e.g., Van der Linden & Bredart, 1994; Vaughan, Basak, Hartman, & Verhaeghen, 2008), and source memory (e.g., Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991).

Despite this empirical support, the frontal lobe hypothesis has not been immune to criticism (Greenwood, 2000; Rabbitt, Lowe, & Shilling, 2001; for a review, see Band, Ridderinkhof, & Segalowitz, 2002). Critics argue that age-related changes are observed throughout the brain, including areas of the parietal and temporal lobe, and therefore, the frontal lobe hypothesis is too limited in scope (Greenwood, 2000). Others argue that the behavioral evidence supporting the hypothesis is methodologically flawed (Rabbitt et al., 2001). Specifically, Rabbitt and colleagues (2001) argue that some of the tests that measure the proposed frontal functions have questionable reliability and validity. Furthermore, the authors point toward relationships between test performance on frontal/executive tests and measures of

general mental ability (i.e., “g^f”), which call into question the construct validity of frontal measures.

Right hemi-aging hypothesis. Several key theories of cognitive aging have focused on age-related changes in the functional asymmetries of the brain. One such hypothesis, the right hemi-aging hypothesis (RHAH), suggests that the right hemisphere is more vulnerable to the effects of age than is the left hemisphere (Brown & Jaffe, 1975; Klisz, 1978; Schaie & Schaie, 1977; Shelton, Parsons, & Leber, 1982). Support for this hypothesis comes primarily from behavioral research (for reviews, see Daselaar & Cabeza, 2005; Dolcos, Rice, & Cabeza, 2002; Ellis & Oscar-Berman, 1989). Specifically, studies show that performance on some right-hemisphere mediated tasks (e.g., measures of visuospatial function) declines more with age than performance on left-hemisphere mediated tasks (e.g., verbal tasks; Goldstein & Shelly, 1981; Klisz, 1978). For example, Klisz (1978) tested the RHAH by comparing the performance of young and older adults on neuropsychological tests that correlated with brain damage in either the right or left hemisphere. Specifically, she re-analyzed normative data from the Halstead-Reitan battery (Reed & Reitan, 1963) and found that tests that were indicative of right-hemisphere impairment were more sensitive to age than those indicative of impairment of the left hemisphere. Additional support for the RHAH comes from the observation of differential decline on the verbal and performance subscales of the Wechsler Adult Intelligence Scale (WAIS; Schaie & Schaie, 1977) and on visual and verbal memory tasks (Tubi & Calev, 1989).

Despite this apparent support for the hypothesis, evidence for the RHAH in the perceptual and motor domains has been less conclusive. Whereas some dichotic listening (Clark & Knowles, 1973; Johnson et al., 1979) and tachistoscopic viewing (Cherry, Adamson, Duclos, & Hellige, 2005) studies provide evidence of accelerated decline in the right hemisphere, other studies in the perceptual and motor domain do not (Borod & Goodglass, 1980; Elias & Kinsbourne, 1974; Moreno et al., 1990; Nebes, Madden, & Berg, 1983), leading researchers to question the validity of the RHAH. Critics argue that early work investigating the age differences in cerebral asymmetries did not use comparable tasks: Measures of visuospatial

functions were often more complex and had time requirements whereas verbal tasks were not time based and drew heavily upon over-learned or well-practiced skills (Elias & Kinsbourne, 1974; Ellis & Oscar-Berman, 1989). In fact, in some studies, when efforts were made to equate tasks, results no longer supported the RHAH (Elias, Winn, & Wright, 1979; Shelton et al., 1982). Finally, critics also point to the lack of neurobiological support, with few neuroimaging and neuropathological studies showing support for the RHAH (e.g., Cabeza, 2002; cf. Resnick et al., 2003).

Hemispheric Asymmetry Reduction in Older Adults (HAROLD) Model. Another hypothesis based upon examinations of age-related changes in hemispheric asymmetry is the HAROLD model (Cabeza, 2002). As mentioned above, one of the limitations of the RHAH is that there is a lack of support from neuroanatomical studies. In contrast, the HAROLD model is based upon a reliable finding in functional imaging research: Increased bilateral activation (i.e., reduced asymmetry) is observed in the brains of older adults during performance of tasks that generally invoke unilateral activation in young adults (e.g., Cabeza, 1997, 2002; Reuter-Lorenz et al., 2000; Rossi et al., 2004). This finding is somewhat counter intuitive, given the general cognitive decline observed in aging (for more detail, see pages 17-18 above). However, reduced asymmetry in older adults has been observed in PET and fMRI studies measuring working memory (Reuter-Lorenz et al., 2000), episodic memory (Cabeza et al., 1997), and visual processing (Grady et al., 1994; for reviews, see Cabeza, 2002; Daselaar & Cabeza, 2005). For example, Reuter-Lorenz (2000) examined age-related differences in memory using verbal and spatial working memory tasks. Results of this study indicated that young adults demonstrated primarily left lateralized activation for working memory and right lateralized activation for spatial memory whereas older adults displayed bilateral activation for both types of tasks.

The function of the age-related changes in activation remains under debate (Cabeza, 2002; Reuter-Lorenz & Lustig, 2005), with some arguing that the changes are compensatory in nature (Reuter-Lorenz & Cappell, 2008; Reuter-Lorenz & Lustig, 2005) and others arguing that they represent age-related dedifferentiation of cognitive abilities (for a review, see Cabeza,

2002). Although support has been shown for both explanations, recent research appears to support the compensatory hypothesis, which suggests that additional bilateral brain regions are recruited in order to maintain cognitive performance in the face of aging (Park & Reuter-Lorenz, 2009). This view is in line with studies indicating that increased bilaterality in older adults is associated with better cognitive performance (e.g., Cabeza, Anderson, Locantore, & McIntosh, 2002; Fera et al., 2005; McIntosh et al., 1999; Reuter-Lorenz et al., 2000; for a review, see Park & Reuter-Lorenz, 2009). In fact, this evidence has spawned another theory of cognitive aging, the *Scaffolding Theory of Aging and Cognition* (Park & Reuter-Lorenz, 2009), which is discussed in detail below.

The Scaffolding Theory of Aging and Cognition (STAC). Park and Reuter-Lorenz (2009) built upon the compensatory hypothesis by proposing the STAC. According to STAC, when the aging brain is faced with challenging cognitive tasks, the usual neural networks may not be adequate to successfully complete the tasks, because of declining neural integrity and, therefore, the brain compensates by recruiting additional brain regions. By engaging alternative neural circuitry, or “scaffolds,” the brain is able to function more effectively (Park & Reuter-Lorenz, 2009). Park and Reuter-Lorenz further argue that studies describing increased bilateral activation in the prefrontal cortex of older adults relative to younger adults during cognitive tasks (e.g., Cabeza, 2002; Cabeza et al., 1997; Reuter-Lorenz et al., 2000; Rossi et al., 2004) can be interpreted as compensatory in nature. Evidence for this view comes from studies demonstrating that when older adults are divided into subgroups, the older adults with increased bilateral activation perform better on cognitive measures than older adults without such activation (Cabeza et al., 2002; Rosen et al., 2002). At this point, it is not clear what the brain may be compensating for, but Park and Reuter-Lorenz argue that the aging brain is faced with a number of neural challenges, including volume loss, white matter changes, cortical thinning, and dopamine depletion, any one of which might make compensatory strategies necessary for cognitive functioning (Park & Reuter-Lorenz, 2009).

Age and emotion processing. As outlined in the sections above, there is abundant research examining the effects of age on cognition. The effects of age on emotion are less clear, with some research arguing that aspects of emotion processing, such as emotion regulation, remain intact or are even enhanced in later life (Mather & Carstensen, 2005) and other studies pointing towards age-related deficits in emotion perception (e.g., Calder et al., 2003; Malatesta et al., 1987; Schaffer et al., 2009; cf. Moreno et al., 1993). The following sections will provide a review of relevant literature regarding aging and emotion processing, including a brief overview of age-related changes in the experience of emotion and a more detailed review of the impact of age on emotion perception.

Age and the experience of emotion. As mentioned above, research suggests that aspects of emotion processing, such as emotion regulation, may improve with age. Consistent with this argument, older adults report experiencing less negative affect (e.g., Lawton, Kleban, & Dean, 1993), attend less to negative stimuli (e.g., Mather & Carstensen, 2003), and have a better memory for positive stimuli than for negative (e.g., Charles, Mather, & Carstensen, 2003). This “positivity bias” may be part of a strategy to maintain emotional control and thus avoid interpersonal conflict (Mather & Carstensen, 2005). In other words, as we get older, we learn to focus on the better things in life and to keep our emotions in check. This argument is consistent with Carstensen’s Socioemotional Selectivity Theory, which suggests that the age-related shift towards positive emotions and increased emotion regulation is related to shifting goals: Relative to younger adults, older adults are more focused on emotional meaning and goals that optimize well-being (Carstensen, Isaacowitz, & Charles, 1999; Carstensen et al., 2010; Riediger, Schmiedek, Wagner, & Lindenberger, 2009).

However, these data, which focus on emotional *experience*, only tell one part of the story. Other aspects of emotion processing, such as emotion *perception*, point towards age-related deficits in the ability to recognize and identify emotional stimuli.

Age and the perception of emotion. In contrast to the literature described above, research examining age-related changes in the perception of emotion point towards some age-

related decline in multiple channels of communication. In the following section, age-related changes in emotion processing will be reviewed within the facial, prosodic, and lexical channels of communication.

Facial channel. Previous research investigating age-related changes in emotion recognition in the facial channel has primarily used posed facial expressions from cross-nationally standardized photographs of facial expression (Biehl et al., 1997; Ekman & Friesen, 1976; Young, Perrett, Calder, Sprengelmeyer, & Ekman, 2002). Overall, findings from these studies have generally been consistent, demonstrating that older adults are less accurate at identifying facial expressions of anger, sadness, and, to a somewhat lesser extent, fear (Calder et al., 2003; Henry et al., 2008; Isaacowitz et al., 2007; Keightley, Chiew, Winocur, & Grady, 2007; Keightley, Winocur, Burianova, Hongwanishkul, & Grady, 2006; MacPherson, Phillips, & Della Sala, 2005; McDowell, Harrison, & Demaree, 1994; Mill, Allik, Realo, & Valk, 2009; Moreno et al., 1993; Orgeta & Phillips, 2008; Phillips, MacLean, & Allen, 2002; Roring, Hines, & Charness, 2006; Sullivan & Ruffman, 2004a; Sullivan, Ruffman, & Hutton, 2007; Suzuki, Hoshino, Shigemasa, & Kawamura, 2007; Wong, Cronin-Golomb, & Nearing, 2005). Similar results have also been found from studies using cartoon drawings (Allen & Brosigole, 1993; Brosigole & Weisman, 1995) and more dynamic video recordings (Henry et al., 2008; Malatesta et al., 1987; Sullivan & Ruffman, 2004b). Although this research appears to point to an isolated decline in negative emotions, it should be noted that not all negative emotions demonstrate age-related deficits. Studies typically failed to find any age-related decline in the recognition of disgust (cf. Keightley et al., 2007), and some studies have even noted age-related *improvements* in identifying disgust (Calder et al., 2003; Suzuki et al., 2007; Wong et al., 2005), although it is not clear if increases in accuracy for older adults relative to younger adults were the result of improved emotion recognition ability, *per se*, or merely maintenance of existing skill level.

Whereas most studies have not found age-related differences in the recognition of positive emotions, a few studies reported that older adults are less accurate in recognizing happiness (Isaacowitz et al., 2007; Mill et al., 2009) and surprise (Mill et al., 2009; Roring et al.,

2006). However, further information is needed regarding the association between age and positive emotions, given that many of the studies limited their examination of positive emotions to happiness and ceiling effects were frequently observed (e.g., Calder et al., 2003; Ebner & Johnson, 2009; Keightley et al., 2007; McDowell et al., 1994; Phillips et al., 2002).

Prosodic channel. Research in the prosodic channel has also demonstrated age-related changes in the ability to recognize emotions (Allen & Brosgole, 1993; Brosgole & Weisman, 1995; Henry et al., 2008; Kiss & Ennis, 2001; Mill et al., 2009; Mitchell, 2007; Orbelo, Grim, Talbott, & Ross, 2005; Orbelo, Testa, & Ross, 2003; Oscar-Berman, Hancock, Mildworf, Hutner, & Weber, 1990; Paulmann, Pell, & Kotz, 2008; Ruffman, Henry, Livingstone, & Phillips, 2008; Ruffman et al., 2009; Schaffer et al., 2009; Wong et al., 2005). Only a few of these studies have included investigations of discrete emotions, but there is some evidence to suggest a differential pattern of change in prosodic perception abilities according to emotion type (Brosgole & Weisman, 1995; Paulmann et al., 2008; Ruffman et al., 2008, 2009; Wong et al., 2005). Most of the studies have shown older adults having difficulty recognizing anger (Brosgole & Weisman, 1995; Paulmann et al., 2008; Ruffman et al., 2008, 2009) and sadness (Brosgole & Weisman, 1995; Paulmann et al., 2008; Ruffman et al., 2008; Wong et al., 2005). Some studies have also shown deficits in the recognition of happiness (Paulmann et al., 2008; Ruffman et al., 2008; Wong et al., 2005) in older adults relative to young adults. However, one study showed age differences for the recognition of disgust (Paulmann et al., 2008), and there was no evidence of age differences for the recognition of fear or surprise.

It should be noted that the existing literature in the prosodic channel has some limitations. First, most of the existing studies are restricted to two age groups: a “young” group, generally between the ages of 20-40, and an “old” group, generally consisting of individuals over the age of 65. Having only two age groups is somewhat limiting as it does not allow us to determine whether or not decline occurs in a linear fashion. A few studies have included more than two age groups and results of these studies suggest that prosodic recognition abilities improve up to age 12 (Brosgole & Weisman, 1995), then remain stable for several decades before

beginning a steady decline around age 45 (Brosgole & Weisman, 1995; Orbelo et al., 2003; Schaffer et al., 2009). However, additional studies are needed to corroborate these results.

A second limitation is the fact that few studies include a non-affective prosodic control task. Therefore, it is unclear if the findings above are due an inability to distinguish prosodic intonation (whether non-emotional or emotional) rather than a specific deficit in emotion processing. To date, only two studies have included non-affective control tasks and both studies found similar impairments in affective and non-affective prosody identification, providing some evidence for an overall deficit in prosodic perception (Allen & Brosgole, 1993; Brosgole & Weisman, 1995). Thus, additional studies are needed investigating the contribution of non-affective prosodic perception to age-related declines in affective prosodic perception.

Lexical channel. The lexical channel has received relatively little attention as compared to the facial and prosodic channel and therefore little is known about age differences in this modality. Only one study has examined age differences in the perception of discrete emotion using lexical stimuli (Isaacowitz et al., 2007). Results from this study suggest that older adults are less accurate at identifying all basic emotions from words (i.e., anger, fear, disgust, happiness, surprise), with the exception of sadness. However, the study did not include a nonaffective control task, which makes it unclear whether the observed decline can be ascribed to specific deficits in emotional processing. Grunwald and colleagues (1999) found that older participants (ages 60-85) evaluated both emotional *and* nonemotional lexical stimuli (words and sentences) less accurately than both middle-aged (ages 40-59) and younger (ages 20-39) adults, but as discrete emotions were not analyzed, potential age-related changes in this study may have been overlooked. The remaining two studies in this area did not report any age-related changes in the perception of emotions in the lexical channel (Keightley et al., 2006; Phillips et al., 2002).

Theoretical explanations for age-related changes in emotion perception. A number of theories have been proposed to account for the age-related changes in emotion processing described above. The following section will include a discussion of the most

plausible explanations: the neuropsychological hypothesis, simulation theory, and the common cause hypothesis.

The neuropsychological hypothesis. One approach, sometimes described as the neuropsychological hypothesis, argues that age-related changes in the accuracy of perceiving discrete emotions reflects the differential effects of aging on the brain (Calder et al., 2003; Ruffman et al., 2008, 2009; Sullivan & Ruffman, 2004a, 2004b). This approach has focused on areas of the brain that undergo structural and functional changes with age. Particular emphasis is placed on the accelerated age-related atrophy seen in the OFC (Tisserand et al., 2002), which has been linked to the recognition of anger (Blair & Cipolotti, 2000; Brower & Price, 2001; Murphy et al., 2003). In addition, the theory focuses on age-related changes in the amygdala, which has been tied to the recognition of fear (e.g., Phelps & LeDoux, 2005) and, to a lesser extent, sadness (Blair et al., 1999; Perrett, & Dolan, 1999; Schmolck & Squire, 2001) and happiness (Jurueña et al., 2010; Somerville et al., 2004). Evidence from anatomical and structural imaging studies suggests that the amygdala undergoes relatively little age-related shrinkage, with an attenuated rate of decline relative to regions such as the OFC (e.g., Good et al., 2001; Grieve et al., 2005); however, functional imaging studies have documented reductions in amygdala response to emotional stimuli in older relative to younger adults (e.g., Gunning-Dixon et al., 2005; Iidaka et al., 2002; Tessitore et al., 2005; cf. Mather et al., 2004). For instance, in a study using fMRI, Iidaka and colleagues (2002) asked participants to identify the gender of faces with negative, positive, or neutral valence. Analysis of the imaging data indicated that, as compared to younger adults, older adults had significantly reduced activity in the left amygdala while viewing negative faces.

Tessitore and colleagues (2005) also found evidence of age-related alterations in amygdala response. Specifically, results from a study using blood oxygenation-level dependent (BOLD) fMRI demonstrated that older adults had reduced activity, bilaterally, in the amygdala relative to younger adults when viewing angry and fearful faces.

There is some evidence that findings of altered amygdala response are not limited to negative emotions. Gunning-Dixon and colleagues (2005) also found attenuated activations in the amygdala in older adults relative to younger adults during a facial emotion discrimination task that included facial expressions of happiness, sadness, anger, fear, disgust, and neutral expressions. However, this fMRI study used a blocked design (i.e., conditions were alternated in blocks), which did not allow for the evaluation of emotion-specific patterns.

Considering the age-related structural and functional changes in the OFC and amygdala, the neuropsychological hypothesis predicts that the most significant age-related changes will be observed in behavioral functions associated with those particular regions. In contrast, functions related to regions of the brain that are less vulnerable to the effects of age, such as the basal ganglia, would remain stable. Therefore, the recognition of emotions such as anger and fear, which have been associated with the OFC and amygdala respectively, should decline the most with age, whereas the perception of disgust, which has been associated with the basal ganglia, should remain relatively stable across the lifespan³ (Calder et al., 2003; Ruffman et al., 2008, 2009; Sullivan & Ruffman, 2004a, 2004b).

Research in the facial channel has largely supported this argument, indicating age-related changes in anger, sadness, and fear, but not happiness or disgust (for a review, see Ruffman et al., 2008). However, research from the prosodic and lexical channels only partially supports the theory: Older adults have difficulty recognizing anger, sadness, and happiness relative to young adults, but not fear, surprise, or disgust (Brosgole & Weisman, 1995; Paulmann et al., 2008; Ruffman et al., 2008, 2009; Wong et al., 2005). One limitation of this research is that few studies have systematically examined change in the perception of discrete emotions

³ There is considerable evidence pointing towards dissociable neural networks mediating the perception of fear, disgust, and, to a somewhat lesser extent, anger; however, at the current time, it is less clear whether separate neural networks mediate emotions such as sadness, happiness, and surprise. Additional evidence is needed to determine whether dissociable networks exist for these emotions, and, until that evidence is obtained, the neuropsychological hypothesis remains difficult to test.

across multiple channels in the same population (cf. Schaffer et al., 2009). Therefore, additional research is needed to determine the applicability of the neuropsychological hypothesis to other communication channels.

The simulation theory. Although not well studied, an alternative model has been proposed to explain age-related changes in emotion processing. This model focuses on the simulation theory, a social cognitive model proposing that an individual identifies the emotion another person is feeling by attempting to simulate or replicate the same emotion in his/her own mind (Goldman & Sripada, 2005). This theory is based on lesion studies demonstrating that deficits in the perception of fear, disgust, and anger reliably co-occur with reductions in the experience of the same emotion (as measured by self-report questionnaires) following damage to the neural substrates mediating these emotions (Calder et al., 2000a; Sprengelmeyer et al., 1999).

As described above, evidence suggests that older adults experience negative emotions less frequently than younger adults (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Carstensen et al., 2010). In addition, older adults appear to have a reduced physiological response to negative emotions (Labouvie-Vief, Lumley, Jain, & Heinze, 2003; Levenson, Carstensen, Friesen, & Ekman, 1991), raising the possibility that reports of less frequent negative emotions reflect alterations in the ability to experience emotions due to reduced physiological reactivity. If this were, in fact, the case, then the simulation theory would predict that older adults would also be limited in their ability to recognize negative emotions. Specifically, the simulation theory would predict age-related declines in the perception of negative, but not positive, emotions across all communication channels.

Past research has shown only partial support for this hypothesis. Suzuki and colleagues (2007) tested the simulation theory by correlating scores on a measure of emotional experience with performance on a facial expression identification test. Results indicated only partial support for the simulation theory, with a significant positive correlation between sadness

recognition and the score of negative affect experience. Other negative emotions tested (i.e., fear, anger, and disgust) were not significantly correlated with the experience of negative affect.

Indirect evidence for the simulation theory also comes from studies of age-related change in emotion perception, although the results of these studies show mixed support for the hypothesis. Although older adults have more difficulty recognizing facial expressions of anger, sadness, and, to a somewhat lesser extent, fear, they do not differ from young adults in their ability to recognize disgust (for a review, see Ruffman et al., 2008). Support is also mixed in the prosodic channel, where most studies indicate that older adults have difficulty recognizing anger (Brosigle & Weisman, 1995; Paulmann et al., 2008; Ruffman et al., 2008, 2009), sadness (Brosigle & Weisman, 1995; Paulmann et al., 2008; Ruffman et al., 2008; Wong et al., 2005), and, to a lesser extent, happiness (Paulmann et al., 2008; Ruffman et al., 2008; Wong et al., 2005), but not fear, surprise, or disgust (Brosigle & Weisman, 1995; Ruffman et al., 2008, 2009; Wong et al., 2005; cf. Paulmann et al., 2008). This research has limitations (as discussed above), and, therefore, research simultaneously examining age-related changes in emotion perception across multiple communication channels may be helpful to further explore the simulation theory.

The common cause hypothesis. Another plausible explanation is that age-related changes in emotion perception reflect general cognitive and sensory disturbances as opposed to emotion-specific factors. As described above, the negative effects of aging on cognitive and sensory functions have been well documented (Glisky, 2007; Schaie & Willis, 2011). In general, older adults demonstrate slowed reaction times (e.g., Verhaeghen & Salthouse, 1997), inefficient working memory (e.g., Bopp & Verhaeghen, 2005; Light & Anderson, 1985), susceptibility to distraction (e.g., Healey et al., 2008), and impairments in hearing and vision (e.g., Clinard et al., 2010; Faubert, 2002). It is possible that age-related changes in emotion perception, as well as changes in cognition and sensory functions, could be secondary to an underlying “common factor” that simultaneously disrupts emotion processing, cognition, and sensory functions. This theory is in line with the common cause hypothesis, which suggests that declines in cognitive

and sensory functions with age are reflections of the deteriorating neural integrity of the brain (Baltes & Lindenberger, 1997; Dulay & Murphy, 2002; Lindenberger & Baltes, 1994). Evidence for the common cause hypothesis comes from studies demonstrating that in older adults, correlations between cognitive and non-cognitive functions are higher relative to younger adults (e.g., Christensen et al., 2001; Lindenberger & Baltes, 1994). For a review of this literature, see page 21 above.

Despite the apparent support for the common cause hypothesis, it is not clear whether or not the hypothesis applies to emotion processing. If a common factor is responsible for the age-related deterioration of cognitive and non-cognitive processes, it might be expected to impact emotional processing as well. Specifically, the common cause hypothesis would predict that the associations among emotional, cognitive, and sensory tasks would be stronger in older than younger adults. Information regarding the associations among these functions and regarding age-related changes in the strength of these associations could be instrumental in understanding the role of non-emotional factors in age-related changes in emotion perception.

However, only one study, to date, has directly investigated the common cause hypothesis as it applies to emotion perception (Hall, 2001). In this study, the relationships among cognition, auditory acuity, and emotion processing were investigated by conducting a hierarchical regression analysis and by calculating correlations among cognition and emotion perception tasks. Results of the regression analysis failed to support the common cause hypothesis: Age, but not auditory acuity, explained a significant amount of variation in performance on the emotion perception tasks. However, correlation analyses revealed a significant relationship between a measure of processing speed (i.e., a cancellation task) and measures of emotion perception in older, but not younger, adults, providing some support for the hypothesis. It is important to note that this study was restricted to individuals under the age of 81, and, therefore, did not include members of the “oldest-old” age group. In addition, correlations among auditory acuity measures and emotion perception tasks were not calculated. Thus, additional research in this area would be helpful to further test the hypothesis.

Overview of the Current Project

In the current project, we have systematically examined changes in the perception of discrete emotions across facial, prosodic, and lexical channels. Data were analyzed from 117 healthy, right-handed adults between the ages of 20-89 who completed the identification and discrimination tasks from the NYEB (Borod et al., 1992b). The NYEB is a comprehensive battery of tests examining the perception, expression, and experience of emotion across three channels of communication (i.e., facial, prosodic/intonational, and lexical/verbal channels; Borod et al., 1998b).

The project extends previous work in a number of important ways. First, unlike previous work in this area, the current study tested perception abilities in multiple channels of communication simultaneously. In addition, the current project also extends previous research by characterizing age-related changes in the perception of eight discrete emotions: five negative and three positive. In previous studies, happiness was often the only positive emotion tested and ceiling effects often made conclusions difficult. By increasing the number of positive emotions to three (i.e., happiness, pleasant surprise, and interest), the current project is in a position to more comprehensively characterize age-related changes. Finally, previous research has not consistently controlled for nonemotional factors. In contrast, participants in the current project completed a comprehensive battery of neurocognitive tests, as well as nonemotional control tasks, thus enabling a better understanding of the role of nonemotional factors in age-related changes in emotion perception.

This project builds upon work previously done in our lab examining age-related changes in emotion perception (Finley, 2011; Finley et al., 2008; Finley et al., 2011; Hall, 2001; Hall, Borod, Sliwinski, Martinez-Pons, & Pick, 2003). This research has indicated a relationship between aging and emotion perception (Hall, 2001), with a robust decline in emotion perception across all three communication channels beginning in the 70-80 year old age group (Finley et al., 2008). The current project extended this work in two ways: First, participants were recruited between the ages of 80-89 to extend our sample age; and second, data analyses

focused on patterns of performance *among the discrete emotions* across all three communication channels. In order to accomplish these goals, data were analyzed from 117 healthy, right-handed adults between the ages of 20-89 who completed the identification and discrimination tasks from the NYEB (Borod et al., 1992b), a comprehensive battery of tests examining the perception, expression, and experience of emotion across three channels of communication (i.e., facial, prosodic/intonational, and lexical channels). Efforts were made in the current project to ensure that participants in the 80-89 year age group were carefully matched to existing age groups in terms of demographic characteristics such as ethnicity, education, and gender.

Aims and Hypotheses

The aims and hypotheses of the study are described in detail below. Please see the “Data Analysis” section for details regarding statistical procedures.

Aim I: To characterize age-related differences in the perception of discrete emotions across the facial, prosodic, and lexical channels. The primary aim of this project was to identify and describe differences in the perception of eight individual discrete emotions (i.e., sadness, anger, disgust, fear, unpleasant surprise, pleasant surprise, happiness, and interest) as a function of age in the facial, prosodic, and lexical channels. As part of this aim, we examined the relationship between age, performance on nonemotional control tasks, and emotion perception ability, with a focus on investigating whether a relationship between aging and emotion perception ability exists independent of nonemotional perception. The majority of studies examining the prosodic and lexical channels have included only two age groups to study emotion perception (i.e., "young" and "old;" cf. Brosgole & Weisman, 1995; Orbelo et al., 2003; Schaffer et al., 2009). By including seven age groups, the current study is in a position to provide more specific information regarding the age at which any decline begins.

In addition, the following hypotheses were tested:

Hypothesis I: Age will account for a significant amount of variability of emotion perception ability, even after controlling for performance on nonemotional control tasks. This

hypothesis was based on results from the few existing studies examining the contribution of nonemotional perception to age-related changes in emotion perception ability (Allen & Brosgole, 1993; Brosgole & Weisman, 1995; Keightley et al., 2006), which suggest that performance on emotional perception tasks is at least partially independent of performance on nonemotional perception tasks.

Hypothesis II: Older adults will perform significantly worse than younger adults on emotion perception tasks in the facial, prosodic, and lexical channels, consistent with the neuropsychological and common cause hypotheses.

Hypothesis III: Accuracy of the perception of discrete emotions will show a differential pattern of change with age, with the ability to perceive some emotions declining over time and others remaining stable. Specifically, it was hypothesized that the pattern of change would parallel age-related changes that have been previously observed in the structure and function of the brain, thus providing support for the neuropsychological hypothesis. The perception of emotions that rely primarily on the amygdala and frontal lobes (i.e., fear, sadness, and anger) will demonstrate age differences in all three channels. In contrast, emotions that rely on regions of the brain that are less sensitive to age (i.e., the emotion of disgust, which is mediated by the basal ganglia and insula) will remain stable across the lifespan. There are no specific hypotheses related to the emotions of happiness, surprise, and interest, as it is not clear at this time whether dissociable networks exist for these emotions. Therefore, age-related changes in the perception of these emotions were characterized on an exploratory basis.

Aim II: To investigate the contribution of cognitive and sensory measures to emotion processing. The final aim of the study was to explore the contribution of sensory and cognitive measures to emotion perception ability.

Hypothesis I: It was hypothesized that the association among measures of emotion perception and auditory acuity (i.e., pure tone threshold) would increase with age, as would be predicted by the common cause hypothesis.

Hypothesis II: In keeping with the common cause hypothesis (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994), it was hypothesized that sensory processes (i.e., auditory acuity) and cognitive measures would be significant predictors of emotion perception ability in older adults, but not in younger adults.

Methods

Participants

The current project builds upon data previously collected as part of an ongoing research program on emotional perception and expression in healthy and brain-damaged individuals. This research program has been funded from NIH and PSC-CUNY research grants, which have been awarded to Dr. Joan Borod, the project's principal investigator. Participants included in the previously collected sample included 101 healthy adults between the ages of 20-81 years. These participants were divided into six decade groups (i.e., 20-29, 30-39, 40-49, 50-59, 60-69, 70-81) with each group carefully matched on key demographic variables, including age, gender, ethnicity, and education. The current project extended this sample by recruiting an additional 16 participants between the ages of 80-89 years, thus increasing the total sample size to 117 participants in seven decade groups: 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89 years of age. Efforts were made to match the participants in the 80-89 year old age group to the previous age groups by demographic characteristics including gender, ethnicity, and education. All participants are right-handed, as assessed by the Coren and Porac (1978) lateral preference inventory, with no history of converting from left-handedness and are native English-speakers or fluent by the age of seven.

Participants were recruited using flyers, newspaper advertisements, internet postings, and announcements at community and senior centers. In addition, participants were actively recruited at community events held on the Queens College campus, including lectures, readings, and concerts.

Procedures

Prior to testing, all participants provided informed written consent. The total time for administration of consent, interviews, questionnaires, and experimental and control tasks was approximately eight hours. Testing was generally conducted in two to four sessions, each lasting

anywhere from one to four hours, depending on the preferences and availability of the participants. Consent was assessed on a continual basis throughout the session and breaks were given as needed. Participants were reimbursed \$100 for their time and effort upon completion of the study (or at a rate of \$12.50 per hour if they were unable to complete the study). Reimbursement was also provided to participants for necessary travel expenses. The research protocol was approved by the Queens College and Mount Sinai School of Medicine Institutional Review Boards.

Screening measures. All participants underwent a comprehensive screening process to ensure an adequate level of cognitive, perceptual, and emotional functioning. Initially, participants were screened for demographic characteristics and medical background using a comprehensive questionnaire from the NYEB. Participants were excluded from the study if information from the screening questionnaire indicated any history of learning disability, neurological disease, psychiatric disorder, psychotropic drug treatment, or substance abuse. Psychiatric history was further assessed using the Schedule for Affective Disorders and Schizophrenia – Lifetime Version (SADS-L; Endicott & Spitzer, 1978) and the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). In the oldest age group (i.e., ages 80-89), mood was also screened with the Geriatric Depression Scale (GDS; Yesavage et al., 1982). Participants were excluded if responses indicated any history of substance abuse or Axis I psychiatric disorder.

Following the initial screening questionnaire, participants were asked to complete a battery of tests (described below) designed to ensure adequate levels of perceptual, cognitive, and intellectual functioning. Cutoff scores for each screening measure were selected based on previous research in our laboratory with neurological populations. Cutoff scores were typically 1 to 2 standard deviations below the mean of the normal population (see Table 1). However, many of the screening measures used do not provide normative data for individuals over the age of 75. In this case, normative data for this age group was obtained from external normative studies (e.g., the Mayo Older Adults Normative Sample [MOANS] study; Ivnik et al., 1992)

when available. If normative data was not available from external sources, normative data were obtained from the oldest normative group possible.

Participants were screened for visual perception deficits with Benton's Visual Form Discrimination Test (VFDT; Benton, Hamsher, Varney, & Spreen, 1983). The verbal and nonverbal Mesulam cancellation tasks (Mesulam, 1985) were used as a qualitative screening for visual inattention. Auditory perception was screened using a pure tone threshold hearing task (Beltone, 1987; Borod, Obler, Albert, & Stiefel, 1983). Reading comprehension was assessed with the Reading Sentences and Paragraphs subtest from the Boston Diagnostic Aphasia Examination (BDAE; Goodglass & Kaplan, 1983). Additional subtests from the BDAE were used to screen for auditory comprehension (Commands and Complex Ideational Material) and oral expression (Reading Sentences and Paragraphs).

Several cognitive variables, namely intelligence, attention, and memory, were assessed due to their potential impact on the experimental tasks. General intellectual ability was assessed using the Information and Block Design subtests of the Wechsler Adult Intelligence Scale – Revised (WAIS-R; Wechsler, 1981). Basic attention and memory function were assessed with the attention and memory subtests of the Dementia Rating Scale (DRS; Mattis, 1988), as well as the Logical Memory Subtest from the Wechsler Memory Scale – Revised (WMS-R; Wechsler, 1987).

Finally, participants were excluded if there was any indication that they met criteria for dementia. In participants between 20-80 years of age, a brief mental status screening test was used to screen for dementia. The test, developed by Katzman, Brown, Fuld, Peck, & Schecter (1983) includes items from the Blessed Mental Status Test (Blessed, Tomlinson, & Roth, 1968) and the Mental Status Questionnaire (Kahn & Miller, 1978). As the risk of dementia increases significantly as a function of age (Gao, Hendrie, Hall, & Hui, 1998), individuals over the age of 80 underwent a more comprehensive screen for dementia, which included the full DRS (Mattis, 1988) and the Mini Mental Status Exam (MMSE; Folstein, Folstein, & McHugh, 1975).

Participants in this age group who scored less than 133 on the DRS were excluded from the study.

Experimental tasks. Following screening procedures, all participants completed the experimental measures from the NYEB, including emotional tasks and nonemotional (i.e., control) tasks. While both perception and expression components were tested, the focus of the current study was on perception and, therefore, only these data were analyzed.

Emotional tasks. The emotional tasks from the NYEB are designed to assess emotion processing in the facial, prosodic, and lexical channels using analogous paradigms. Each channel includes identification and discrimination tasks with a similar level of difficulty across channels. Each task includes three positive (happiness, pleasant surprise, interest) and five negative (sadness, fear, anger, disgust, unpleasant surprise) discrete emotions. Emotions were selected based on the primary emotions as proposed by Ekman and Friesen (1975) and Izard (1977a). Task order is randomized.

Facial perception. Stimuli used for the facial perception task include Ekman and Friesen's (1976) slides showing happiness, sadness, fear, anger, and disgust, as well as new slides created to show pleasant surprise, unpleasant surprise, and interest. Slides were presented on a Caramate projector.

For the *identification* task (FID), participants are shown slides of different emotional expression and are asked to identify the emotion being expressed by naming or pointing to the correct response on a 8½ X 11 inch (21.6 X 27.9 centimeter) card, which was centrally placed and vertically listed all eight emotions. Slides are exposed for a maximum of 20 seconds. Prior to beginning the task, participants are asked to read the eight choices aloud to ensure familiarity with their meaning. Four response cards, each with the emotions presented in a different order, were randomized within and across participants. The task consists of 2 practice trials and 32 experimental trials, with each emotion appearing four times (16 male and 16 female posers, balanced across emotions). Two randomized stimulus sets are used for the identification task.

For the *discrimination* task (FDIS), participants are shown two slides on the Caramate projector of different posers depicting either the same or different emotional facial expressions. Participants are asked to indicate whether the emotions expressions shown are the same or different verbally or by pointing to the response on a printed card. For each pair of images, slides are presented for five seconds with a one-second interstimulus interval (ISI). Two equivalent sets of stimuli were used (A, B), each consisting of 28 pairs (14 male and 14 female) along with three practice trials. Each set contains 14 same and 14 different pairs.

Prosodic perception. Stimuli for prosodic tasks are neutral-content sentences (e.g., “They found it in the room.”), spoken by actors and actresses in eight emotional tones. Four different sentences are used, selected for similar grammar, rhythm, and length; comprehensibility; and low emotionality ratings. Sentences are tape-recorded. All auditory stimuli were presented open field via a tape recorder at a volume level that was sufficiently loud for each participant.

For the *identification* task (PID), recordings of emotionally intoned sentences are presented on audiotape and participants are asked to identify the emotion portrayed verbally or by pointing to one of the choices listed on the 8½ X 11 inch (21.6 X 27.9 centimeter) response cards described above. The task consists of 2 practice trials and 24 experimental trials. Posers in the 24 trials are gender-balanced and each emotion appears three times. Two randomized stimulus sets were used for the identification task.

For the *discrimination* task (PDIS), two sentences intoned by the same poser with the same or different emotional tone are presented on audiotape and participants are asked to indicate whether the emotional tones used were the same or different verbally or by pointing to a printed card. For each pair, sentences are presented at a normal cadence (i.e., approximately three seconds in length) with a one-second ISI. Two equivalent sets of stimuli were used (A, B), each consisting of 28 pairs (14 male and 14 female) along with three practice trials. Each set contained 14 “same” and 14 “different” pairs.

Lexical perception. Stimuli for the lexical tasks are emotional-content words and sentences presented in the center of a white sheet of 8½ X 11 inch (21.6 X 27.9 centimeter) paper for no more than 20 seconds.

Two lexical identification tasks were used: *word identification (WID)* and *sentence identification (SID)*. In the WID task, three-word clusters (each word representing the same emotion) are presented and participants are asked to indicate (verbally or by pointing to the response card) which emotion each cluster represents. For the lexical SID task, sentences are presented one at a time and participants are asked to indicate the emotion represented by the sentence. Each task has 24 trials, with each emotion represented three times in each task.

For the lexical *discrimination* task (WDIS), two printed words are presented, one directly above the other, representing either the same or different emotions. An example of a same trial is “grief” and “regret”, representing sadness, and an example of a different trial is “loving” and “stench”, representing “happiness” and “disgust”, respectively. Participants are asked to indicate whether the emotions represented by the words were the same or different verbally or by pointing to a printed card. Two stimulus sets were used for the discrimination task (A, B), each containing 28 pairs of words and three practice trials.

Scoring procedures for the emotion tasks. Emotion perception task responses were scored for accuracy (0: inaccurate, 1: accurate) and raw scores were converted to percent correct to enable comparisons across tasks and channels. For each task, a total score was obtained. As the main hypothesis involves an examination of the effects of discrete emotion on perception, accuracy scores for each discrete emotion were also obtained for the emotion tasks.

Nonemotional control tasks. All participants were asked to complete nonemotional tasks in all three channels to control for cognitive and perceptual factors that could potentially confound performance on the emotional experimental tasks.

Facial channel. To control for nonemotional aspects of face perception, all participants completed the shortened version of the *Benton Facial Recognition Test* (Benton et al., 1983), a measure of nonemotional identity recognition. For this test, participants are shown a reference

face, along with a set of six 2 X 3 inch black and white photographs of neutral/nonemotional faces, and are asked to identify the photograph showing the same person as the reference face. Angle of orientation and degree of lighting is varied to increase item difficulty. Six items require one recognition response and seven items require three recognition responses, with each correct match yielding one point, resulting in 27 possible points. The total score was converted to the long form score, based on 54 possible points. In addition, the *Visual Matrices Test* (Borod, Martin, Alpert, Brozgold, & Welkowitz, 1993) was administered to control for basic form recognition. In this test, participants are shown pictures of squares in which portions of the squares are blackened. They are subsequently shown a second page with four squares and are asked to identify the square that is identical to the square on the first page. The test consists of 24 items and the number of blackened portions gradually increases throughout the test to vary the level of difficulty. The total number of squares correctly identified was summed to create a total score out of 24 possible points.

Prosodic channel. Within the prosodic channel, the *Phoneme Discrimination Test* (Benton et al., 1983) was used to control for auditory discrimination. In this test, participants are presented with 30 tape-recorded pairs of nonsense words and are asked to judge whether the phonemes were the same or different from each other. Half of the stimuli presented are identical and the other half of the pairs are similar, but not identical (e.g., “ur-ur” and “pedzap-pelzap”). In addition, all participants completed the *Intonation Contours Perception Task* (Borod et al., 1992b), which comprises 24 tape-recorded nonsense syllable strings expressed in different intonations. Four nonsense syllable strings are used (e.g., pa-da-ka), with three types of intonational stress (i.e., declarative, interrogative, and emphatic; Blumstein & Cooper, 1974). Each of the 12 items is presented twice. Upon hearing the syllable string, participants are asked to identify which intonational stress was being expressed using a multiple-choice response card containing a drawing, verbal label, and punctuation symbol to represent each contour.

Lexical channel. Nonemotional lexical control tasks were used which have been designed to be analogous to the lexical emotional experimental tasks in terms of structure,

instructions, and degree of difficulty (Borod et al., 1992c). Stimuli for the lexical control tasks are nonemotional-content words and sentences presented in the center of a white sheet of 8½ X 11 inch (21.6 X 27.9 centimeter) paper for no more than 20 seconds. Eight categories are depicted, each representing a nonemotional human characteristic: body type, complexion, hair type, intelligence, personality, teeth, vision, and voice type. Comparable to the emotion tasks, lexical control tasks include the *nonemotional word identification (NE WID)* task (e.g., “yellow, crooked crown” for the teeth category), the *nonemotional sentence identification (NE SID)* task (e.g., “He watched the concert until the end” for the vision category), and the *nonemotional word discrimination (NE WDIS)* task (e.g., “scarred, light” for the same item pertaining to “complexion”, and “tall, wise” for a different item pertaining to “body type” and “intelligence,” respectively). Two randomized stimulus sets were used for each of the nonemotional control tasks.

Data Analyses

Data inspection. Prior to testing specific hypotheses, data entry was double-checked and the data were inspected for outliers. In order to screen for outliers, scatterplots and boxplots were created for each of the experimental emotional tasks and nonemotional control tasks for each age group and the resulting charts were visually inspected for outliers. In addition, *z*-scores were calculated for each variable using the means and standard deviations of each age group. If the *z*-score indicated that a score fell more than 2.5 standard deviations above or below the mean of the participant’s age group, the score was inspected to determine whether it represented a true outlier or whether it represented normal variation within the sample.

Tests of normality and homogeneity of variance. A number of the planned analyses (e.g., ANOVA, Pearson’s product-moment correlations) are based on the assumption that data are normally distributed and the variance of each variable is approximately equal among groups. Therefore, the Shapiro-Wilk test (Shapiro & Wilk, 1965) was performed for each

of the experimental and nonemotional control tasks within each age group. In addition, the Levene's Test of Homogeneity of Variance (Levene, 1960) was also conducted for each variable.

Several of the variables tested had negatively skewed distributions and unequal variance (see Results section below). Therefore, attempts were made to transform the data so that the distribution more closely approximated normal distributions and the Shapiro-Wilk and Levene's tests were re-run for each variable.

Participant demographics. In order to ensure that the seven age groups were matched in terms of demographic characteristics, age groups were compared on key demographic variables (i.e., years of education, socioeconomic status, handedness, sex, and ethnicity). Group differences on the BDI were also compared, as research has shown emotion perception impairments in individuals with depression (Borod et al., 1990; Gur et al., 1992; Langenecker et al., 2005). For continuous variables (i.e., years of education, socioeconomic status, handedness [i.e., scores on Coren and Porac's (1978) lateral preference inventory], and BDI scores), differences among the seven age groups were examined using a one-way Analysis of Variance (ANOVA) with age group as the independent variable (IV). Chi-square tests were used to assess group differences in dichotomous variables, such as sex (male = 1, female = 2) and ethnicity (Caucasian = 1, non-Caucasian = 2). For exploratory purposes only, education was also examined as a dichotomous variable using a chi-square test (split was determined by calculating the median years of education).

Statistics specific to aims and hypotheses. Statistical analyses were conducted for each of the primary aims and hypotheses.

Aim I. To characterize the effect of age on the perception of discrete emotions across facial, prosodic, and lexical channels.

Hypothesis I: In order to test the first hypothesis that age would contribute significant amounts of variance to emotion perception ability, even after controlling for performance on nonemotional control tasks, multiple regression analyses were conducted separately for each of the seven experimental tasks (i.e., FID, PID, WID, SID, FDIS, PDIS, and WDIS). Multiple

regression procedures were chosen because of their robustness to minor deviations from the normal distribution (Mertler & Vannatta, 2009; Tabachnick & Fidell, 1996). Another advantage of multiple regression is that it enabled us to treat age as a continuous, rather than a categorical, variable.

In each of these analyses, the DV was the percentage correct for each task. The following control variables were used: FID – Visual Matrices Test (NYEB) and the Benton Facial Recognition Test (Benton et al., 1983); PID – Intonation Contours Task (NYEB) and Benton Phoneme Discrimination (Benton et al., 1983); SID – NE SID (NYEB); WID – NE WID (NYEB); FDIS – Visual Matrices Test (NYEB) and the Benton Facial Recognition Test (Benton et al., 1983); PDIS – Intonation Contours Test (NYEB) and Benton Phoneme Discrimination (Benton et al., 1983); WDIS – NE WDIS (NYEB). Age was also entered in the model, as a continuous variable, in order to determine the contribution of age to emotion perception ability after controlling for nonemotional perceptual ability. All predictors were entered simultaneously using the forced-entry method.

Hypothesis II and III: Hypotheses II and III both involved understanding age differences in performance on emotion perception tasks. As a number of the test variables had non-normal distributions, these hypotheses were initially tested with non-parametric procedures. Specifically, a series of Kruskal-Wallis Tests was conducted to investigate age differences in the identification of discrete emotions in the facial, prosodic, and lexical channels. A total of 32 analyses were conducted, one for each discrete emotion (n = 8) for each emotion identification task (n = 4). An additional three Kruskal-Wallis tests were conducted for each discrimination task, resulting in a total of 35 analyses. For each Kruskal-Wallis Test, the percent correct for each emotion was the dependent variable and age group was the independent variable. A Bonferroni correction was applied to control for Type I error across tests.

Hypothesis III was focused on the interaction among age, communication channel, and emotion type. However, it is not possible to test a three-way interaction using standard non-

parametric procedures. Therefore, two mixed-design repeated-measures ANOVAs were also conducted on accuracy scores of the identification tasks (Age Group [7: 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, & 80-89] x Channel [3: Facial, Prosodic, & Lexical] x Emotion [8: anger, disgust, fear, sadness, unpleasant surprise, pleasant surprise, happiness, & interest]). The FID and PID tasks were used in both ANOVAs. For the lexical channel, WID was used in one ANOVA, and SID was used in the second ANOVA. (This will be done for statistical purposes so that each channel has equal weight in the analyses conducted.) A third mixed-design repeated measures ANOVA was conducted on accuracy scores of the discrimination tasks in the facial, prosodic, and lexical channel (Age Group [7] x Channel [3]). Discrete emotions were not included in this analysis because the format of the discrimination tasks does not easily allow the isolation of individual discrete emotions. The DV for all three analyses was the percent correct for each task. The Greenhouse-Geisser correction was applied. Significant main effects were investigated using the Tukey-Kramer post-hoc test. The Tukey-Kramer method was chosen as a conservative method of post-hoc analysis for unequally sized samples. Tests of simple main effects were used to investigate significant interactions. To test Hypothesis II, which stated that older adults would perform significantly worse than young adults on emotion perception tasks, the main effect of age was examined. Hypothesis III stated that accuracy in the perception of discrete emotions would show a differential pattern of change with age, consistent with age-related changes in the brain. To test this hypothesis, we focused on understanding the interaction between age and emotion.

Aim II: To investigate the contribution of cognitive and sensory measures to emotion processing.

Hypothesis I: To investigate the hypothesis that associations among measures of emotion perception and auditory acuity would increase with age, the Spearman Rho statistic was calculated among these variables for each age group. A non-parametric analysis was selected because a number of test variables did not demonstrate normal distributions. In order to gain a more stable factor of auditory acuity, a weighted composite score was calculated by

converting each puretone threshold variable (i.e., left ear: 500, 1000, 2000; right ear: 500, 1000, 2000) into a *z*-score and then averaging the *z*-scores to create an aggregate variable. The new composite variable was correlated with the percent correct from each of the seven experimental tasks (i.e., FID, PID, WID, SID, FDIS, PDIS, and WDIS). Initially, analyses were conducted separately for each of the seven age groups (i.e., 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, & 80-89). Next, in order to increase power, the analyses were performed after dividing the sample into four age groups (Young: 20-39; Middle 40-59; Older: 60-79; Oldest-Old: 80-89). To simplify the comparisons among the age groups, the resulting correlations were collapsed over specific channels to derive the median correlation for each channel (i.e., Facial, Prosodic, and Lexical). Median correlations were then visually inspected to determine whether or not the magnitude of the correlations increased with age.

In order to objectively test age differences, Pearson product-moment correlations were also calculated among performance on emotion perception tasks and the puretone threshold composite score. The Pearson product-moment correlation was selected because it enabled statistical comparison among age groups using the Fisher's *z*-test. Median correlations were then compared across age groups using the Fisher's *z*-test for correlation coefficients in order to determine whether correlations were significantly higher for the older age group.

Hypothesis II: The second hypothesis for this aim stated that auditory acuity and cognitive measures would be significant predictors of emotion perception ability in older adults, but not in younger adults. In order to investigate this hypothesis, multiple regression analyses were conducted for each of the experimental tasks (i.e., FID, PID, WID, SID, FDIS, PDIS, and WDIS). In these analyses, the DV was the percentage correct for the experimental task. Predictors included auditory acuity (i.e., pure tone threshold composite score), performance on measures of cognition (i.e., WAIS-R Block Design, WAIS-R Information, WMS-R Logical Memory I & II, and completion time on Cancellation Task), and age. For these analyses, age was converted to a dichotomous variable (i.e., young = 0, old = 1). Interaction terms (age by

auditory acuity, age by cognition) were calculated and included in additional multiple regression models. All predictors were entered simultaneously using the forced-entry method.

Results

Data Inspection

Prior to testing specific hypotheses, the data were inspected for outliers. For the experimental tasks, 5 scores fell 2.5 standard deviations below the mean, and no scores were greater than 2.5 standard deviations above the mean. For the nonemotional control tasks, 14 scores fell 2.5 standard deviations below the mean, and 2 scores were greater than 2.5 standard deviations above the mean. Each of these scores was investigated and it was determined that most of the outliers represented normal variability in performance. Therefore, the scores were included in subsequent analyses. Only one score was determined to be the result of experimental error (Visual Matrices = 5; 56 year-old Caucasian man with 11 years of education), and it was removed from subsequent analyses.

Tests of Normality and Homogeneity of Variance

Shapiro-Wilk Tests of Normality (Shapiro & Wilk, 1965) were performed for all emotion perception tasks (i.e., FID, PID, SID, WID, FDIS, PDIS, and WDIS) for both total scores and for individual emotion scores, as well as for the nonemotional control tasks. When the total score was used, results indicated that distributions were non-normal for a majority of the age groups for the following tasks: WID, PDIS, and WDIS. See Tables 1 and 2 of the Appendix. When these tests were conducted using the individual emotion scores, results indicated that the majority of age groups had non-normal distributions for all emotions in the four identification tasks. Results of these analyses are presented in Tables 3 – 6 of the Appendix. With regard to the nonemotional control tasks, results of the Shapiro-Wilk tests indicated that the majority of age groups had non-normal distributions for the following tasks: the NE WID, NE WDIS, Visual Matrices, Intonation Contours, Benton Phoneme Discrimination, and the Beck Depression Inventory. See Table 7 of the Appendix.

In addition, the Levene's Test of Homogeneity of Variance (Levene, 1960) was conducted for each emotion perception and nonemotional control task. When the total score was used for each emotion perception task, results indicated unequal variances among the age groups for the

following tasks: FID, PID, WID, FDIS, and PDIS. For the individual emotion scores, unequal variances were also observed for the following emotions in each task: FID (Sad and Pleasant Surprise), PID (Anger and Unpleasant Surprise), WID (Anger, Sad, Unpleasant Surprise, Pleasant Surprise, Happy, Disgust, and Interest), and SID (Sad, Fear, Unpleasant Surprise, and Disgust). Finally, for the nonemotional control task, results of the Levene's test indicated unequal variances for NE SID, Visual Matrices, Benton Facial Recognition, Intonation Contours, Benton Phoneme Discrimination, and the Beck Depression Inventory. See Tables 1-7 of the Appendix.

Several attempts were made to normalize the data using reverse score, square root, and logarithmic transformations, but these attempts were largely unsuccessful. Therefore, non-parametric procedures were conducted as appropriate. Multiple regression procedures are relatively robust for minor deviations from normality (Mertler & Vannatta, 2009; Tabachnick & Fidell, 1996), so residuals were plotted to enable visual inspection of the distributions (see Figures 1-7 in the Appendix for normal P-P plots and normal detrended P-P plots for each task). Visual inspection of these plots did not indicate gross departures from normality, indicating it was acceptable to proceed with the multiple regression procedures. Initially, non-parametric analyses (i.e., Kruskal-Wallis tests) were used to test age group differences. However, the primary hypotheses related to understanding the interactions among age, channel, and emotion. As it is not possible to test a three-way interaction using standard non-parametric procedures and because the ANOVA procedure is relatively robust at least to violations of homoscedasticity (Lix & Keselman, 1998; Ramsey, 1994), a series of mixed-design repeated-measures ANOVAs were also conducted to test age differences on an exploratory basis. Finally, Spearman's rho statistics were calculated to examine the relationship between auditory acuity and emotion perception. As the Fisher's z-test is not designed for use with the Spearman statistic, Pearson's product-moment correlations were also calculated.

Demographic Characteristics

In the current project, we expanded our sample to include 18 healthy adults in the 80-89 year age group. Thus, the final sample consisted of 117 healthy adults, ranging in age from 20-89 years. The demographic characteristics of the sample are listed in Table 2. Analyses comparing demographic variables across the seven age groups indicated that there were no significant differences for education ($F[6,110] = 1.047, p = .40$), socioeconomic status ($F[6,109] = 1.476, p = .19$), handedness (i.e., scores on lateral preference inventory; $F[6, 108] = 0.845, p = .54$), gender ($\chi^2[6] = 6.002, p = .42$), or ethnicity (i.e., Caucasian vs. Non-Caucasian; $\chi^2[6] = 5.456, p = .49$). See Table 3.

Aim I: Age-related differences in discrete emotions across communication channels

For Aim I, a series of analyses was conducted in order to identify and describe age differences in the perception of eight individual discrete emotions in the facial, prosodic, and lexical channels. Analyses were also included to examine the relationships among aging, emotion perception ability, and nonemotional perception. Results of these analyses are presented below. Descriptive statistics for the seven experimental tasks for each age group are presented in Table 4.

Hypothesis I. To test the hypothesis that age would contribute a significant proportion of variance to performance on measures of emotion perception ability, multiple regression analyses were performed for all experimental tasks. In order to examine the contribution of nonemotional perceptual ability, raw scores from the nonemotional control tasks were entered as predictors. Age was also entered in the model, as a continuous variable, to identify the contribution of age to emotion perception ability after controlling for performance on the nonemotional control tasks. All predictors were entered simultaneously using the forced-entry method. Descriptive statistics for the nonemotional control tasks for each age group are presented in Table 5.

Facial identification. For the FID task, the Benton Facial Recognition and Visual Matrices tests were used as nonemotional control tasks. See Table 6. There was a significant overall model (i.e., Model 3) for Visual Matrices, Benton Facial Recognition, and age, $R^2 = .422$, $F = 26.774$, $p < .001$. Significant effects were observed for the Benton Facial Recognition Test ($t = 4.551$, $p < .001$) and age ($t = -6.209$, $p < .001$), but not for the Visual Matrices Test ($t = 1.556$, $p = .123$). When age was added to the model, it explained an additional 20.3% of the variance in performance after accounting for performance on the nonemotional control tasks, R^2 change = .203, $F = 38.548$, $p < .001$.

Prosodic identification. Nonemotional control tasks for PID included the Benton Phoneme Discrimination Test and the Intonation Contours Perception Test. When both tests were entered along with age, the resulting model (i.e., Model 3) accounted for 46.8% of the variance in PID scores, $R^2 = .468$, $F = 32.842$, $p < .001$. See Table 7. Performance on the Intonation Contours Perception Test explained a significant proportion of the variance in PID scores ($t = 3.169$, $p = .002$), but the Phoneme Discrimination Test did not ($t = 1.721$, $p = .088$). Age was also a significant predictor of performance ($t = -6.171$, $p < .001$), explaining an additional 18.1% of the variance in performance after accounting for performance on the nonemotional control tasks, R^2 change = .181, $F = 38.085$, $p < .001$.

Lexical word identification. Results of the multiple regression analysis indicated that the final model (i.e., Model 2), which included both NE WID and age, was significant, $R^2 = .355$, $F = 31.391$, $p < .001$. See Table 8. NE WID was a significant predictor of performance, $t = 4.981$, $p < .001$. When age was added to the model, it explained an additional 11% of the variance in performance (R^2 change = .110, $F = 19.371$, $p < .001$) and was also a significant predictor of performance, $t = -4.401$, $p < .001$.

Lexical sentence identification. For SID, there was a significant overall model (i.e., Model 2), which included both NE SID and age, $R^2 = .196$, $F = 13.856$, $p < .001$. See Table 9. However, age was the only significant predictor of performance, $t = -3.997$, $p < .001$.

Facial discrimination. The Visual Matrices and Benton Facial Recognition Tests were included as nonemotional control tasks for the Facial Discrimination Test. When both tests were entered along with age, the overall model (i.e., Model 3) was significant, accounting for 30.9% of the variance, $R^2 = .309$, $F = 16.400$, $p < .001$. See Table 10. Both the Visual Matrices ($t = 3.263$, $p = .001$) and Benton Facial Recognition ($t = 2.306$, $p = .023$) tests were significant predictors of performance on FDIS. Age also explained a significant proportion of the variance of FDIS scores, $t = -4.239$, $p < .001$. Age accounted for an additional 11.3% of the variability in performance on the FDIS task after accounting for performance on the nonemotional control tasks, R^2 change = .113, $F = 17.966$, $p < .001$.

Prosodic discrimination. The Benton Phoneme Discrimination and Intonation Contours Perception tests were used as nonemotional control tasks for PID. When both tests were entered, along with age, the overall model (i.e., Model 3) was significant ($R^2 = .115$, $F = 4.833$, $p = .003$), but only age was a significant predictor of performance on the PDIS task $t = -2.416$, $p = .017$. Neither the Benton Phoneme Discrimination ($t = .221$, $p = .826$) nor Intonation Contours Perception ($t = 1.640$, $p = .104$) tests were significant predictors of performance. See Table 11.

Lexical word discrimination. For WDIS, the overall model (i.e., Model 2), which included age, was significant ($R^2 = .273$, $F = 21.440$, $p < .001$), but NE WDIS was the only significant predictor, $t = 5.788$, $p < .001$. Age did not contribute significantly to the variance in performance, $t = -.790$, $p = .431$. See Table 12.

Hypotheses II and III. Hypotheses II and III related to understanding differences in performance on emotion perception tasks as a function of age. Hypothesis II stated that older adults would perform worse than younger adults on emotion perception tasks; and Hypothesis III stated that accuracy of the perception of discrete emotions would show age differences, with decreased recognition accuracy for older adults relative to younger adults observed for some emotions, but not others. As a number of the test variables had non-normal distributions, hypotheses were tested with both non-parametric (i.e., Kruskal-Wallis test) and parametric (i.e.,

ANOVA) procedures. Results are reported below.

Non-parametric analyses. A series of Kruskal-Wallis tests was conducted to evaluate age differences in performance on emotion perception tasks for each channel. A total of 32 analyses were conducted, one for each discrete emotion ($n = 8$) for each emotion perception task ($n = 4$). An additional three Kruskal-Wallis tests were run for each discrimination task, resulting in a total of 35 analyses. A Bonferroni correction was applied to control for Type I error across tests. Therefore, tests were reported as significant at $p < .002$.

Facial identification. A total of eight Kruskal-Wallis tests were conducted with the total accuracy score for each discrete emotion on FID as the dependent variable and age as an independent variable. Results of these analyses indicated a significant age difference for the Fear items, $H(6) = 33.44, p < .001$. Age differences were not observed for any other emotions after applying the Bonferroni correction (see Table 13). Follow-up tests were conducted to evaluate pairwise differences among the age groups, controlling for Type I error across tests by using the Bonferroni correction. However, after applying the correction, there were no significant differences among age groups.

Prosodic identification. Eight Kruskal-Wallis tests were conducted with the total scores for each discrete emotion as dependent variables and age as an independent variable. Results of these analyses indicated significant age differences for Fear ($H[6] = 33.601, p < .001$), Happy ($H[6] = 33.515, p < .001$), and Interest ($H[6] = 33.611, p < .001$) items. See Table 13. Follow-up pairwise comparisons were conducted, controlling for Type I error with the Bonferroni correction. For *Fear* items, pairwise comparisons indicated that individuals in the 70-79 and 80-89 year age groups scored significantly lower than those in the 20-29 and 30-39 year age groups. For *Happy* items, follow-up pairwise comparisons indicated that individuals in the 80-89 year age group performed significantly worse than individuals in the 20-29 year age group. Finally, for *Interest* items, individuals in the 70-79 year age group scored significantly lower than participants in the 20-29 and 30-39 year age groups.

Lexical word identification. A series of eight Kruskal-Wallis tests were conducted to

examine age differences in the perception of discrete emotions on the lexical word identification task. Following the Bonferroni correction, results demonstrated significant age differences only for Pleasant Surprise items, $H(6) = 24.697, p < .001$. See Table 13. However, follow-up pairwise comparisons did not indicate any significant age differences after the Bonferroni correction was applied.

Lexical sentence identification. Eight Kruskal-Wallis tests were conducted with the scores for each emotion on the lexical sentence identification test as dependent variables and age as an independent variable. Results indicated significant age differences only on the *Pleasant Surprise* items, $H(6) = 26.235, p < .001$. See Table 13. Follow-up pairwise comparisons indicated that, after applying the Bonferroni correction, participants in the 80-89 year age group performed significantly worse than those in the 20-29 year age group.

Facial discrimination. The Kruskal-Wallis test comparing performance among age groups on the facial discrimination task was significant, $H(6) = 24.696, p < .001$. However, follow-up pairwise comparisons did not indicate any significant age differences after applying the Bonferroni correction.

Prosodic discrimination. A Kruskal-Wallis test was conducted with scores on the prosodic discrimination as the dependent variable and age as an independent variable. Results indicated that there were no significant age differences on the prosodic discrimination task, $H(6) = 11.590, p = .072$.

Lexical word discrimination. A Kruskal-Wallis test was conducted with scores on the lexical word discrimination test to examine age differences in performance. Results indicated that there was not a significant age difference on this test, $H(6) = 8.351, p = .241$.

Parametric analyses with identification tasks using WID for the lexical channel. In order to investigate the interaction among age, communication channel, and discrete emotions, a series of mixed-design repeated-measures ANOVAs were conducted on accuracy scores from the emotion perception tasks, separately for identification and discrimination tasks.

The first mixed-design ANOVA was conducted using accuracy scores of the identification tasks (Age Group [7] x Channel [3] x Emotion [8]), with WID for the lexical task. See Table 14 for a summary of the results from the ANOVA.

Main effect of age. Results from this analysis indicated a significant main effect of age on identification task scores, $F(6, 110) = 12.450, p < .001$. See Figure 1. Tukey's HSD post-hoc analyses indicated that participants in the 70-79 and 80-89 year age groups had significantly lower scores than all other age groups. There was no significant difference between the 70-79 and 80-89 age groups. Furthermore, there were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups.

Main effect of channel. There was also a significant main effect of channel, $F(1.623, 178.49) = 356.806, p < .001$, such that performance on PID ($M = 55.91 \pm 18.30$) was significantly worse than performance on FID ($M = 71.61 \pm 12.62$) or WID ($M = 86.11 \pm 12.39$). Furthermore, performance on FID was significantly worse than on WID. See Figure 2.

Main effect of emotion. The main effect of emotion was also significant, $F(6.394, 703.30) = 11.467, p < .001$. See Figure 3. Pairwise comparisons indicated that participants obtained significantly higher scores on the Anger items than on the Disgust, Happy, Unpleasant Surprise, Pleasant Surprise, Interest, and Fear items. There was no significant difference between Anger and Sad items. Participants scored significantly higher on the Sad items than on the Fear, Interest, or Unpleasant Surprise items. There were no significant differences among performance on the Disgust, Happy, Unpleasant Surprise, Pleasant Surprise, Interest, and Fear items.

Interaction between channel and age. Several significant interaction effects modified the main effects described above. First, a significant interaction effect was observed between channel and age, $F(9.736, 178.49) = 2.502, p = .008$. To investigate this interaction, tests of simple main effects were performed two ways: first by comparing performance in each channel separately for each age group, and then by comparing age differences within each communication channel. The first method indicated that the pattern of performance among

channels was the same for all age groups: performance on FID was higher than performance on PID, and performance on WID was higher than both channels. However, interactions emerged when examining age differences within each communication channel. See Figure 4.

Visual inspection of Figure 4 indicates that performance in the lexical channel remains relatively stable through the 60s, before age differences emerge in the 70s and 80s. In contrast, age differences occurred more gradually within the prosodic and facial channels, with age differences beginning around age 50 (facial channel) or 60 (prosodic channel).

These observations were confirmed with pairwise comparisons. Results of these analyses indicated that for the *facial channel*, individuals in the 70-79 and 80-89 year age groups performed significantly worse than those in the 20-29, 30-39, and 40-49 year age groups. There were no significant differences among the 50-59, 60-69, 70-79, and 80-89 year age groups. Furthermore, there were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups. For the *prosodic channel*, individuals in the 70-79 and 80-89 year age groups attained significantly lower scores than individuals in the 20-29, 30-39, and 40-49 year age groups. There were no significant differences in performance between the 70-79 and 80-89 year age groups. Results also showed that the 60-69 and 70-79 year age groups were not significantly different. Finally, the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups were not significantly different from each other. For the *lexical channel* (i.e., WID), individuals in the 70-79 and 80-89 year groups attained scores that were significantly lower than individuals in the 20-29, 30-39, 40-49, and 60-69 year age groups. There were no significant differences in performance among the 50-59, 70-79, and 80-89 year age groups. There were also no group differences among the 20-29, 30-39, 40-49, and 60-69 year age groups.

Interaction between channel and emotion. Results of the mixed-design ANOVA also indicated a significant interaction between emotion and channel, $F(11.463, 1260.968) = 16.458$, $p < .001$. See Figure 5. To investigate this interaction, pairwise comparisons were conducted to examine differences in performance in each communication channel for each discrete emotion. Results indicated that for Anger and Sadness, performance on WID was significantly better than

performance on either FID or PID. There was no significant difference between FID and PID. For Fear and Happy items, performance on WID and FID were significantly higher than PID and there was not a significant difference between WID and FID. Finally, for the remaining emotions (i.e., Unpleasant Surprise, Pleasant Surprise, Disgust, and Interest), performance on WID was significantly better than both FID and PID and performance on FID was better than performance on PID.

Interaction between emotion and age. In addition, there was a significant interaction between emotion and age group, $F(38.363, 703.30) = 1.728, p = .005$. Significant effects of age were observed for all emotions except for disgust. The pattern of age-related differences in performance varied according to emotion. See Figure 6. For *Anger* items, individuals in the 80-89 year age groups had significantly lower scores than individuals in the 20-29, 30-39, and 40-49 year age groups. The 70-79 year age group also scored significantly lower than the 20-29 year age group. There were no significant differences among the 30-39, 40-49, 50-59, 60-69, and 70-79 year age groups. There were also no significant differences among the 50-59, 60-69, 70-79 and 80-89 year age groups.

For *Sad* items, participants in the 70-79 and 80-89 year age group scored significantly lower than participants in the 20-29, 30-39, and 40-49 year age groups. There were no significant differences among the 50-59, 60-69, 70-79, and 80-89 year age groups. Finally, there were no significant differences among the 20-29, 30-39, and 40-49 year age groups.

For *Fear* items, participants in the 70-79 and 80-89 year age groups scored significantly lower than the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups. There was no significant difference between the 70-79 and 80-89 year age groups. Furthermore, there were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups.

For *Unpleasant Surprise* items, individuals in the 70-79 and 80-89 year age groups performed significantly worse than those in the 20-29 year age group. In addition, individuals in the 70-79 year age group performed significantly worse than individuals in the 40-49 year age group. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69

year age groups. Nor were there significant differences among the 30-39, 50-59, 60-69, 70-79, and 80-89 year age groups.

For *Disgust* items, there were no significant differences among any of the age groups.

For *Pleasant Surprise* items, individuals in the 80-89 year age groups scored significantly lower than individuals in the 20-29 year age group. There were no significant differences among any other age groups for the pleasant surprise items.

For *Happy* items, individuals in the 70-79 and 80-89 year age group scored significantly lower than individuals in the 20-29 year age groups. In addition, participants in the 80-89 year age group performed significantly worse than those in the 30-39 and 40-49 year age groups. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups. Nor were there any significant differences among the 50-59, 60-69, 70-79, and 80-89 year age groups.

Finally, for *interest* items, individuals in the 70-79 and 80-89 year age groups performed significantly worse than those in the 20-29, 30-39, and 40-49 year age groups. Furthermore, individuals in the 70-79 year age group scored significantly lower than the 50-59 and 60-69 year age groups. There were no significant differences among individuals in the 20-29, 30-39, 40-49, 50-59, and 60-69. There were also no significant differences among the 50-59, 60-69, and 80-89 year age groups, or between the 70-79 and 80-89 year age groups.

Interaction among age, channel, and emotion. The interactions described above were superseded by a significant three-way interaction among age, channel, and emotion, $F(68.780, 1260.968) = 1.336, p = .038$. In order to examine the interaction, two-way ANOVAs (Age group [7] x Channel [3]) were run separately for each emotion. Focus was placed upon understanding the interactions between age and channel for each of the emotions tested, rather than on main effects.

A significant interaction was observed between channel and age for Happy and Interest items, but not for any other emotions. To better understand these interactions, pairwise comparisons were conducted comparing performance within each channel for each age group

within each emotion. With regard to *Interest* items, results of the pairwise comparisons indicated that for the 20-29, 30-39, 40-49, and 50-59 year age groups, performance on the facial and prosodic identification tasks was significantly worse than performance on the lexical word identification task. There was not a significant difference between performance on the facial and prosodic tasks for these age groups. However, a different pattern was observed for the 60-69, 70-79, and 80-89 year age groups: performance on the prosodic channel was significantly worse than performance on the facial channel and performance in both channels was significantly worse than performance in the lexical channel. To better understand this interaction, a bar graph was created (see Figure 7). Visual inspection of this graph indicates that whereas performance in the lexical and facial channel gets worse with age beginning around age 70, performance in the prosodic channel declines more steeply with age and differences are observed somewhat earlier (i.e., around age 60).

Similarly, for *Happy* items, an interaction was observed between channel and age such that larger age differences were observed for the prosodic identification task as compared to the other channels. Specifically, for the 20-29 and 40-49 year age groups, there were no differences in performance among the three communication channels. However, for the 30-39, 50-59, 60-69, 70-79, and 80-89 year age groups, scores on the prosodic identification task were significantly lower than scores on both the facial and lexical word identification tasks. There were no group differences in performance between the facial and lexical channels. To better understand this analysis, the data were visually inspected. See Figure 7. Visual inspection of this graph indicated that, whereas performance in the lexical and facial channels remains relatively stable across the seven age groups, performance in the prosodic channel declines steeply.

Parametric analyses with identification tasks using SID for the lexical channel. A second mixed-design repeated measures ANOVA (Age group [7] x Channel [3] x Emotion [8]) was conducted for the identification tasks using SID for the lexical channel. See Table 15 for a summary of the results of the ANOVA.

Main effect of age. Results of this analysis indicated a significant main effect of age, $F(6, 110) = 11.757, p < .001$. See Figure 8. Tukey's HSD tests indicated that participants in the 70-79 and 80-89 year age groups did not differ from each other and that both groups had significantly lower scores than all the other age groups. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups.

Main effect of channel. In addition, there was a significant main effect of channel, $F(1.921, 211.356) = 161.747, p < .001$, such that overall performance on PID ($M = 55.91 \pm 18.30$) was significantly worse than on FID ($M = 71.61 \pm 12.62$) or SID ($M = 78.17 \pm 14.68$). Furthermore, performance on FID was significantly worse than performance on SID. See Figure 9.

Main effect of emotion. A significant main effect of emotion was also observed, $F(6.385, 702.302) = 10.016, p < .001$. See Figure 10. Pairwise comparisons indicated that participants scored significantly higher on the Sad items than all other emotion items. In addition, participants obtained significantly higher scores on the Anger items than the Disgust, Pleasant Surprise, Unpleasant Surprise, and Interest items. There was no significant difference between the Anger and Sad items. Participants performed significantly better on the Happy items than the Interest items. There were no significant differences observed among the Happy, Fear, Disgust, Pleasant Surprise, and Unpleasant Surprise items. Furthermore, there were no significant differences among the Fear, Disgust, Unpleasant Surprise, Pleasant Surprise, and Interest items.

The main effects described above are modified by several significant interactions, which are described below.

Interaction between channel and emotion. A significant interaction was observed between channel and emotion, $F(11.919, 1311.126) = 12.011, p < .001$. Pairwise comparisons were conducted in order to examine the differences in performance in each communication channel for each discrete emotion. See Figure 11 for a summary of these comparisons. Results indicated that for Anger, there were no significant differences among scores on the FID, PID,

and SID tasks. Significant differences among scores in all channels were observed for all other emotions. For Sadness, scores on SID were significantly higher than scores on either FID or PID, but there was no significant difference between scores on FID and PID. For Fear, Happiness, and Disgust, scores on both SID and FID were significantly higher than scores on PID. There was no difference between performance on SID and FID. Finally, on Unpleasant Surprise, Pleasant Surprise, and Interest, performance on SID was significantly better than performance on FID and PID, and performance on FID was significantly better than performance on PID. See Figure 11.

Interaction between emotion and age. In addition, there was a significant interaction between emotion and age, $F(38.307, 702.302) = 1.516, p = .025$. Significant effects of age were observed for all emotions except disgust. The pattern of performance in each age group varied by emotion. See Figure 12. Specifically, for *Anger* items, individuals in the 70-79 and 80-89 year age group had significantly lower scores than individuals in the 20-29 year age group. In addition, individuals in the 80-89 year age group performed significantly worse than those in the 30-39 year age group. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups. Nor were there significant differences among the 40-49, 50-59, 60-69, 70-79, and 80-89 year age groups.

For *Sad* items, individuals in the 70-79 and 80-89 year age groups scored significantly lower than individuals in the 20-29, 30-39, and 40-49 year age groups. Individuals in the 70-79 year age group performed significantly worse than the 60-69 year age group, but there was no significant difference between the 60-69 and 80-89 year age groups. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups. Nor were there significant differences among the 50-59, 70-79, and 80-89 year age groups.

A similar pattern emerged for *Fear* items. Pairwise comparisons showed that individuals in the 70-79 and 80-89 year age groups performed significantly worse than those in the 20-29, 30-39, and 40-49 year age groups. Individuals in the 70-79 year age group performed significantly worse than the 50-59 year age groups, but there were no significant difference

between the 50-59 and 80-89 year age groups. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups. Nor were there significant differences among the 60-69, 70-79, and 80-89 year age groups.

For *Unpleasant Surprise* items, individuals in the 70-79 and 80-89 year age groups obtained significantly lower scores than individuals in the 20-29 year age groups. Furthermore, individuals in the 70-79 year age groups scored significantly lower than individuals in the 40-49 year age groups. There were no significant differences among the 30-39, 50-59, 60-69, 70-79 and 80-89 year age groups. Nor were there any differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups.

When examining *Disgust* items, pairwise comparisons did not indicate any significant differences among age groups.

For *Pleasant Surprise* items, participants in the 80-89 year age groups scored significantly lower than those in the 20-29 and 50-59 year age groups. There were no significant differences among the 20-29, 30-39, 40-49, 50-59, 60-60, and 70-79 year age groups. Nor were there significant differences among the 30-39, 40-49, 60-69, 70-79, and 80-89 year age groups.

For *Happy* items, individuals in the 50-59, 60-69, 70-79, and 80-89 year age groups scored significantly lower than those in the 20-29 year age groups. Furthermore, participants in the 80-89 year age group also scored significantly lower than individuals in the 40-49 year age group. There were not significant differences among the 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89 year age groups. Nor were there significant differences among the 20-29, 30-39, and 40-49 year age groups.

Finally, for *Interest* items, individuals in the 70-79 and 80-89 year age groups performed significantly worse than the 20-29 and 30-39 year age groups. In addition, participants in the 70-79 year age group scored significantly lower than the 40-49, 50-59, and 60-69 year age groups. There were no differences among the 20-29, 30-39, 40-49, 50-59, and 60-69 year age groups, or among the 40-49, 50-59, 60-69, and 80-89 year age groups.

Interaction among age, channel, and emotion. The interactions described above were superseded by a significant three-way interaction among age, channel, and emotion, $F(71.516, 1311.126) = 1.407, p = .016$, such that the interaction between channel and age varied according to the type of emotion. See Figure 7. In order to examine the interaction, two-way ANOVAs (Age Group [7] x Channel [3]) were run separately for each emotion. Focus was placed upon understanding the interactions between age and channel for each of the emotions tested, rather than on the main effects.

A significant interaction was observed between channel and age for Happy and Fear items, but not for any other emotions. To better understand these interactions, pairwise comparisons were conducted comparing performance in each channel for each age group within each emotion. With regard to the *Fear* items, results of the pairwise comparisons indicated that there was not a significant difference among the channels for the 20-29, 30-39, 40-49, and 50-59 year age groups. However, for the 60-69, 70-79, and 80-89 year age groups, performance on the prosodic channel was significantly worse than performance on both the facial channel the lexical channel, and there was not a significant difference between the facial and lexical channels. To better understand this interaction, a bar graph was created (Figure 7). Visual inspection of this graph indicates that whereas performance in the lexical and facial channel gets worse with age beginning around age 70, performance in the prosodic channel declines more steeply with age and differences are observed somewhat earlier (i.e., around age 60).

For *Happy* items, the pattern was the same as the description above for the ANOVA using WID for the lexical channel. Specifically, for the 20-29 and 40-49 year age groups, there were no differences in performance among the three communication channels, but for the 30-39, 50-59, 60-69, 70-79, and 80-89 year age groups, scores on the prosodic identification task were significantly lower than scores on both the facial and lexical word identification tasks. There were no group differences in performance between the facial and lexical channels.

Parametric analyses with discrimination tasks. A third mixed-design repeated

measures ANOVA (Age Group [7] x Channel [3]) was conducted for the discrimination tasks (i.e., FDIS, PDIS, WDIS). See Table 16 for a summary of the results of the ANOVA.

Main effect of age. There was a significant main effect of age on the mean of the discrimination task scores, $F(6, 110) = 4.068, p < .001$. See Figure 13. Tukey's HSD post-hoc analyses were performed and results indicated that participants in the 70-79 and 80-89 year age groups had significantly lower scores than participants in the 20-29 year age groups. There were no significant differences among scores in any other age group.

Main effect of channel. Results of the ANOVA also indicated a significant main effect of channel, $F(1.820, 200.164) = 112.822, p < .001$, such that performance on the PDIS task was significantly higher than performance on either FDIS or WDIS. There was no significant difference between scores on the FDIS and PDIS tasks. See Figure 14.

Interaction between channel and age. The interaction between channel and age was not significant, $F(10.918, 200.164) = 1.188, p = .298$.

Aim II: Relationships among cognitive test performance, auditory acuity, and emotion perception ability

For Aim II, a series of correlation and regression analyses was conducted in order to characterize relationships among emotion perception ability, auditory acuity, and cognitive functions. Results of these analyses are described below.

Hypothesis I. To test the first hypothesis, which states that associations among measures of emotion perception and auditory acuity will increase with age, Spearman rho statistics were calculated between auditory acuity and the percent correct for each experimental task (i.e., FID, PID, WID, SID, FDIS, PDIS, and WDIS) for each age group. The correlations were collapsed across task by determining the median correlation for each age group. The median scores for the seven age groups, in order, were: -.159, -.239, .113, -.160, -.129, .124, and -.436. See Table 17.

In order to increase power, the groups were further combined into four age groups: Young (20-39), Middle (40-59), Older (60-79), and Oldest-Old (80-89). Median correlations for these groups, in order, were: -.189, -.056, -.083, and -.436. See Table 18.

Pearson product-moment correlations were also calculated between the auditory acuity composite score and the percent correct for each experimental task for each age group, in order to enable comparison of the correlations with the Fisher's *z*-test. Median scores for the seven age groups, in order, were: -0.142, -0.161, 0.139, -0.160, -0.170, 0.139, and -.391. See Table 19. Scores were compared using Fisher's *z*-test for Pearson's *r*. Although the correlation for the oldest age group appears to be larger than the other groups, none of the comparisons was significant. See Table 21. When the data were combined into four age groups, median correlation coefficients, in order, were: -0.152, -0.131, -0.129, and -0.391. See Table 20. These scores were compared using Fisher's *z* test for Pearson's *r*, but none of the comparisons were significant. See Table 22.

Hypothesis II. To examine the effect of age, cognitive function, and auditory acuity on emotion perception ability, multiple linear regression analyses were performed with each of the emotion perception tasks as the dependent variables and with auditory acuity (i.e., pure tone threshold composite score) and performance on cognitive measures (i.e., WAIS-R Block Design, WAIS-R Information, WMS-R Logical Memory I, and completion time on the Cancellation Task) as the predictor variables. For these analyses, age was coded as a dichotomous variable with a median split (i.e., "0" = less than or equal to age 52; "1" = older than age 52) and entered as a predictor to identify the contribution of age to emotion perception ability after controlling for performance on the cognitive and sensory tasks. An interaction term (i.e., age by auditory acuity) was also calculated and included in the model. All predictors were entered simultaneously using the forced-entry method.

Facial identification. Multiple regression analyses indicated that there was a significant overall model, $R^2 = .401$, $F = 8.615$, $p < .001$. However, the only significant predictors in this model were the Cancellation Task Time ($t = -2.623$, $p = .010$) and WAIS-R

Information ($t = 2.603, p = .011$). There were no other significant predictors in the model. See Table 23.

Prosodic identification. For PID, the overall model was significant, $R^2 = .515, F = 13.697, p < .001$, but age was the only significant predictor of performance on PID ($t = -2.736, p = .007$). See Table 24.

Lexical word identification. Results of the multiple regression analysis indicated that there was a significant overall model, $R^2 = .466, F = 11.243, p < .001$. For this model, WAIS-R Information ($t = 4.128, p < .001$) and WMS-R Logical Memory I ($t = 2.013, p = .047$) were the only significant predictors of performance on WID. See Table 25.

Lexical sentence identification. For SID, there was a significant overall model, $R^2 = .516, F = 13.711, p < .001$, but the Cancellation Task Time ($t = -2.101, p = .038$) and WAIS-R Information ($t = 5.144, p < .001$) were the only significant predictors of performance. There were no other significant predictors in the model. See Table 26.

Facial discrimination. For FDIS, there was a significant overall model, $R^2 = .397, F = 8.482, p < .001$. WAIS-R Information ($t = 3.050, p = .003$) and age ($t = 3.05-3.441, p = .001$) were both significant predictors of performance on FDIS. There were no other significant predictors in the model. See Table 27.

Prosodic discrimination. Results of the multiple regression analysis showed a significant overall model, $R^2 = .370, F = 2.046, p < .048$, but there were no significant predictors of performance. See Table 28.

Lexical word discrimination. Results of the multiple regression analysis indicated a significant overall model, $R^2 = .437, F = 10.002, p < .001$. In this model, scores on the WAIS-R Information ($t = 5.047, p < .001$) and Block Design ($t = 2.433, p = .017$) tests were significant predictors of performance on the WDIS test. There were no other significant predictors. See Table 29.

Discussion

Summary of Results

The primary goal of this project was to characterize age-related differences in the perception of discrete emotions across facial, prosodic, and lexical channels of communication. Using the NYEB (Borod et al., 1992b), a comprehensive battery of tests examining the perception, expression, and experience of emotion, we demonstrated that older adults had more difficulty recognizing emotions than younger adults across all three channels of communication. Age was related to performance for all tasks, even after controlling for nonemotional control tasks. When examining age differences among the seven age groups, results indicated that, overall, emotion perception abilities remained relatively stable until around age 70, at which point a steep decline in ability was observed. Results of both parametric and non-parametric analyses also suggested that age differences may be specific to certain channels and emotions, with the most significant differences occurring in the prosodic channel for fear, happiness, and interest. Finally, an examination of the relationship among auditory acuity, cognitive functions, age, and emotion perception ability indicated that certain cognitive tasks (i.e., a cancellation task and the WAIS-R Information) might be stronger predictors of performance on emotion perception tasks than either age or auditory acuity.

Age differences in emotion perception. The primary goal of this project was to characterize age differences in emotion perception across facial, prosodic, and lexical channels of communication. To examine the effect of age, multiple regression analyses were conducted, which demonstrated that age was related to emotion perception ability on both identification and discrimination tasks in all three channels. In an effort to further characterize the impact of age on emotion perception ability, the sample was divided into seven age groups. Age differences among the groups were investigated with mixed-design repeated measures ANOVAs, separately for identification and discrimination tasks. With regards to age, results of these analyses indicated that, overall, older adults were less accurate at recognizing emotions than the younger participants. For both the identification and discrimination tasks, age differences

emerged in the eighth and ninth decades of life (i.e., in the 70s and 80s). These results were consistent with previous work in the area, which has demonstrated age differences in emotion perception accuracy (e.g., Allen & Brosigole, 1993; Grunwald et al., 1999; Moreno et al., 1993; Orbelo et al., 2005; Oscar-Berman et al., 1990).

Age differences in the perception of discrete emotions across facial, prosodic, and lexical channels. Previous research has suggested that there may be a differential change in emotion perception according to emotion type, with the perception of some emotions declining with age and the perception of other emotions remaining relatively stable across the life span (e.g., Allen & Brosigole, 1993; Calder et al., 2003; Malatesta et al., 1987; Schaffer et al., 2009). Therefore, in order to more fully characterize the nature of the observed age differences in emotion perception, another primary aim of the current study was to examine age differences in individual discrete emotions across multiple communication channels. To that end, non-parametric (i.e., Kruskal-Wallis Test) and parametric (i.e., mixed-design repeated measures ANOVAs) analyses were conducted to characterize the recognition accuracy of eight discrete emotions on identification tasks within the three communication channels. Of note, discrimination tasks were not used for these analyses because the format of the discrimination tasks does not easily allow for isolation of individual emotions.

Results of both non-parametric and parametric analyses were largely consistent, indicating that the pattern of age differences varied according to emotion type and channel; older adults were less accurate than younger adults in recognizing fear, interest, and happiness within the prosodic channel. To the best of our knowledge, the current study represents the first attempt to characterize age differences in the perception of discrete emotions across the facial, prosodic, and lexical channel in the same sample.

The finding that age differences for discrete emotions were specific to the prosodic channel was somewhat unexpected, as it was predicted that significant age differences would be found in all three communication channels, reflecting a central neural mechanism for emotion perception. This finding was also contrary to previous literature indicating age-related changes

in emotion perception in the facial channel, particularly for fear, anger, and sadness (for a review, see Ruffman et al., 2008).

However, there are a number of potential explanations for this finding. First, the age differences in the prosodic channel may be related to task difficulty. Results of the current study indicated that emotions were more difficult to recognize on the prosodic task than on either the facial or lexical tasks. It is possible that age differences in emotion perception were amplified by the increased demands of the task. That is, when the task was easier, as in the case of the facial and lexical channels, the demands on emotional processing were more manageable. However, when the task was more difficult, as in the case of the prosodic channel, age differences were exposed. In fact, visual inspection of the data indicate that, although not statistically significant, the pattern of age differences was similar across the facial and lexical channels, with performance remaining relatively stable until a precipitous decline occurs in the 8th decade (see Figure 7). This observation lends credibility to the idea that task difficulty may have played a role in the observed age differences. However, it does not explain why decreased accuracy would be observed primarily for fear, happiness, and interest items. Disgust was the most difficult emotion to recognize in the prosodic channel ($M = 45.30\%$), followed by happiness ($M = 48.43\%$) and pleasant surprise ($M = 48.72\%$). Fear and interest both had higher accuracy rates, at 58.97% and 52.99% respectively. Given this pattern of recognition accuracy rates, the level-of-difficulty interpretation does not seem as likely.

Another possibility to consider is that changes in aspects of auditory acuity may account for observed age differences in the prosodic channel. Specifically, declines in perceptual processing (i.e., auditory acuity) may interfere with accurate emotion recognition in the prosodic channel. Although the participants in the current study were screened for hearing loss, age-related changes in auditory acuity can occur even among individuals with normal hearing. It is possible that these age-related changes in hearing made it more difficult for older adults in the current study to perceive the acoustic cues that signal emotional tone.

Support for this idea comes from a related line of work in memory and cognition. Specifically, research has demonstrated that the ability to remember and recall information is reduced when noise masking is used to simulate hearing loss in younger adults (Murphy, Craik, Li, & Schneider, 2000; Rabbitt, 1991). Furthermore, older adults with mild hearing loss are impaired on word recall tests relative to individuals without hearing loss (Rabbitt, 1991). It has been argued that impairments in auditory acuity result in an impoverished or inaccurate representation of the stimuli a participant is trying to hear. As a consequence, top-down processes are activated in an attempt to recover the information lost during sensory processes (e.g., turning to contextual lexical cues to try to understand what was said), thereby increasing the demand on cognitive resources (Murphy et al., 2000; Pichora-Fuller, 2008). To relate this work to emotion processing, it is possible that if an individual has even mild hearing loss, a large proportion of an individual's cognitive resources may be devoted to trying to hear and understand what was said, limiting his or her ability to pay attention to relevant emotional cues.

To compound the problem, research has shown that acoustic profiles of fear and happiness, two of the emotions that demonstrated age differences in the current study, have both been characterized by variable pitch, increased volume, and accelerated speech rate (Banse & Scherer, 1996; Johnstone & Scherer, 2000). Accelerated speech rate, in particular, could account for the observed age differences in the recognition of these emotions, as research has consistently demonstrated slowed information processing in older adults (e.g., Salthouse, 1992; Verhaeghen & Salthouse, 1997). It is possible that as the rate of speech increases, older adults have more difficulty processing the speech content, resulting in greater demands on their cognitive resources, and thus, restricting the amount of emotional information that reaches their attention. This hypothesis could also account for the age differences observed for interest. In terms of acoustic profiles of discrete emotions, there is not as much research investigating interest. However, a comprehensive study by Banse and Scherer (Banse & Scherer, 1996) examining the vocal profiles of 14 different emotions indicated that interest was characterized as

having one of the highest (i.e., fastest) rates of speech of all the emotions profiled, along with happiness and panic.

It was also somewhat unexpected that age differences were observed for two out of the three positive emotions. Although we did not have specific predictions about valence, previous research has suggested that age effects are found for negative, but not positive, emotional stimuli (Calder et al., 2003; Henry et al., 2008; Isaacowitz et al., 2007; Keightley et al., 2007; McDowell et al., 1994; Moreno et al., 1993). However, previous studies have limited their examination of positive emotions to happiness, and data have been difficult to interpret due to ceiling effects (Calder et al., 2003; Ebner & Johnson, 2009; Keightley et al., 2007; McDowell et al., 1994; Phillips et al., 2002). In the present study, we used a wide range of emotional expressions, including five negative and three positive emotions, in order to more comprehensively characterize age-related changes. Furthermore, the stimuli used in the study were less subject to ceiling effects, particularly in the facial and prosodic channels (see Figure 7). Other studies that have avoided ceiling effects have also demonstrated age differences in the recognition of happiness (Isaacowitz et al., 2007), suggesting that when tasks are made more difficult, age effects emerge for positive emotions.

The effect of nonemotional perception on emotion perception ability.

Another purpose of the current study was to examine the contribution of nonemotional perception to age differences in emotion perception ability. Only a handful of previous studies have accounted for the contribution of nonemotional perception to emotion recognition ability to age differences in the facial (Allen & Brosgole, 1993; Brosgole & Weisman, 1995; Schaffer et al., 2009 & Froming, 2009; Suzuki et al., 2007), prosodic (Allen & Brosgole, 1993; Brosgole & Weisman, 1995; Schaffer et al., 2009), and lexical (Grunwald et al., 1999) channels. Thus, an advantage of the current study was the inclusion of measures to assess nonemotional perceptual abilities in all three channels (e.g., visuospatial stimuli, intonation contours, and neutral printed words), which enabled a more comprehensive understanding of age-related changes in emotion processing abilities.

Multiple regression analyses were conducted with nonemotional control tasks and age entered as predictors. For the most part, these analyses indicated that the nonemotional control tasks were significant predictors of performance on emotion perception tasks ($n = 7$), with two exceptions. First, the Benton Phoneme Discrimination Test (Benton et al., 1983) was not a significant predictor for either the prosodic identification or discrimination task when age was included as a predictor, although the second nonemotional control task for the prosodic channel (i.e., the Intonation Contours Perception Test; Borod et al., 1992b) was a significant predictor of performance. Second, NE SID did not predict emotion perception ability for the lexical sentence identification task.

Although nonemotional perception ability successfully predicted performance, it did not fully account for the variability observed in emotion perception ability; age also contributed a significant proportion of variance, above and beyond that contributed by nonemotional perception. These findings are in accordance with previous work suggesting that age effects are independent of performance on nonemotional control tasks (Brosgole & Weisman, 1995; Schaffer et al., 2009; Suzuki et al., 2007).

The effect of auditory acuity and cognitive functions on emotion perception ability. Another goal of the current project was to investigate the relationships among auditory acuity, cognitive functions, and emotion perception ability. To that end, correlational and multiple regression analyses were conducted examining the relationship among these variables. These analyses were considered within the context of the common cause hypothesis, a de-differentiation model that suggests that relationships between sensory acuity and cognitive functions become stronger with increasing age. To date, very little research has considered the question of whether or not the common cause hypothesis applies to emotion processing (cf. Hall et al., 2003). Results of these analyses are discussed below.

Correlations among variables. Correlations between auditory acuity and performance on emotion perception tasks were calculated to test the hypothesis that the association between these measures would increase with age. However, the results did not support this hypothesis.

Although the correlations were greater in magnitude for the oldest group than for the younger groups, the difference between the correlations did not reach significance.

It is possible that, given a larger sample, the difference between the correlations would reach the level of significance. However, it must be considered as a possibility that the common cause hypothesis, which predicts that skills will become de-differentiated (i.e., less specialized) with increasing age (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994), does not apply to emotion processing.

Multiple regression analyses. Multiple regression analyses were conducted separately for each emotion perception task with age, auditory acuity, and performance on cognitive measures (i.e., cancellation task, WAIS-R Information, WAIS-R Block Design, and WMS-R Logical Memory) entered as predictors of performance. In order to test aspects of the common cause hypothesis, age was coded as a dichotomous variable (i.e., young = 0; old = 1) for these analyses using a median split. In accordance with the common cause hypothesis, it was hypothesized that sensory processes would be significant predictors of performance on emotion perception ability in older, but not younger, adults. An interaction term (i.e., age x auditory acuity) was included to specifically test this hypothesis.

Results of the multiple regression analyses did not support our hypothesis. When age was entered into the analysis as a dichotomous variable, it predicted performance only on the prosodic identification task and the facial discrimination task. Neither auditory acuity nor the interaction between age and auditory acuity predicted performance on any of the emotion perception tasks. However, according to the results of these analyses, performance on some cognitive tasks was predictive of some aspects of emotion perception ability: the WAIS-R Information subtest explained a significant proportion of the variance for both the identification and discrimination tasks in the facial and lexical channel (i.e., FID, WID, SID, FDIS, and WDIS); in addition, time to complete the cancellation task was a significant predictor of performance on both the FID and SID tasks; WMS-R Logical Memory I predicted performance on WID; and WAIS-R Block Design predicted performance on WDIS.

Results of the current study might suggest that emotion perception ability is more closely related to an individual's level of cognitive functioning than his/her age or auditory acuity. However, this conclusion would be contrary to previous research demonstrating that emotion perception ability is independent of cognitive functions (Hall et al., 2003; McDowell et al., 1994; Sullivan & Ruffman, 2004b; Suzuki et al., 2007). Another important consideration is that all participants in our sample were screened for hearing loss. Thus, the range of auditory acuity for the sample was restricted, which may have impacted the results of the regression analyses.

However, an alternative explanation is possible, which is methodological in nature: the relationship described above among age, auditory acuity, cognitive function, and emotion perception ability may be due to how age was coded as a dichotomous variable. Specifically, a median split was used to divide the sample, such that individuals at or below the sample's median age of 52 years were coded as "young" and those over the age of 52 were coded as "old." The median split method was chosen because it enabled an even split between young and older participants. However, this method may have led to a misrepresentation of the relationship among the variables. In order to follow-up on this theory, the multiple regression analyses were repeated with age as a continuous variable. The interaction term (i.e., age x auditory acuity) was removed from the analysis.

With age as a continuous variable, performance on cognitive tasks continued to be a significant predictor of emotion perception ability. Specifically, WAIS-R Information predicted performance on all tasks except PDIS; time to complete the cancellation task predicted performance on FID; WMS-R Logical memory still predicted performance on WID; and WAIS-R Block Design predicted performance on WDIS. Interestingly, as might be expected, auditory acuity predicted performance on PID, though not on PDIS. Finally, when entered as a continuous variable, age predicted performance on all four identification tasks (i.e., FID, PID, WID, and SID). Furthermore, age contributed a significant proportion of variance to emotion perception performance on identification tasks even after accounting for cognitive functioning

and auditory acuity, suggesting that age effects are actually independent of non-emotion factors. See Tables 8 – 14 in the Appendix for a summary of the follow-up analyses.

Evaluating Theoretical Explanations

A secondary aim of the current project was to evaluate age-related differences in emotion perception within the context of theoretical explanations that have been purported to explain these differences. In particular, data from our project are relevant to the discussion of the following theories: the neuropsychological hypothesis, the common cause hypothesis, and the simulation theory. Each of these theories is discussed below in relation to the results from the current study.

The neuropsychological hypothesis. The neuropsychological hypothesis argues that age-related changes in emotion perception reflect the structural and functional changes in the neural substrates that mediate the perception of individual emotions. Thus, the hypothesis predicts that the largest age effect for emotion perception ability will occur for emotions such as anger and fear, which are linked to areas of the brain that demonstrate substantial age-related changes (i.e., the OFC and amygdala). Conversely, the perception of disgust, which has been associated with the basal ganglia, should remain relatively stable across the lifespan (Calder et al., 2003; Ruffman et al., 2008, 2009; Sullivan & Ruffman, 2004a, 2004b), as the structure of the basal ganglia does not appear to change significantly with age.

The results of the current study provide only limited support for the neuropsychological hypothesis. In support of the theory, age differences were observed for the recognition of fear, whereas the recognition of disgust remained relatively stable across the lifespan. However, contrary to the predictions of the neuropsychological hypothesis, age differences were not observed for anger, which has been associated with the areas of the frontal lobes (e.g., Adolphs, 2002a; Murphy et al., 2003). Some of the largest age-related structural changes of the brain occur in the frontal lobes (e.g., Jernigan et al., 2001; Jonides et al., 2000; Raz et al., 1997). Therefore, the lack of age differences for anger does not support the hypothesis. Age differences were also observed for happiness and interest, which was not specifically predicted by the

hypothesis. However, current evidence does not clearly indicate whether these emotions are mediated by separate neural networks, and, therefore, it is not clear whether or not these findings are supportive of the hypothesis.

The common cause hypothesis. One of the goals of this study was to investigate the contribution of sensory acuity and cognitive functions to emotion perception ability, within the context of the common cause hypothesis. Although several studies have provided support for the common cause hypothesis, little research has examined whether or not the hypothesis applies to emotion processing (cf. Hall, 2001, 2003). To test this hypothesis, the current study examined the relationships among auditory acuity, cognitive function, age, and emotion perception ability using correlation and multiple regression analyses. Results did not support the common cause hypothesis. Contrary to our predictions, analyses indicated that the strength of the correlation between performance on emotion perception tasks and auditory acuity did not differ among age groups. Furthermore, multiple regression analyses did not provide evidence that the relationship among auditory acuity, cognitive functioning, and emotion perception varied as a function of age. Although these results suggest that the common cause hypothesis does not apply to emotion processing, it would be interesting in the future to use structural equation modeling to further explore the relationship between these variables within the context of this hypothesis.

The simulation theory. The simulation theory suggests that in order to identify the emotion another person is feeling, it is necessary to first simulate or replicate the emotion within our own minds (Goldman & Sripada, 2005). In terms of age-related changes, the simulation theory might predict declines in the perception of negative, but not positive, emotions as a function of age because older adults reportedly experience negative emotions less frequently. The results of the current study did not fully support this hypothesis: age differences were observed for the perception of fear, but not for the perception of other negative emotions such as anger, sadness, and disgust. Furthermore, age differences were also observed for happiness and interest, two of the three positive emotions tested.

Of course, the prediction of decline in only negative emotions is based on the assumption that reports of less frequent negative emotions reflect alterations in the ability of older adults to experience these emotions due to reduced physiological activity. However, at this point, there is only indirect evidence to support this idea (Labouvie-Vief et al., 2003; Levenson et al., 1991); (Suzuki et al., 2007)}. Therefore, in order to understand how the simulation theory applies to age-related changes in emotion perception, it would be necessary in the future to more fully explore changes in the experience of emotion with age, along with the interaction between experience and perception.

Limitations

The current study had a number of limitations, which should be noted. First, our study was cross-sectional in design and was therefore subject to potential cohort effects. It is possible that the age differences we observed were confounded by generational experiences that influenced how particular age groups processed emotion. However, we were particularly interested in characterizing emotion perception abilities across the entire adult lifespan, which makes a longitudinal design impractical due to time restraints. Nonetheless, it would be interesting for future research to examine how emotion perception ability changes over a period of time using a longitudinal sample.

In addition, the current study was limited by the fact that the data were strictly behavioral and neuroimaging techniques were not employed. A descriptive approach, such as the approach taken in this study, is an important step in understanding age differences in emotion perception, but it is impossible to draw conclusions about underlying neural mechanisms based on this approach alone. Thus, although we have discussed the age differences observed in the current study within the context of age-related changes in the brain, it is important to emphasize that this discussion is purely inferential in nature.

Another limitation of the study is that scores on the lexical tasks were restricted in range, resulting in ceiling effects. Specifically, ceiling effects were observed for at least some age groups when anger, disgust, interest, and pleasant surprise were tested (see Figure 7). Although

age effects were still observed on most of these emotions, the restricted range of variability may have affected the pattern of age-related change across individual emotions.

Finally, it is possible that the current study was limited by the fact that the emotional stimuli used in the NYEB were created using posers on the younger end of the age spectrum. There is some evidence to suggest that viewers may be impacted by an “own-age” bias, whereby emotion perception is more accurate when viewing someone of the same age (Malatesta et al., 1987; cf. Borod et al., 2004). For example, Malatesta and colleagues (1987) asked young, middle-aged, and older women to relate emotional experiences after undergoing a mood induction procedure. The sessions were videotaped and later shown to three groups of raters (also young, middle aged, and older). Results of this study indicated an interaction between “encoder” and “decoder” age: decoders were more accurate at identifying the emotion of the encoder when the decoder age was congruent with their own age. Thus, by including only younger posers, the current study may not represent the full range of emotion perception abilities for older adults. It would be important for future research to include older posers in emotional stimuli to better understand age-related differences in emotion perception ability.

Directions for future research

Our findings are suggestive of an age-related decline in emotion perception ability, but there are numerous aspects of this research that remain to be fully explored. First and foremost, it would be important for future research to address some of the limitations listed above. For example, future work would benefit from the use of neuroimaging techniques in conjunction with behavioral methods to identify the relationship between age-related changes in the brain and emotion perception abilities. In addition, it would be important for future work to explore the interaction between poser age and viewer age.

In addition, the field would likely benefit from research exploring the relationship between auditory acuity, information processing speed, and emotion perception abilities in the prosodic channel. Aspects of the current study touch upon these issues, but more comprehensive research is needed. For instance, it would be helpful to directly measure specific

acoustic parameters of the prosodic stimuli (e.g., rate of speech and frequency) and determine how those parameters relate to emotion perception abilities as a function of age.

Another interesting avenue of future research would be to investigate whether or not age-related differences in emotion perception ability are observed when dynamic emotional stimuli are used. Research examining age effects in emotion perception ability has been almost entirely restricted to posed expressions, despite the fact that in everyday life, most emotion cues are dynamic. To the best of our knowledge, only one study to date has used dynamic displays of facial expression to test age differences in emotion perception (Henry et al., 2008). In this study, younger and older participants were compared using two tests: the Ekman 60 Faces Test (Young et al., 2002), an emotion identification test using posed facial expressions, and the Emotion Evaluation Test from the Awareness of Social Inference Test (TASIT; McDonald, Flanagan, Rollins, & Kinch, 2003), which uses dynamic video stimuli. Results of the Henry et al., (2008) study indicated that older adults had more difficulty than younger adults on the Ekman 60 Faces Test, but the groups did not differ on the more dynamic TASIT. The authors point out that the two tests differ on a number stimulus dimensions that might have affected performance, including the number of contextual cues (more cues for the TASIT) and the speed of stimuli presentation (stimuli were presented more rapidly in the static task). Additional research would be helpful to confirm this finding, and to further investigate how the type of emotional cue impacts age-related performance.

It would also be important for future research to characterize the impact that age-related changes have on day-to-day life for older adults, as very little is known about the effects. Results of the current study provide further evidence of age-related differences with experimental measures of emotion perception, but it is not clear whether or not those differences impact social functioning for older adults. In real life, emotional cues are rarely limited to one modality of information, and contextual cues are generally abundant. So it is possible that older adults may not have any difficulty interpreting emotional information in their daily lives because they are provided with a multitude of cues (Isaacowitz & Stanley, 2011). Additional research is

needed to determine whether emotion perception deficits are related to changes in social functioning. Incidentally, it would also be interesting to know if emotion perception deficits are associated with prevalence rates of late life depression.

Another area of potential research involves examining how gaze preference might interact with age and emotion perception ability. Specifically, aging research has proposed that there may be age-related changes in visual scanning patterns, which may adversely affect emotion recognition. Eye-tracking studies examining visual scanning patterns of facial expressions find that older adults preferentially focus on the lower half of the face (i.e., the mouth region), regardless of the viewed emotion (Sullivan et al., 2007; Wong et al., 2005). As highlighted in the literature review above, studies examining configural information in facial expressions have shown that the accurate identification of fear, anger, and sadness is easier to recognize from the upper half of the face, while happiness and disgust are easier to recognize from the bottom half (Calder et al., 2000b). If older adults tend to look at the mouth region rather than the eyes, then they may have more difficulty recognizing these particular emotions. Thus, it would be interesting for future research to test specifically for age differences in emotion perception using eye tracking technology.

Finally, another interesting avenue of research would be investigating the relationship between perception and the subjective experience of emotion. As described above, the simulation theory (Goldman & Sripada, 2005), a recent theory of emotion processing, suggests that in order to recognize the emotion someone else is feeling, we must first simulate that emotion within ourselves. In the future, it would be interesting for research to investigate the interaction between the perception and experience of emotion, and explore how this interaction changes as a function of age.

Clinical implications

Understanding how emotion changes as a function of age has important clinical implications. Most importantly, the ability to recognize and understand another person's feelings is critical for successful social interactions. Difficulties recognizing emotions have been

associated with different aspects of social function impairment, including poor interpersonal relationships (Blonder, Creed Pettigrew, & Kryscio, in press; Carton et al., 1999) and decreased social competence (Shimokawa et al., 2001). As mentioned above, there is currently very little research examining the day-to-day impact of emotion recognition deficits on older adults. However, it stands to reason that emotion perception deficits have the potential to adversely affect the quality of an individual's social relationships, leading to increased social isolation and feelings of loneliness. Social isolation and loneliness, in turn, have been related to depression (Weeks, 1980; Wenger, Davies, Shahtahmasebi, & Scott, 1996). Restricted social networks and poor interpersonal relationships have also been related to attempted suicide in late-life depression (Szanto et al., 2012). Given the potential for adverse effects on social functioning, it is critical that we understand how emotion perception changes with age and how it may interact with social support and symptoms of depression.

In addition, results from the current study have the potential to serve as normative data to help differentiate between normal and pathological aging. Given the extent to which emotion perception abilities are impaired in patient populations (e.g., frontotemporal dementia, Alzheimer's disease, Parkinson's disease, stroke, schizophrenia, depression, etc.), emotion recognition abilities should be assessed during standard neuropsychological batteries. Yet, at this time, there is very little normative data by which to compare performance. The results of the current project go a long way towards characterizing emotion perception abilities in normal aging and should, therefore, be helpful in delineating between changes occurring normally and those occurring as part of a disease process.

Conclusions

In summary, results of the current study provide evidence that emotion perception abilities decline with age. In terms of overall total scores, participants in the 8th and 9th decades of life were less accurate in their perception of emotion than were younger participants across all three channels of communication. However, results of the current study indicated that the most significant age differences were observed in the prosodic channel specifically for fear, happiness,

and interest. Age effects were observed even after controlling for nonemotional factors such as general perception, auditory acuity, and cognitive functions. The current study extended previous work by including multiple channels of communication, eight discrete emotions, and a sample ranging in age from 20-89. As such, this work has important implications for understanding normal emotion processing and for understanding the relationship between social functions and age.

Table 1
Screening Measures: Cut-Off Scores for Exclusion from Study

<u>SCREENING MEASURE</u>	<u>RANGE OF SCORES</u>	<u>CUTOFF</u>
BDAE Commands	0-15	3 of 6 pts. on first 6 items
Complex Ideational Material	0-12	Raw score < 4/6 for first 6 items
Reading Sentences and Paragraphs	0-10	Raw score < 5/10
WAIS-R Information	1-19	Age-Corrected SS < 7
Block Design	1-19	Age-Corrected SS < 7
MDRS Attention	0-37	Raw score < 34 pts
Memory	0-25	Raw score < 22 pts
Total Score	0-144	Age-Corrected SS < 7
WMS-R Logical Memory I	0-50	Raw score < 1 SD below mean
Logical Memory II	0-50	Raw score < 1 SD below mean
Pure tone threshold (L+R Mean 500, 1000, 2000)		Exclude if any L+R mean is more than 40
Benton Visual Form Discrimination	0-32	Raw score < 26 pts
Benton Phoneme Discrimination	0-30	Raw score < 19 pts
MMSE	0-30	Raw score < 27 points
GDS	0-30	Raw score > 8

Abbreviations: BDAE = Boston Diagnostic Aphasia Exam; WAIS-R = Wechsler Adult Intelligence Scale – Revised; MDRS = Mattis Dementia Rating Scale; WMS-R = Wechsler Memory Scale – Revised; MMSE = Mini Mental Status Exam; GDS = Geriatric Depression Scale

Table 2
Demographic Characteristics of Sample by Age Group

VARIABLE	AGE GROUPS						
	20-29 (n = 18)	30-39 (n = 19)	40-49 (n = 17)	50-59 (n = 15)	60-69 (n = 15)	70-79 (n = 15)	80-89 (n = 18)
Age (in years)	25.1 (3.0)	34.0 (2.9)	45.4 (3.0)	54.3 (2.8)	62.5 (2.5)	73.6 (2.7)	83.3 (2.6)
Sex (% women)	50.0%	52.6%	64.7%	60.0%	40.0%	53.3%	77.8%
Ethnicity (% Caucasian)	44.4%	47.4%	47.1%	66.7%	53.3%	66.7%	72.2%
Education (in years)	15.5 (1.8)	15.3 (3.1)	13.8 (1.5)	14.5 (2.9)	14.7 (2.9)	15.3 (2.5)	14.4 (2.9)
SES ^a	6.9 (1.9)	6.4 (1.6)	6.2 (2.0)	6.6 (1.4)	6.6 (1.4)	6.9 (1.1)	5.6 (1.3)
Handedness ^b	12.0 (0.0)	11.7 (0.7)	12.0 (0.0)	11.7 (0.6)	11.7 (0.6)	11.9 (0.4)	11.8 (0.9)

Note: Values are listed as mean (standard deviation) or percent

^aSocioeconomic status based on Hollingshead Scale (Hollingshead, 1977)

^bStrength of right hand dominance (Coren, Porac, & Duncan, 1979)

Table 3
One-way ANOVAs and Chi-Squares on Age Group for Participant Demographics

	<u>Df</u>	<u>F</u>	<u>P</u>
Education	6, 110	1.047	.399
SES ^a	6, 109	1.476	.193
Handedness ^b	6, 108	0.845	.538
	<u>Df</u>	<u>χ²</u>	<u>P</u>
Gender	6	6.002	.423
Ethnicity	6	5.456	.487

^aSocioeconomic status based on Hollingshead Scale (Hollingshead, 1977)

^bStrength of right hand dominance (Coren, Porac, & Duncan, 1979)

Table 4
Descriptive Statistics for Experimental Tasks by Age Group

VARIABLE	AGE GROUPS						
	20-29 (n = 18)	30-39 (n = 19)	40-49 (n = 17)	50-59 (n = 15)	60-69 (n = 15)	70-79 (n = 15)	80-89 (n = 18)
Facial Identification	82.12 (7.79)	75.33 (9.43)	74.26 (9.79)	73.33 (10.22)	70.63 (10.68)	61.88 (9.32)	62.15 (16.43)
Prosodic Identification	70.14 (11.28)	64.04 (11.04)	63.24 (11.24)	56.39 (18.02)	55.83 (13.71)	39.72 (17.81)	39.35 (19.03)
Word Identification	93.75 (5.00)	88.82 (9.83)	89.46 (6.09)	86.39 (12.55)	90.83 (6.90)	75.00 (13.55)	77.55 (16.68)
Sentence Identification	87.27 (10.64)	80.92 (11.31)	81.13 (11.33)	78.06 (11.62)	81.67 (11.55)	68.06 (15.64)	68.98 (19.56)
Facial Discrimination	88.29 (4.55)	88.16 (4.30)	87.82 (5.06)	82.62 (11.44)	81.67 (8.84)	80.95 (7.10)	80.16 (8.77)
Prosodic Discrimination	96.83 (2.71)	96.43 (3.15)	96.01 (3.06)	95.95 (3.79)	92.86 (7.01)	92.38 (6.02)	94.05 (3.67)
Word Discrimination	88.29 (9.23)	82.89 (10.21)	82.77 (9.47)	82.86 (10.47)	83.57 (7.37)	78.57 (12.07)	80.75 (9.66)

Note: Values are listed as percent correct (standard deviation)

Table 5
Descriptive Statistics for Nonemotional Control Tasks by Age Group

VARIABLE	AGE GROUPS						
	20-29 (n = 18)	30-39 (n = 19)	40-49 (n = 17)	50-59 (n = 15)	60-69 (n = 15)	70-79 (n = 15)	80-89 (n = 18)
Word Discrimination (% correct)	84.72 (8.01)	82.71 (9.01)	82.77 (7.91)	80.48 (9.91)	81.43 (11.07)	76.19 (10.07)	74.80 (9.60)
Word Identification (% correct)	95.83 (4.52)	94.74 (5.70)	96.32 (5.68)	95.28 (6.66)	95.28 (4.69)	91.39 (7.95)	89.58 (9.72)
Sentence Identification (% correct)	80.56 (8.81)	83.11 (6.58)	80.39 (9.05)	75.00 (10.80)	79.44 (10.26)	67.78 (15.14)	69.68 (11.94)
Visual Matrices	23.61 (0.92)	23.42 (1.12)	23.76 (0.56)	23.31 (1.25)	23.67 (0.62)	22.47 (1.51)	23.00 (1.50)
Benton Facial Recognition	48.89 (2.52)	47.00 (3.48)	47.00 (3.97)	46.93 (4.61)	47.86 (4.29)	45.07 (6.45)	47.56 (3.99)
Intonation Contours	22.5 (2.09)	20.95 (3.46)	21.71 (1.65)	22.07 (1.83)	20.33 (3.28)	20.80 (3.41)	20.06 (4.55)
Benton Phoneme Discrimination	28.67 (1.14)	28.16 (1.80)	28.12 (1.32)	27.53 (2.20)	27.93 (1.67)	26.47 (1.73)	25.67 (3.50)
Beck Depression Inventory	0.89 (1.23)	1.63 (2.27)	1.59 (2.48)	1.60 (1.77)	1.87 (2.20)	1.33 (1.84)	2.28 (1.32)

Note: Values are listed as mean (standard deviation)

Table 6
Multiple Regression with Nonemotional Control Tasks for Facial Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.087	10.630	.001					
Constant				-2.655	22.806		-.116	.908
Visual Matrices				3.183	.976	.294	3.260	.001
Model 2	.219	15.607	< .001					
Constant				-37.991	22.684		-1.675	.097
Visual Matrices				2.483	.921	.230	2.697	.008
Benton Facial Recognition				1.094	.252	.370	4.346	< .001
Model 3	.422	26.774	< .001					
Constant				10.513	21.108		.498	.619
Visual Matrices				1.275	.819	.118	1.556	.123
Benton Facial Recognition				.993	.218	.336	4.551	< .001
Age				-.292	.047	-.466	-6.209	< .001

Note: R^2 change for Model 3 = .203, F change = 38.548, $p < .001$

Table 7
Multiple Regression with Nonemotional Control Tasks for Prosodic Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.236	35.155	< .001					
Constant				-53.109	18.448		-2.879	.005
Phonemic Discrimination				3.961	.668	.485	5.929	< .001
Model 2	.287	22.753	< .001					
Constant				-57.600	17.964		-3.206	.002
Phonemic Discrimination				2.950	.739	.362	3.995	< .001
Intonation Contours				1.523	.534	.258	2.854	.005
Model 3	.468	32.842	< .001					
Constant				14.701	19.500		.754	.452
Phonemic Discrimination				1.205	.700	.148	1.721	.088
Intonation Contours				1.467	.463	.249	3.169	.002
Age				-.434	.070	-.478	-6.171	< .001

Note: R^2 change for Model 3 = .181, F change = 38.085, p < .001

Table 8
Multiple Regression with Nonemotional Control Tasks for Lexical Word Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.246	37.431	< .001					
Constant				2.478	13.706		.181	.857
NE WID				.889	.145	.496	6.118	< .001
Model 2	.355	31.391	< .001					
Constant				31.231	14.306		2.183	.031
NE WID				.704	.141	.392	4.981	< .001
Age				-.213	.048	-.347	-4.401	< .001

Note: R^2 change for Model 2 = .110, F change = 19.371, p < .001

Table 9
Multiple Regression with Nonemotional Control Tasks for Lexical Sentence Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.083	10.381	.002					
Constant				50.272	8.757		5.741	< .001
NE SID				.363	.113	.288	3.222	.002
Model 2	.196	13.856	< .001					
Constant				79.211	10.966		7.223	< .001
NE SID				.172	.116	.136	1.481	.141
Age				-.268	.067	-.368	-3.997	< .001

Note: R^2 change for Model 2 = .113, F change = 15.979, $p < .001$

Table 10
Multiple Regression with Nonemotional Control Tasks for Facial Discrimination Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.153	20.198	< .001					
Constant				21.908	13.929		1.573	.119
Visual Matrices				2.680	.596	.391	4.494	< .001
Model 2	.196	13.546	< .001					
Constant				9.097	14.599		.623	.534
Visual Matrices				2.426	.593	.354	4.094	< .001
Benton Facial Recognition				.397	.162	.212	2.448	.016
Model 3	.309	16.400	< .001					
Constant				32.058	14.636		2.190	.031
Visual Matrices				1.854	.568	.270	3.263	.001
Benton Facial Recognition				.349	.151	.186	2.306	.023
Age				-.138	.033	-.348	-4.239	< .001

Note: R^2 change for Model 3 = .113, F change = 17.966, $p < .001$

Table 11
Multiple Regression with Nonemotional Control Tasks for Prosodic Discrimination Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.046	5.494	.021					
Constant				83.061	5.121		16.220	< .001
Phonemic Discrimination				.435	.185	.214	2.344	.021
Model 2	.068	4.153	.018					
Constant				82.323	5.102		16.135	< .001
Phonemic Discrimination				.269	.210	.132	1.280	.203
Intonation Contours				.250	.152	.171	1.652	.101
Model 3	.115	4.833	.003					
Constant				91.394	6.250		14.623	< .001
Phonemic Discrimination				.050	.225	.024	.221	.826
Intonation Contours				.243	.148	.166	1.640	.104
Age				-.054	.023	-.241	-2.416	.017

Note: R^2 change for Model 3 = .046, F change = 5.836, p = .017

Table 12
Multiple Regression with Nonemotional Control Tasks for Lexical Word Discrimination Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model 1	.269	42.393	< .001					
Constant				40.047	6.630		6.040	< .001
NE WDIS				.532	.082	.519	6.511	< .001
Model 2	.273	21.440	< .001					
Constant				43.823	8.182		5.356	< .001
NE WDIS				.507	.088	.495	5.788	< .001
Age				-.033	.042	-.068	-.790	.431

Note: R^2 change for Model 2 = .004, F change = .624, p = .431

Table 13
Kruskal-Wallis Test for Emotion Identification Tasks, Separately for Each Emotion

Channel	Emotion	Test Statistic	<i>df</i>	<i>p</i>
Facial	Anger	13.167	6	.040
	Sad	19.959	6	.003
	Fear	33.438	6	< .001
	Disgust	2.477	6	.871
	Unpleasant Surprise	14.018	6	.029
	Pleasant Surprise	8.023	6	.236
	Happy	7.455	6	.281
	Interest	6.333	6	.387
Prosodic	Anger	17.542	6	.007
	Sad	18.184	6	.006
	Fear	33.601	6	< .001
	Disgust	5.059	6	.536
	Unpleasant Surprise	14.992	6	.020
	Pleasant Surprise	4.412	6	.621
	Happy	33.515	6	< .001
	Interest	33.611	6	< .001
Lexical (Word)	Anger	12.286	6	.056
	Sad	13.663	6	.034
	Fear	12.619	6	.050
	Disgust	11.291	6	.080
	Unpleasant Surprise	11.739	6	.068
	Pleasant Surprise	24.697	6	< .001
	Happy	16.267	6	.012
	Interest	18.138	6	.006
Lexical (Sentence)	Anger	8.886	6	.180
	Sad	20.415	6	.002
	Fear	7.336	6	.291
	Disgust	8.097	6	.231
	Unpleasant Surprise	5.971	6	.426
	Pleasant Surprise	26.235	6	< .001
	Happy	5.882	6	.437
	Interest	14.107	6	.028

Table 14
Summary of Mixed-Design Repeated Measures ANOVA with WID for the Lexical Channel

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Channel	430072.422	1.623, 178.487	265049.726	356.806	< .001
Age Group	7588.866	6, 110	1264.811	12.450	< .001
Emotion	43730.587	6.394, 703.330	6839.413	11.467	< .001
Channel x Age Group	18097.779	9.736, 178.487	1858.916	2.502	.004
Channel x Emotion	116006.250	11.463, 1260.968	10119.758	16.458	< .001
Emotion x Age Group	39530.643	38.363, 703.330	1030.424	1.728	.005
Age Group x Channel x Emotion	56510.216	68.780, 1260.968	821.608	1.336	.038

Note: Greenhouse-Geisser correction applied to tests of within-subjects effects and interaction

Table 15
Summary of Mixed-Design Repeated Measures ANOVA with SID for the Lexical Channel

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Channel	247603.219	1.921, 11.529	128864.706	161.747	< .001
Age Group	7715.780	6, 110	1285.963	11.757	< .001
Emotion	47954.005	6.385, 702.302	7510.926	1.516	.021
Channel x Age Group	16111.341	11.529, 211.529	1397.520	1.754	.060
Channel x Emotion	92437.766	11.949, 1311.126	7755.282	12.011	< .001
Emotion x Age Group	43541.085	38.307, 702.302	1136.623	1.516	.025
Age Group x Channel x Emotion	64954.191	71.516, 1311.126	908.247	1.407	.016

Note: Greenhouse-Geisser correction applied to tests of within-subjects effects and interaction

Table 16
Summary of Mixed-Design Repeated Measures ANOVA for Discrimination Tasks

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Channel	10166.479	1, 820, 200.164	5586.984	112.822	< .001
Age Group	657.052	6, 110	109.509	4.068	.001
Channel x Age Group	642.245	10, 918, 200.164	53.520	1.188	.293

Note: Greenhouse-Geisser correction applied to tests of within-subjects effects and interaction

Table 17

Spearman's Rho Statistics Among Emotion Perception Tasks and Auditory Acuity Composite Score: Seven Age Groups

	Age Groups						
	<u>20-29</u>	<u>30-39</u>	<u>40-49</u>	<u>50-59</u>	<u>60-69</u>	<u>70-79</u>	<u>80-89</u>
FID	-.062	-.239	.049	.069	.076	.437	-.436
PID	-.159	-.481*	.113	-.493	-.237	-.005	-.476
WID	-.472*	-.494*	.089	-.130	.023	.229	-.502*
SID	-.133	-.072	.288	-.205	-.174	.343	-.304
FDIS	-.524*	-.286	-.216	-.160	-.124	-.295	-.610*
PDIS	-.013	-.037	.311	-.122	-.129	.048	-.287
WDIS	-.412	.390	.079	-.592*	-.161	.124	-.189
<u>Median</u>							
Spearman's ρ	-.159	-.239	.113	-.160	-.129	.124	-.436

* $p < .05$

Table 18

Spearman's Rho Statistics Among Emotion Perception Tasks and Auditory Acuity Composite Score: Four Age Groups

	Age Groups			
	<u>20-39</u>	<u>40-59</u>	<u>60-79</u>	<u>80-89</u>
FID	-.189	.084	0.63	-.436
PID	-.289	-.296	-.221	-.476
WID	-.486*	-.056	-.140	-.502*
SID	-.124	-.027	-.083	-.304
FDIS	-.403*	-.245	-.192	-.610*
PDIS	-.015	.049	-.077	-.287
WDIS	-.101	-.273	-.033	-.189
<u>Median</u>				
Spearman's ρ	-.189	-.056	-.083	-.436

* $p < .05$

Table 19

Pearson Correlations Between Emotional Perception Task and Auditory Acuity Composite Score: Seven Age Groups

	Age Groups						
	20-29	30-39	40-49	50-59	60-69	70-79	80-89
FID	-0.142	-0.184	0.102	0.135	-0.057	0.354	-0.391
PID	-0.095	-0.386	0.062	-0.355	-0.334	-0.345	-0.500*
WID	-0.480*	-0.386	0.139	-0.144	-0.102	0.166	-0.398
SID	-0.064	0.063	0.299	-0.160	-0.170	0.220	-0.297
FDIS	-0.424	-0.161	-0.337	-0.220	-0.149	-0.303	-0.524*
PDIS	0.030	0.076	0.324	-0.089	-0.155	-0.269	-0.305
WDIS	-0.393	0.345	0.233	-0.502	-0.256	0.139	-0.177
<u>Median</u>							
Pearson's <i>r</i>	-0.142	-0.161	0.139	-0.160	-0.170	0.139	-0.391

* $p < .05$

Table 20

Pearson Correlations Between Emotional Perception Task and Auditory Acuity Composite Score: Four Age Groups

	Age Groups			
	20-39	40-59	60-79	80-89
FID	-0.152	0.095	-0.007	-0.391
PID	-0.219	-0.302	-0.434*	-0.500*
WID	-0.368*	-0.131	-0.129	-0.398
SID	-0.007	-0.044	-0.078	-0.297
FDIS	-0.307	-0.316	-0.218	-0.524*
PDIS	0.051	-0.032	-0.226	-0.305
WDIS	-0.040	-0.232	-0.048	-0.177
<u>Median</u>				
Pearson's <i>r</i>	-0.152	-0.131	-0.129	-0.391

* $p < .05$

Table 21

Fisher's Z-Tests Comparing Correlations Between Auditory Acuity and Emotion Perception Tasks: Seven Age Groups

	Age Group						
	20-29 (n = 18)	30-39 (n = 19)	40-49 (n = 17)	50-59 (n = 15)	60-69 (n = 14)	70-79 (n = 15)	80-89 (n = 17)
20-29	-	.05	-.76	.05	.07	-.73	0.73
30-39	-	-	-.83	0.0	.02	-.79	.68
40-49	-	-	-	.77	.77	0.0	1.46
50-59	-	-	-	-	.02	-.74	.64
60-69	-	-	-	-	-	-.75	.60
70-79	-	-	-	-	-	-	-.139
80-89	-	-	-	-	-	-	-

Note: Statistics reported are Fisher's z values derived from Fisher's *r*-to-*z* transformation.

* $p < .05$

Table 22

Fisher's Z-Tests Comparing Correlations Between Auditory Acuity and Emotion Perception Tasks: Four Age Groups

	Age Group			
	20-39 (n = 37)	40-59 (n = 32)	60-79 (n = 29)	80-89 (n = 17)
20-39	-	-.08	-.09	.82
40-59	-	-	-.01	.86
60-79	-	-	-	.85
80-89	-	-	-	-

Note: Statistics reported are Fisher's z values derived from Fisher's *r*-to-*z* transformation.

* $p < .05$

Table 23
Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.401	8.615	< .001					
Constant				62.856	6.466		9.721	<.001
Letter Cancellation Time				-.104	.040	-.237	-2.623	.010
WAIS-R Information				.572	.220	.239	2.603	.011
WAIS-R Block Design				.228	.123	.204	1.861	.066
WMS-R Logical Memory I				.043	.330	.022	.130	.897
Pure Tone Threshold Composite				-.292	2.731	-.019	-.107	.915
Age (dichotomous)				-4.818	2.666	-.192	-1.807	.074
Age x Pure Tone Threshold				-.005	3.196	< .001	-.001	.999

Table 24
Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.515	13.697	< .001					
Constant				35.134	8.427		4.169	<.001
Letter Cancellation Time				-.031	.052	-.048	-.591	.556
WAIS-R Information				.534	.287	.154	1.864	.065
WAIS-R Block Design				.249	.160	.154	1.561	.122
WMS-R Logical Memory I				.710	.430	.252	1.651	.102
Pure Tone Threshold Composite				-3.538	3.559	-.159	-.994	.323
Age (dichotomous)				-9.507	3.475	-.261	-2.736	.007
Age x Pure Tone Threshold				-4.493	4.165	-.145	-1.079	.283

Table 25

Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.466	11.243	< .001					
Constant				61.769	5.991		10.310	<.001
Letter Cancellation Time				-.045	.037	-.104	-1.222	.225
WAIS-R Information				.841	.204	.358	4.128	<.001
WAIS-R Block Design				.137	.114	.125	1.205	.231
WMS-R Logical Memory I				.616	.306	.323	2.013	.047
Pure Tone Threshold Composite				-2.274	2.530	-1.51	-.899	.371
Age (dichotomous)				-3.591	2.470	-.146	-1.453	.149
Age x Pure Tone Threshold				-.173	2.961	-.008	-.058	.954

Table 26

Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Sentence Identification Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.516	13.711	< .001					
Constant				48.390	6.758		7.160	<.001
Letter Cancellation Time				-.087	.041	-.171	-2.101	.038
WAIS-R Information				1.182	.230	.425	5.144	<.001
WAIS-R Block Design				.071	.128	.054	.554	.581
WMS-R Logical Memory I				.481	.345	.213	1.394	.166
Pure Tone Threshold Composite				1.692	2.854	.095	.593	.555
Age (dichotomous)				-4.927	2.787	-.169	-1.768	.080
Age x Pure Tone Threshold				-3.137	3.341	-1.26	-.939	.350

Table 27
Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Discrimination Task

	<i>R</i> ²	<i>F</i>	<i>p</i> (<i>F</i>)	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i> (<i>t</i>)
Model	.397	8.482	< .001					
Constant				76.191	4.113		18.523	<.001
Letter Cancellation Time				-.018	.025	-.063	-.698	.487
WAIS-R Information				.427	.140	.281	3.050	.003
WAIS-R Block Design				-.067	.078	-.094	-.854	.395
WMS-R Logical Memory I				.249	.210	.202	1.187	.238
Pure Tone Threshold Composite				-2.119	1.737	-.218	-1.220	.225
Age (dichotomous)				-5.837	1.696	-.366	-3.441	.001
Age x Pure Tone Threshold				.641	2.033	.047	.315	.753

Table 28
Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Discrimination Task

	<i>R</i> ²	<i>F</i>	<i>p</i> (<i>F</i>)	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>P</i> (<i>t</i>)
Model	.137	2.046	.048					
Constant				96.137	2.794		34.408	<.001
Letter Cancellation Time				-.021	.017	-.135	-1.242	.217
WAIS-R Information				-.019	.095	-.022	-.196	.845
WAIS-R Block Design				-.011	.053	-.027	-.208	.836
WMS-R Logical Memory I				.018	.143	.026	.126	.900
Pure Tone Threshold Composite				.467	1.180	.085	.396	.693
Age (dichotomous)				-1.714	1.152	-.189	-1.488	.140
Age x Pure Tone Threshold				-1.041	1.381	-.135	-.753	.453

Table 29

Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Discrimination Task

	R^2	F	$p(F)$	B	$SE B$	β	t	$P(t)$
Model	.437	10.002	< .001					
Constant				51.326	4.959		10.350	<.001
Letter Cancellation Time				.027	.030	.076	.872	.385
WAIS-R Information				.851	.169	.450	5.047	<.001
WAIS-R Block Design				.219	.094	.247	2.328	.022
WMS-R Logical Memory I				.157	.253	.102	.619	.537
Pure Tone Threshold Composite				-1.338	2.094	-.110	-.639	.524
Age (dichotomous)				-.091	2.045	-.005	-.044	.965
Age x Pure Tone Threshold				1.748	2.451	.103	.713	.477

Figure 1
Main Effect of Age for Identification Tasks with WID for the Lexical Channel

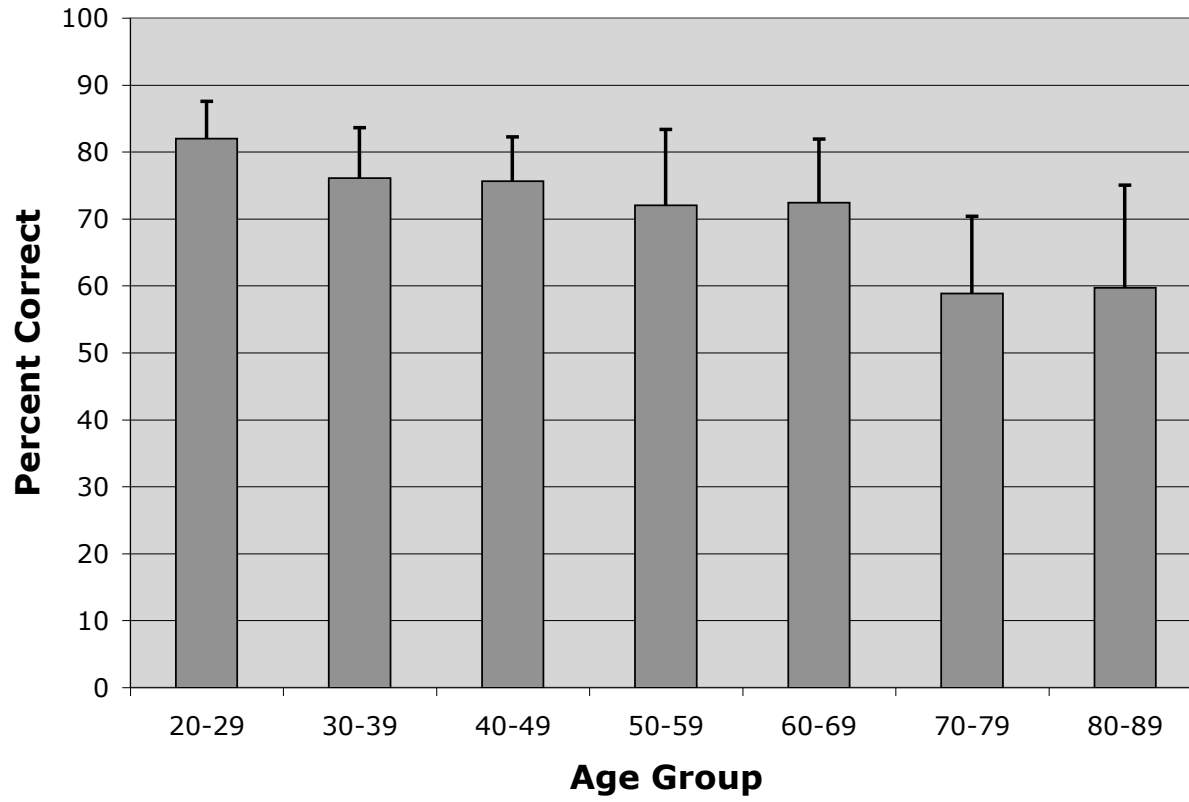


Figure 2
Main Effect of Channel for Identification Tasks with WID for the Lexical Channel

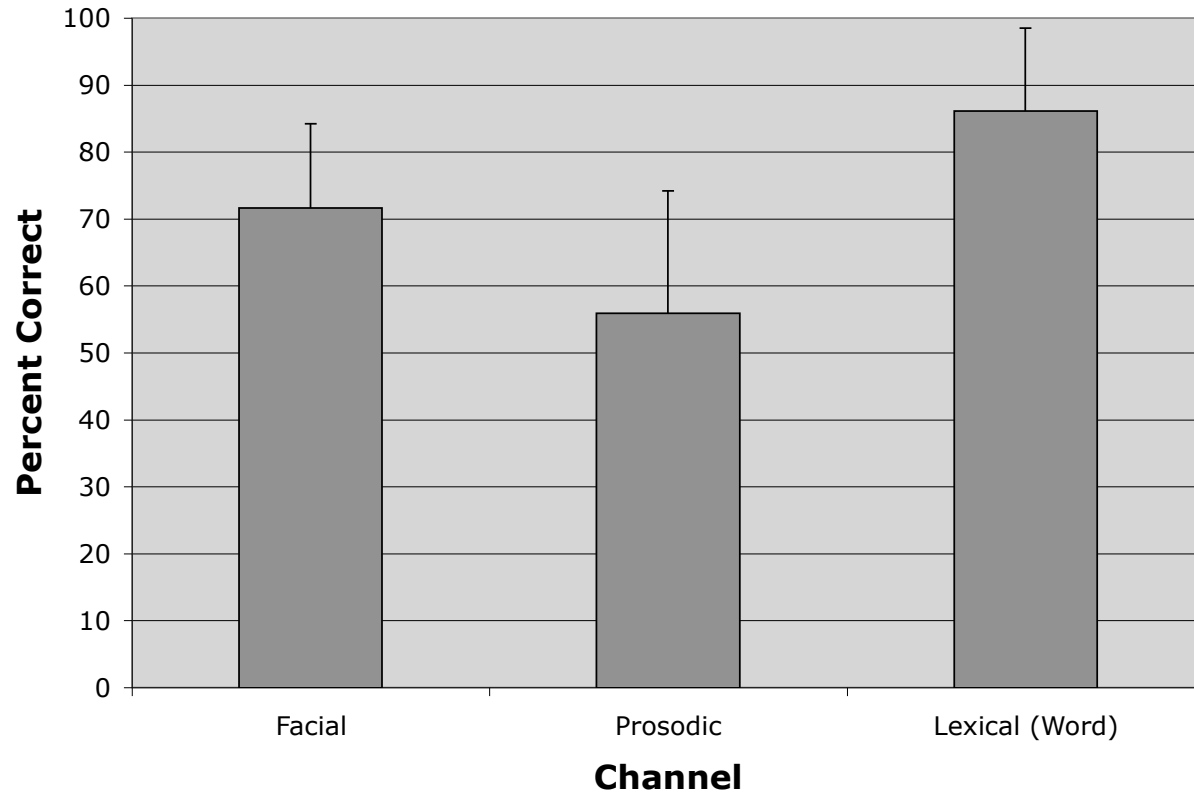


Figure 3
Main Effect of Emotion for Identification Tasks with WID for the Lexical Channel

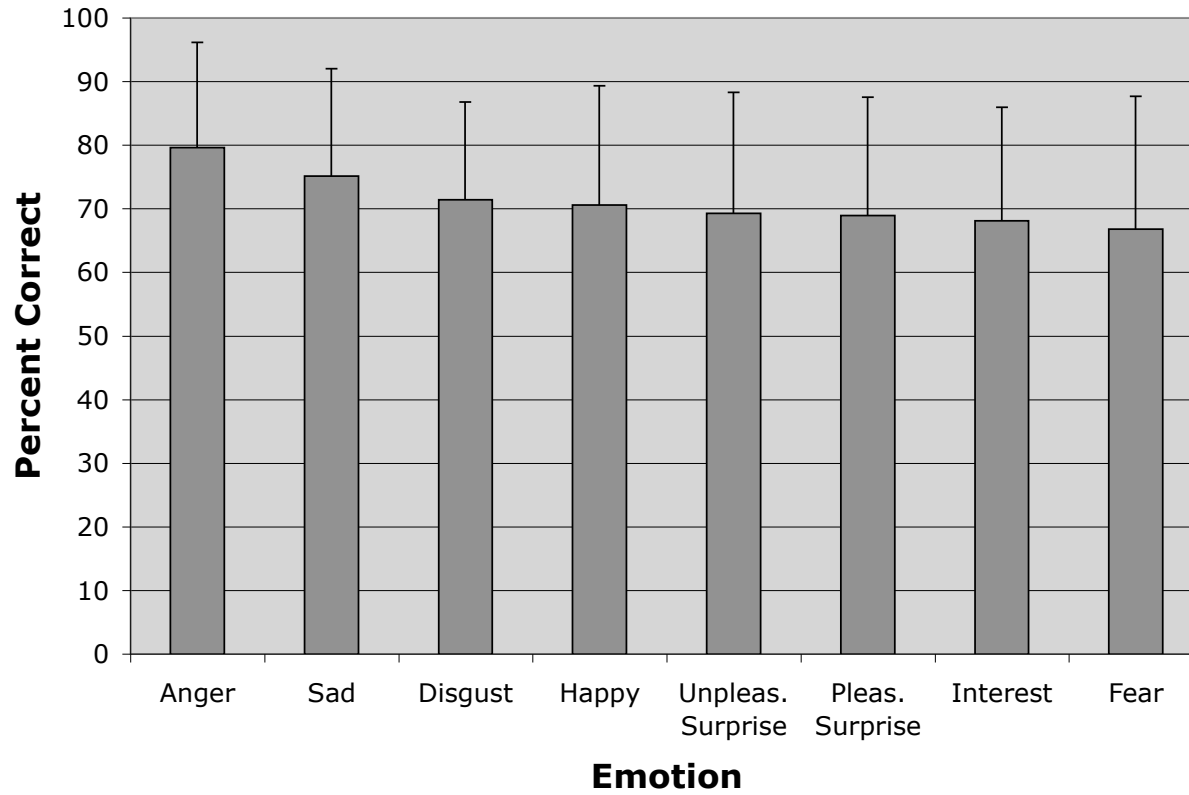


Figure 4
Channel by Age Group Interaction for Identification Tasks with WID for the Lexical Channel

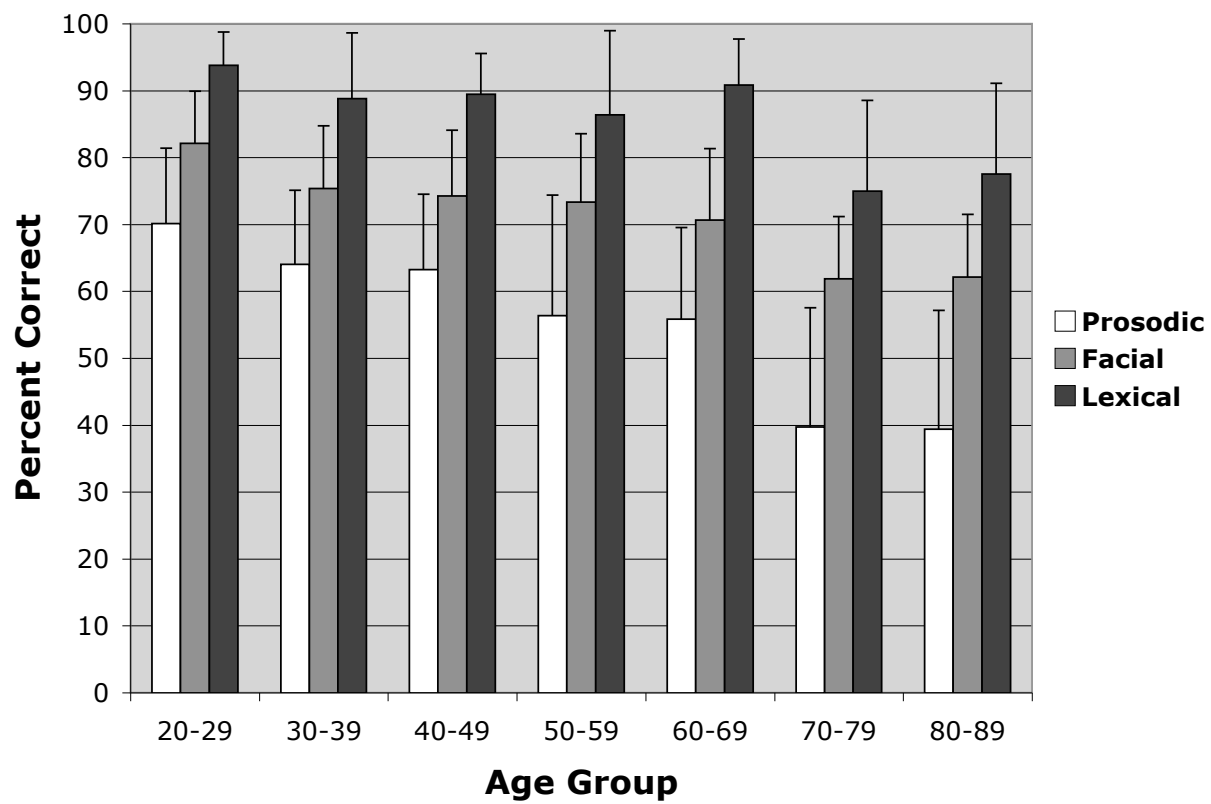


Figure 5
Channel by Emotion Interaction for Identification Tasks with WID for the Lexical Channel

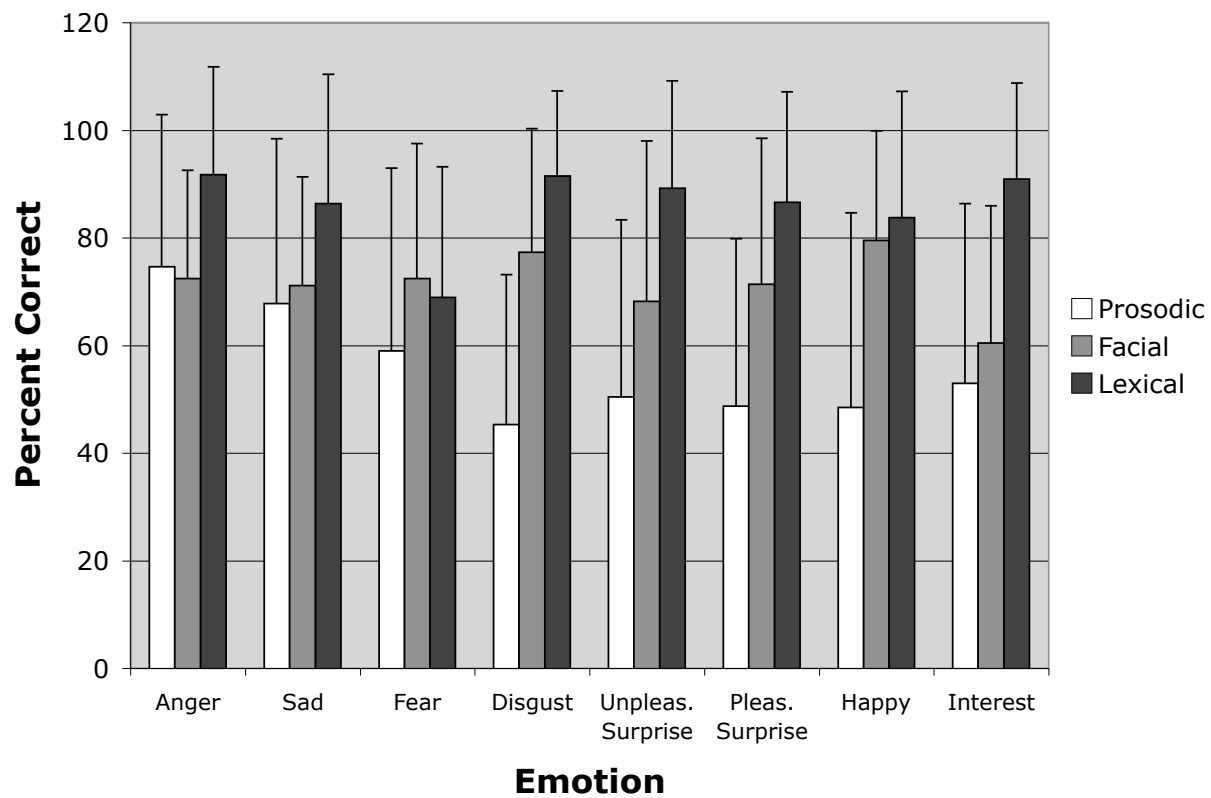


Figure 6a
Performance of Each Age Group on Identification Tasks with WID for the Lexical Channel (Separately for Each Emotion)

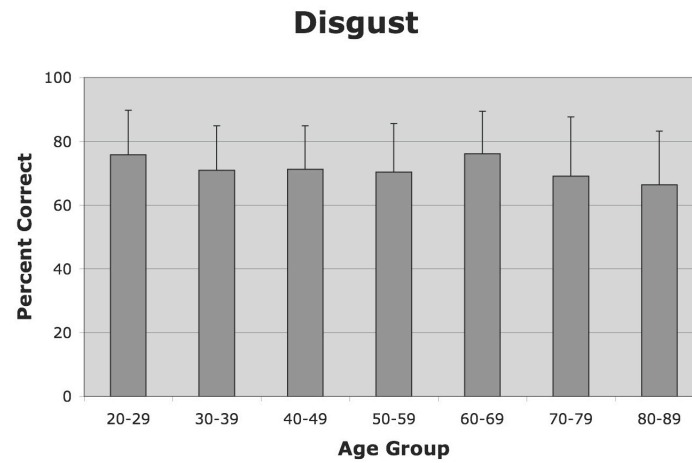
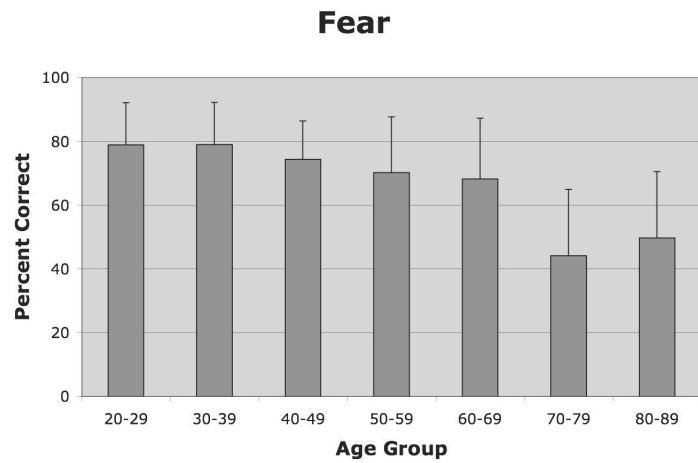
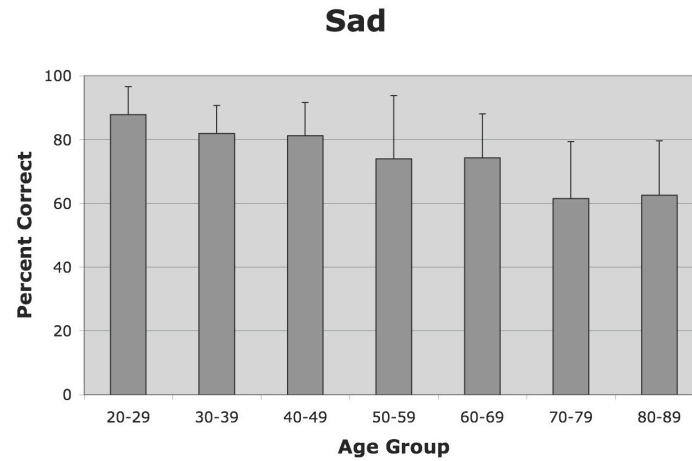
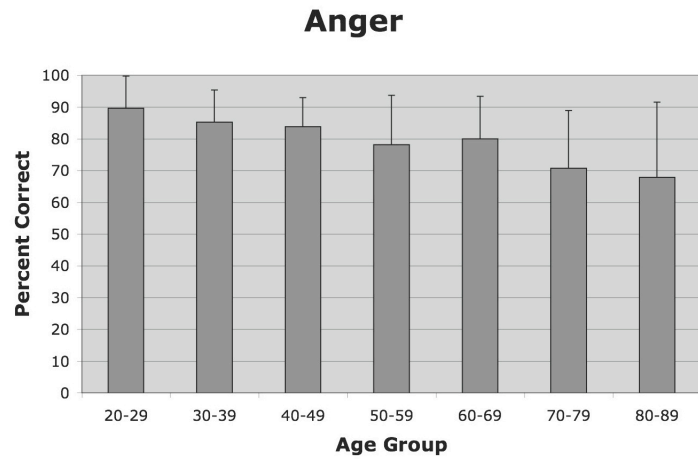


Figure 6b
Performance of Each Age Group on Identification Tasks with WID for the Lexical Channel (Separately for Each Emotion)

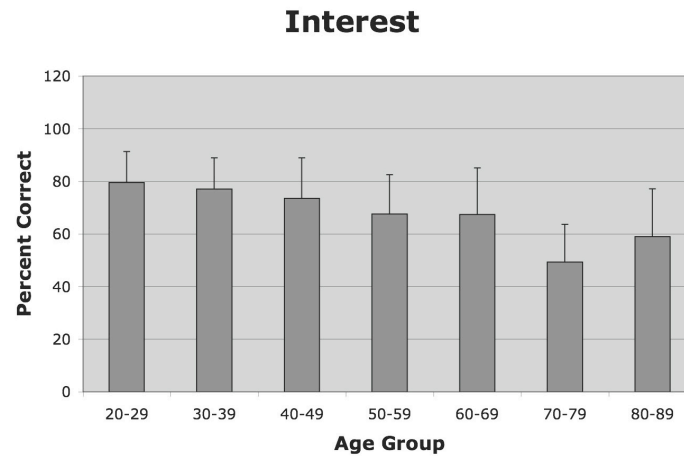
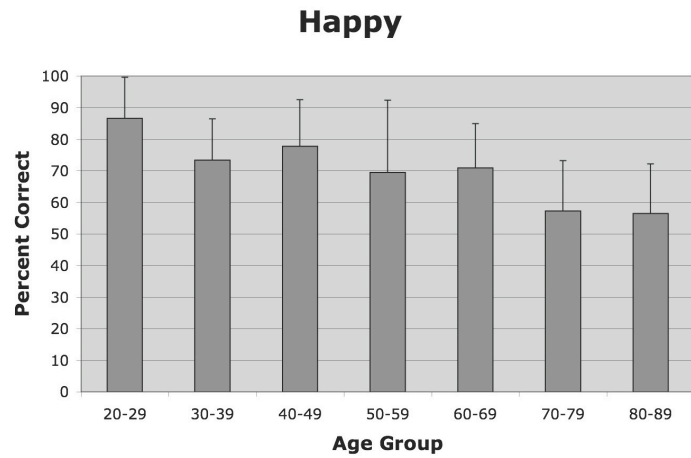
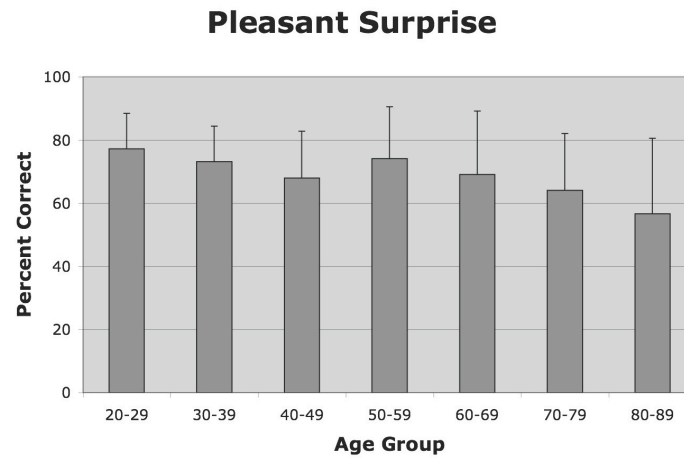
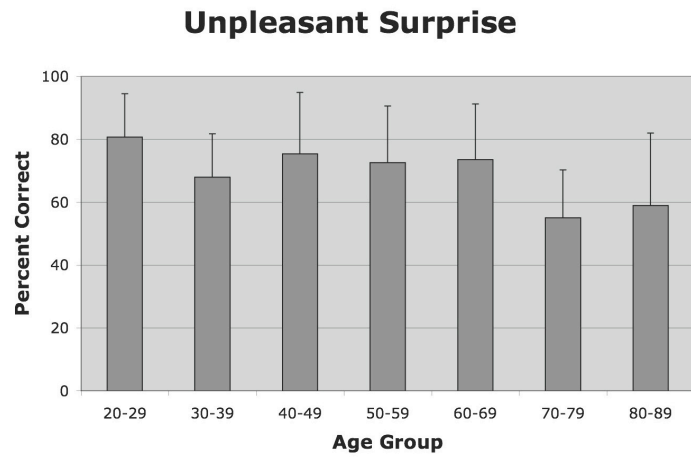


Figure 7a
Performance on Identification Tasks for Each Age Group by Channel (Separately for Each Emotion)

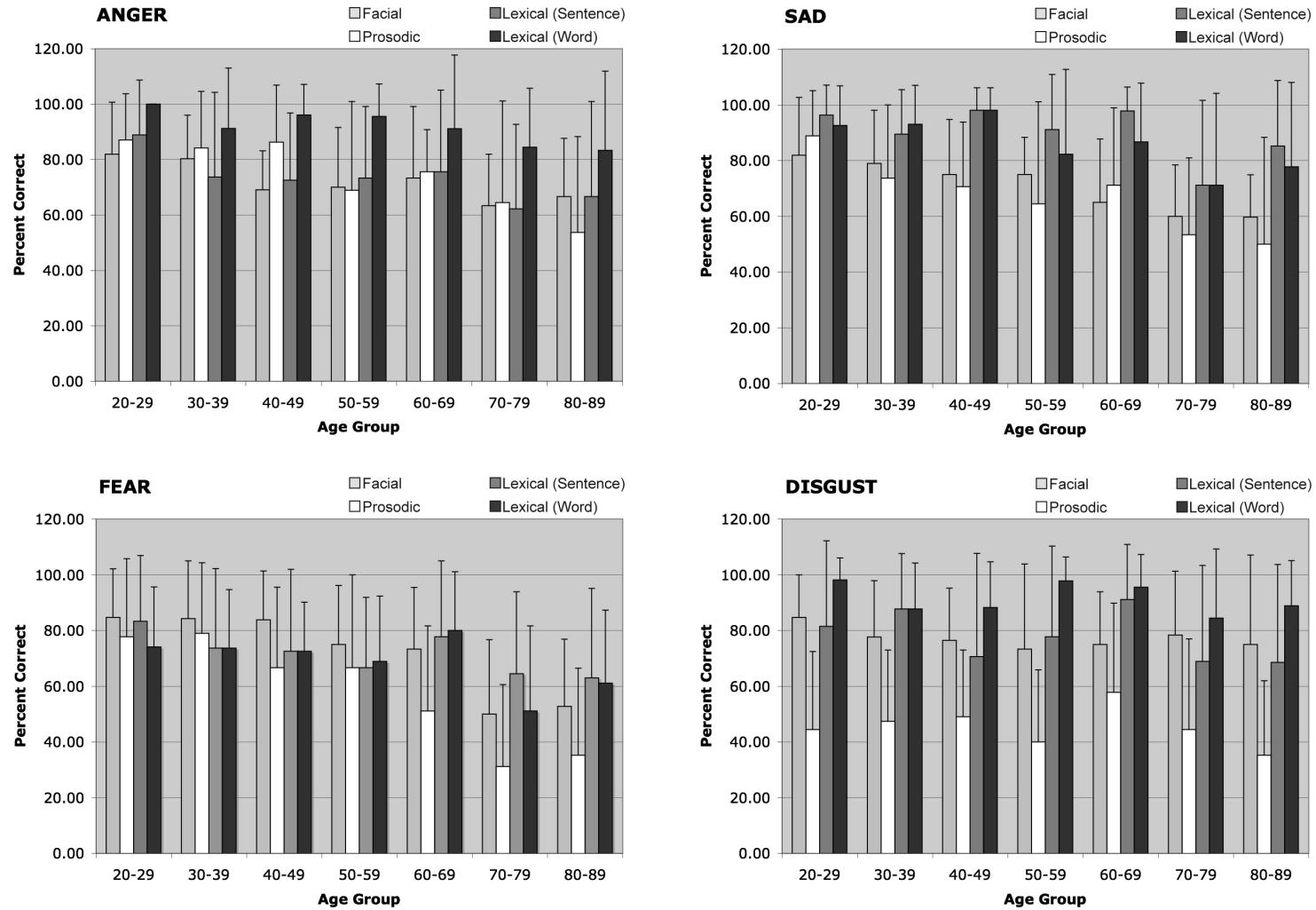


Figure 7b
Performance on Identification Tasks for Age Groups by Channel (Separately for Each Emotion)

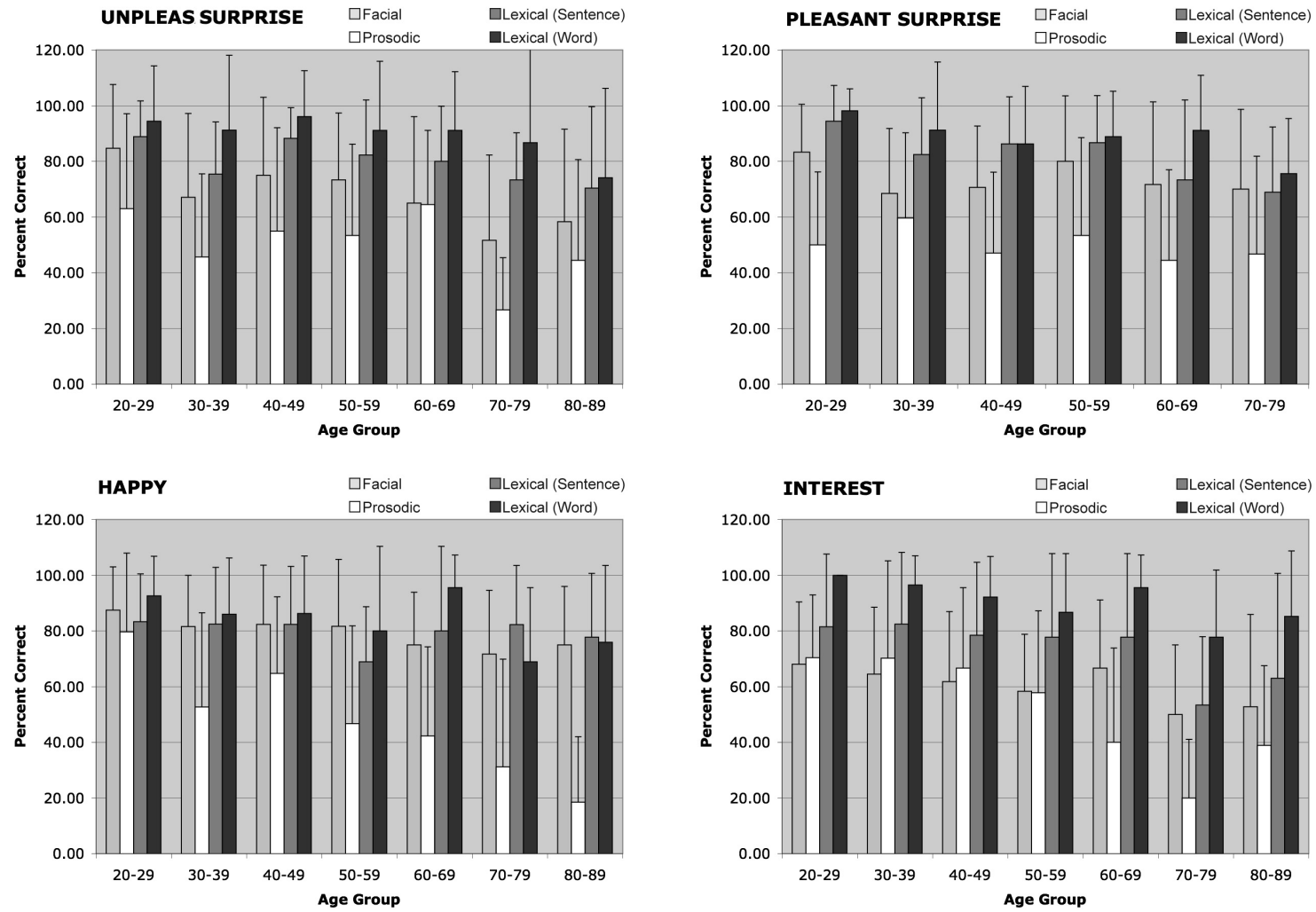


Figure 8
Main Effect of Age for Identification Tasks with SID for the Lexical Channel

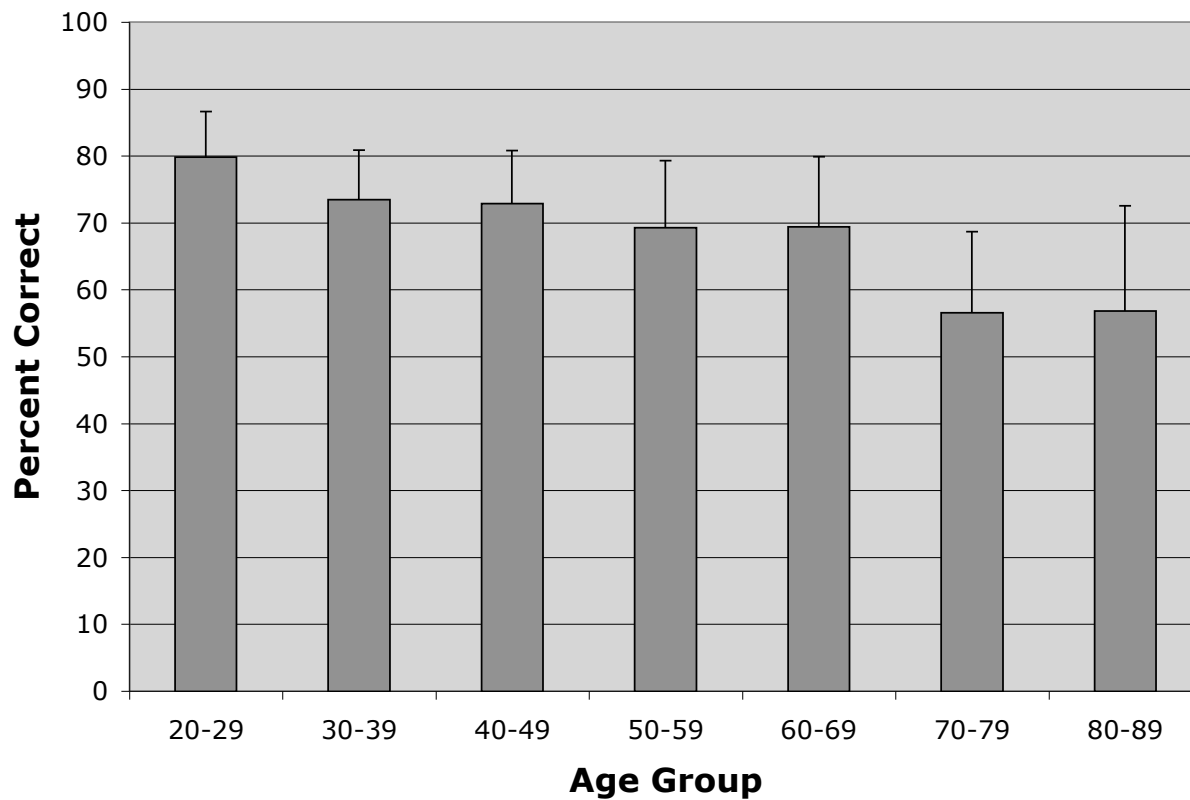


Figure 9
Main Effect of Channel for Identification Tasks with SID for the Lexical Channel

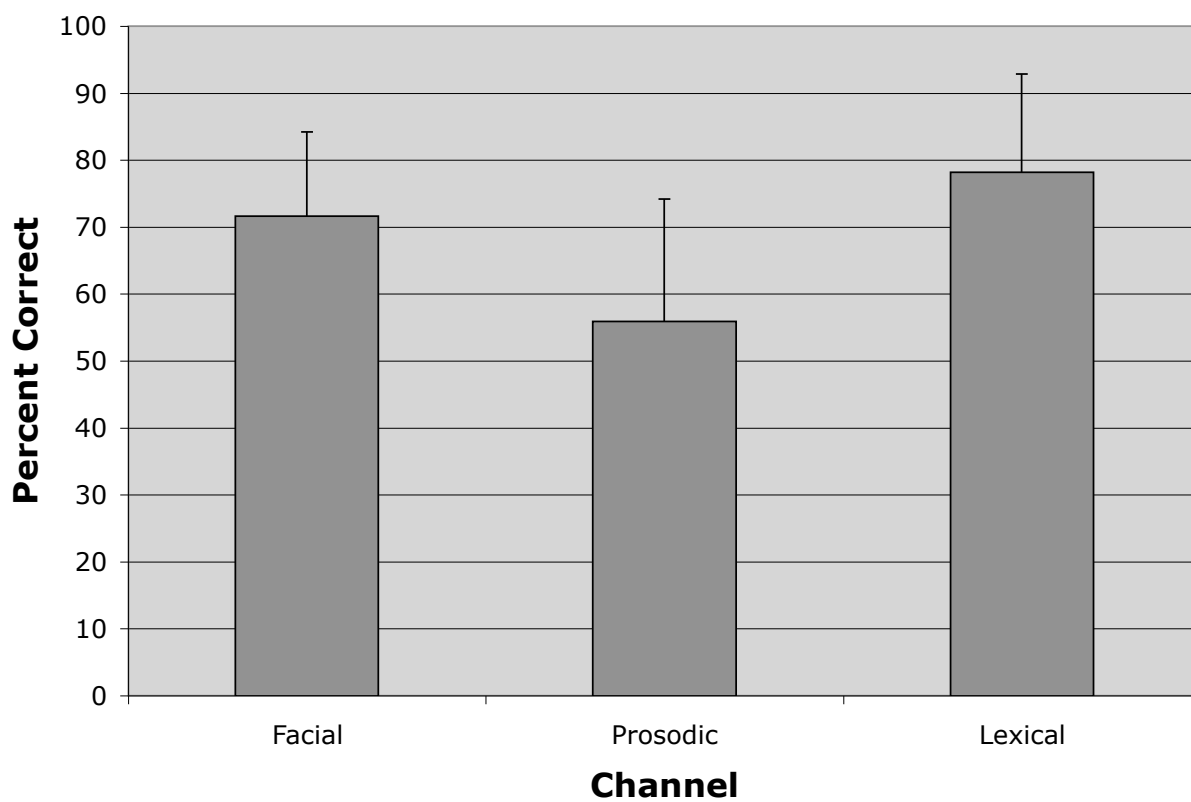


Figure 10
Main Effect of Emotion for Identification Tasks with SID for the Lexical Channel

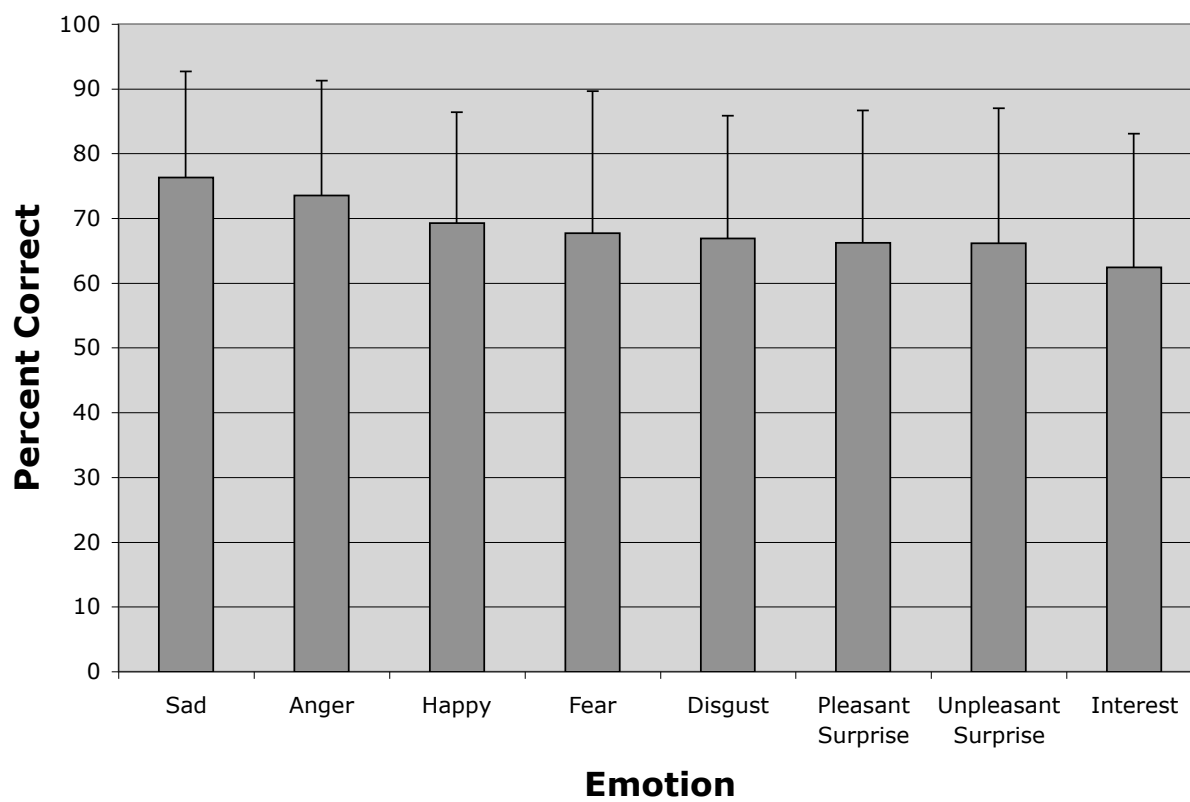


Figure 11
Channel by Emotion Interaction for Identification Tasks with SID for the Lexical Channel

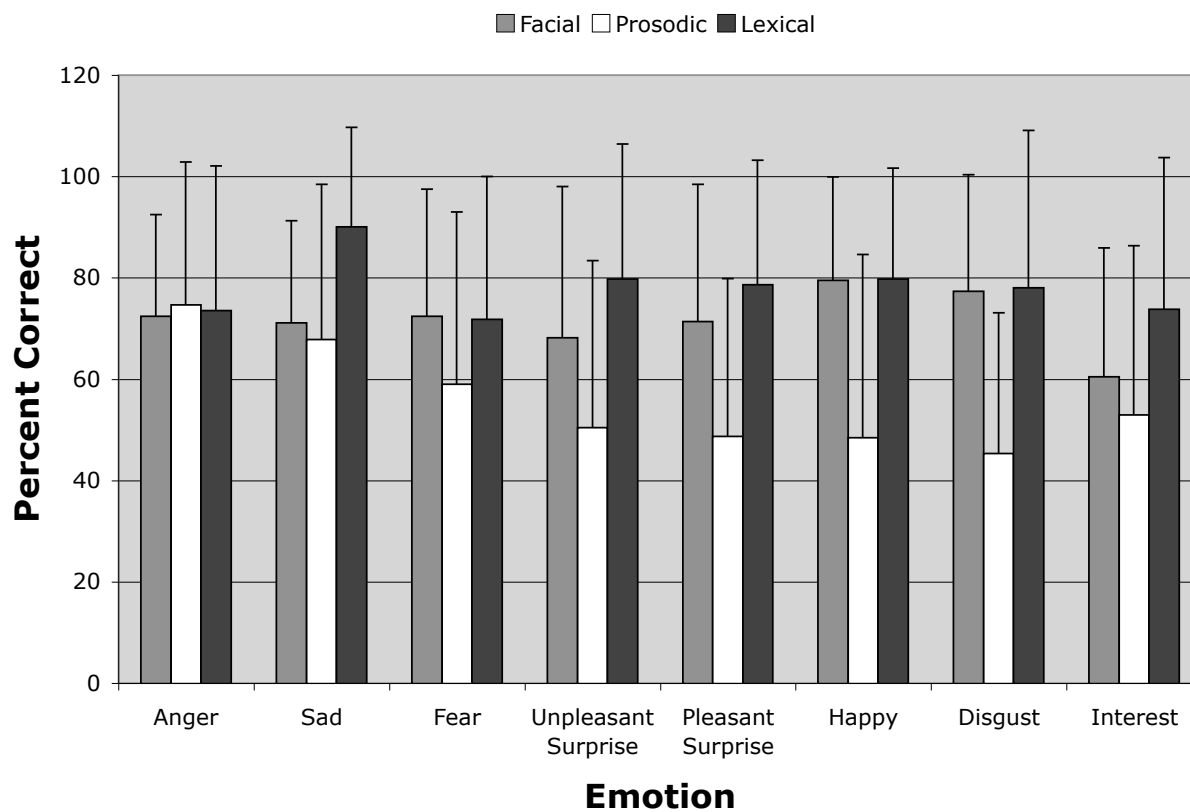


Figure 12a

Performance of Each Age Group on Identification Tasks with SID for the Lexical Channel (Separately for Each Emotion)

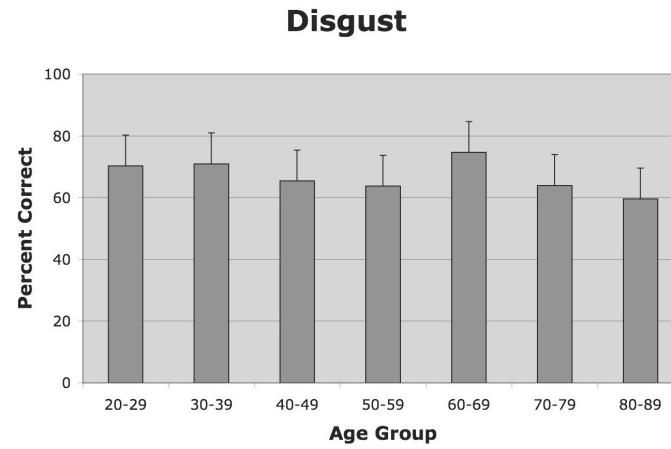
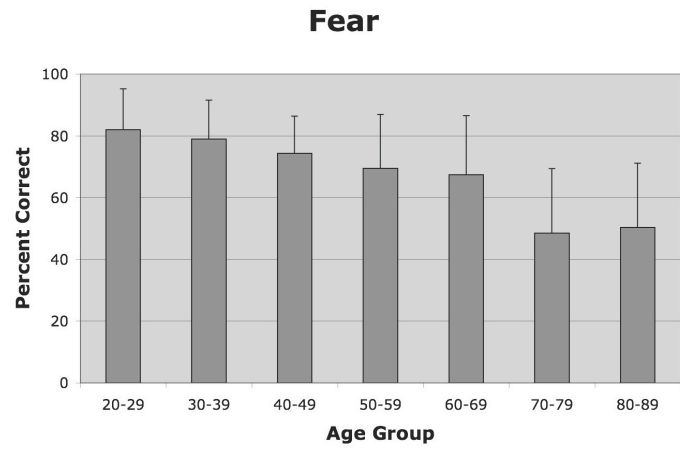
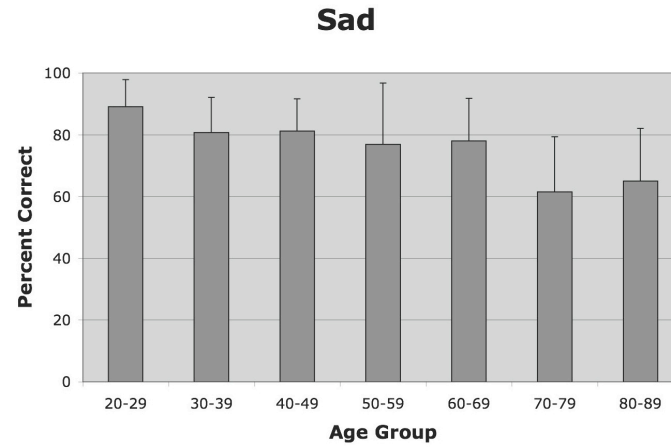
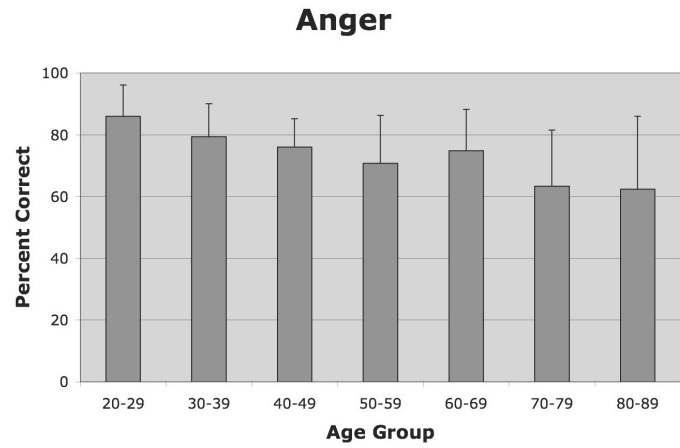


Figure 12b

Performance of Each Age Group on Identification Tasks with SID for the Lexical Channel (Separately for Each Emotion)

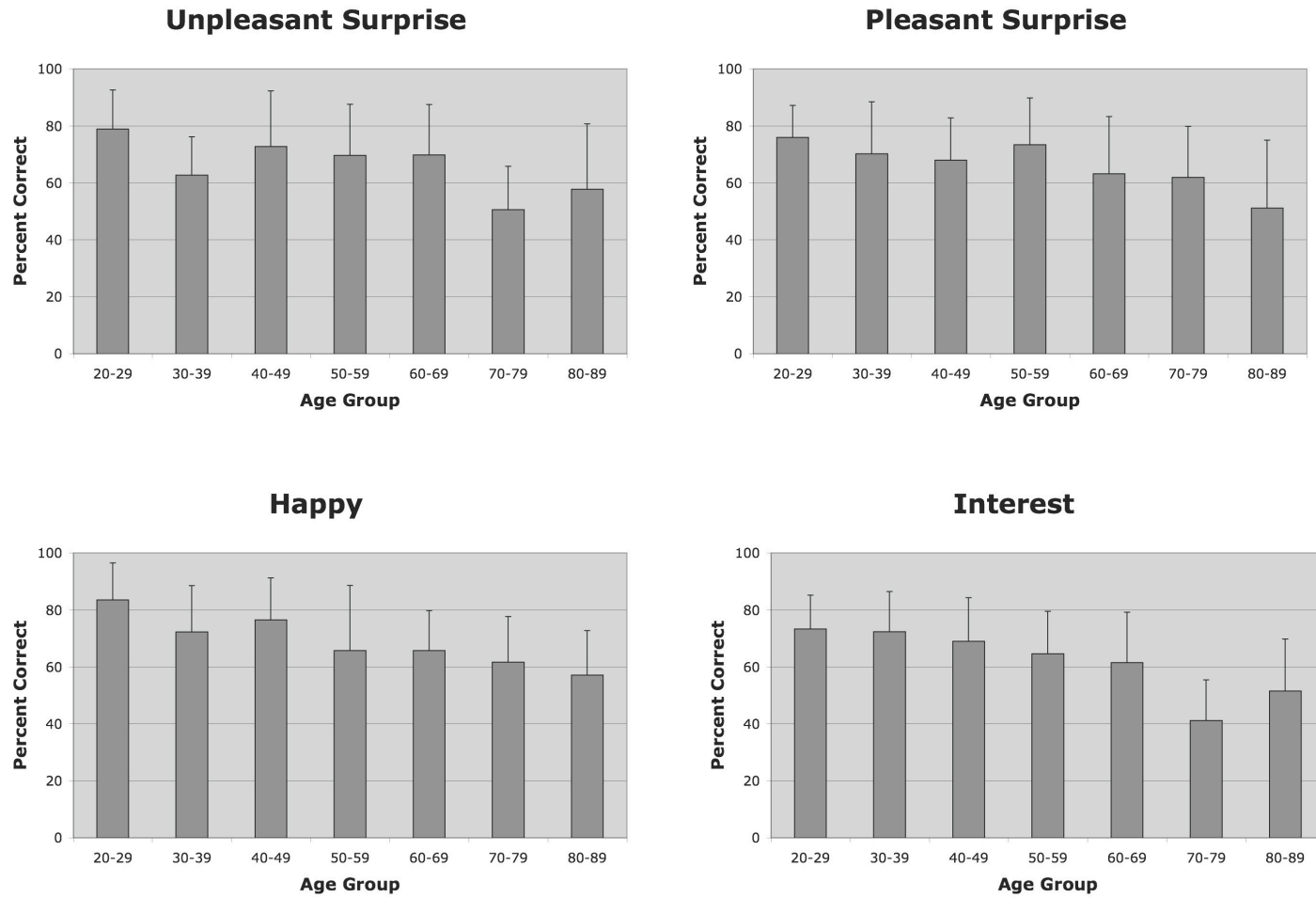


Figure 13
Main Effect of Age for Discrimination Tasks

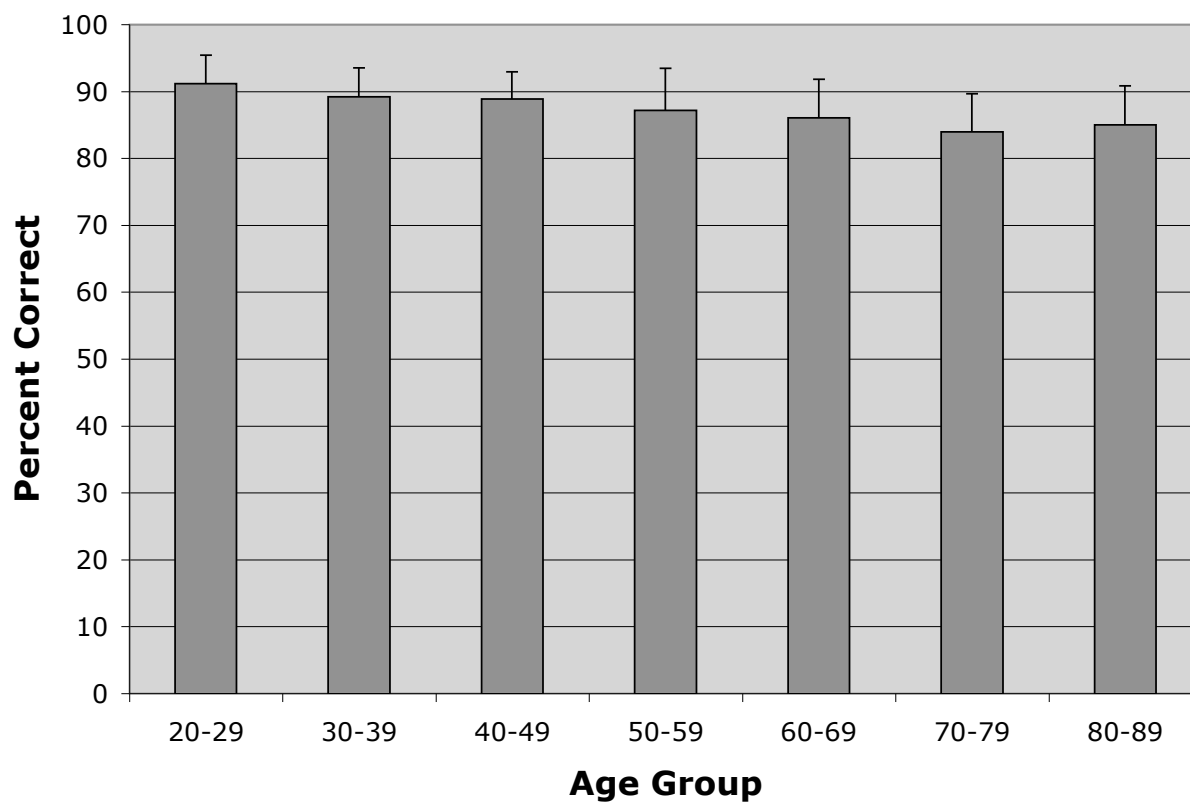
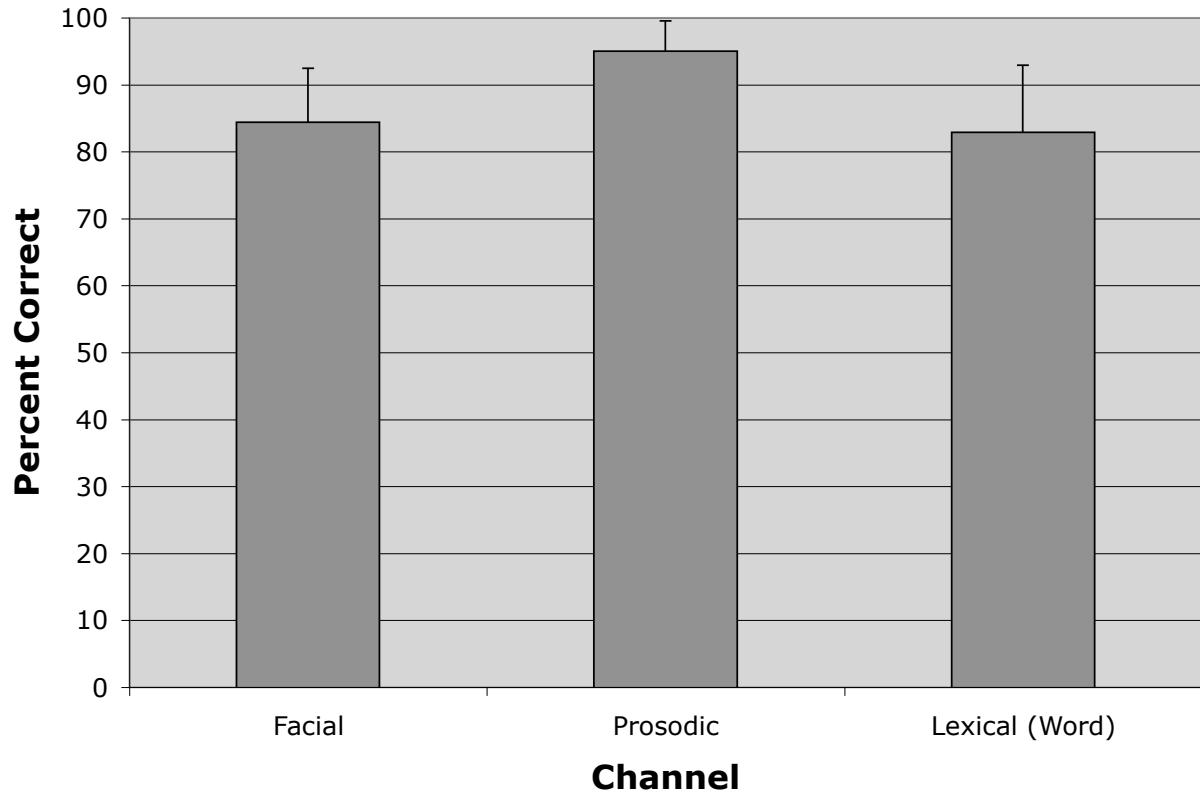


Figure 14
Main Effect of Channel for Discrimination Tasks



Appendix

Table 1
Shapiro-Wilk Tests of Normality and Levene's Test of Homogeneity of Variance for Identification Tasks with Total Scores

Task	Shapiro-Wilk Test of Normality				Levene Test of Homogeneity of Variance		
	Age Group	Statistic	df	p	Statistic	df	p
Facial Identification	20-29	.925	18	.160	2.568	6, 110	.023
	30-39	.929	19	.168			
	40-49	.960	17	.628			
	50-59	.952	15	.555			
	60-69	.871	15	.035			
	70-79	.930	15	.276			
	80-89	.926	18	.165			
Prosodic Identification	20-29	.949	18	.411	2.624	6, 110	.020
	30-39	.939	19	.250			
	40-49	.966	17	.748			
	50-59	.950	15	.517			
	60-69	.920	15	.191			
	70-79	.956	15	.617			
	80-89	.923	18	.144			
Word Identification	20-29	.907	18	.077	4.540	6,110	< .001
	30-39	.894	19	.039			
	40-49	.946	17	.402			
	50-59	.840	15	.013			
	60-69	.903	15	.106			
	70-79	.953	15	.575			
	80-89	.891	18	.039			
Sentence Identification	20-29	.911	18	.090	1.366	6, 110	.235
	30-39	.930	19	.172			
	40-49	.941	17	.329			
	50-59	.904	15	.110			
	60-69	.908	15	.128			
	70-79	.972	15	.885			
	80-89	.943	18	.330			

Table 2
Shapiro-Wilk Tests of Normality and Levene's Test of Homogeneity of Variance for Discrimination Tasks

Task	Age Group	Shapiro-Wilk Test of Normality			Levene Test of Homogeneity of Variance		
		Statistic	df	p	Statistic	df	p
Facial Discrimination	20-29	.902	18	.063	3.116	6, 110	.007
	30-39	.934	19	.203			
	40-49	.927	17	.196			
	50-59	.887	15	.059			
	60-69	.939	15	.366			
	70-79	.965	15	.784			
	80-89	.948	18	.389			
Prosodic Discrimination	20-29	.814	18	.002	4.291	6, 110	.001
	30-39	.859	19	.009			
	40-49	.872	17	.023			
	50-59	.822	15	.007			
	60-69	.889	15	.066			
	70-79	.848	15	.016			
	80-89	.914	18	.100			
Word Discrimination	20-29	.924	18	.151	.705	6, 110	.646
	30-39	.927	19	.152			
	40-49	.974	17	.878			
	50-59	.945	15	.454			
	60-69	.957	15	.641			
	70-79	.941	15	.392			
	80-89	.913	18	.097			

Table 3
Shapiro-Wilk Tests of Normality & Levene's Test of Homogeneity of Variance for Discrete Emotions – Facial Identification

Task	Age Group	Shapiro-Wilk Test of Normality			Levene Test of Homogeneity of Variance		
		Statistic	df	p	Statistic	df	p
Anger	20-29	.788	18	.001	.695	6, 110	.654
	30-39	.779	19	.001			
	40-49	.733	17	< .001			
	50-59	.882	15	.050			
	60-69	.778	15	.002			
	70-79	.663	15	< .001			
	80-89	.875	18	.022			
Sad	20-29	.760	18	< .001	2.369	6, 110	.034
	30-39	.808	19	.001			
	40-49	.817	17	.003			
	50-59	.716	15	< .001			
	60-69	.882	15	.050			
	70-79	.755	15	.001			
	80-89	.752	18	< .001			
Fear	20-29	.764	18	< .001	.270	6, 110	.950
	30-39	.738	19	< .001			
	40-49	.776	17	.001			
	50-59	.805	15	.004			
	60-69	.868	15	.031			
	70-79	.934	15	.316			
	80-89	.915	18	.104			
Unpleasant Surprise	20-29	.713	18	< .001	.507	6, 110	.802
	30-39	.858	19	.009			
	40-49	.814	17	.003			
	50-59	.868	15	.032			
	60-69	.896	15	.082			
	70-79	.888	15	.062			
	80-89	.865	18	.014			
Pleasant Surprise	20-29	.780	18	.001	3.404	6, 110	.004
	30-39	.803	19	.001			
	40-49	.880	17	.032			
	50-59	.805	15	.004			
	60-69	.819	15	.006			
	70-79	.828	15	.008			
	80-89	.879	18	.025			
Happy	20-29	.726	18	< .001	.790	6, 110	.579
	30-39	.793	19	.001			
	40-49	.742	17	< .001			
	50-59	.772	15	.002			
	60-69	.823	15	.007			
	70-79	.887	15	.050			
	80-89	.848	18	.008			

Table 3 (cont.)

Task	Age Group	Statistic	<i>df</i>	<i>p</i>	Statistic	<i>df</i>	<i>p</i>
Disgust	20-29	.752	18	< .001	1.827	6, 110	.100
	30-39	.814	19	.002			
	40-49	.819	17	.004			
	50-59	.823	15	.007			
	60-69	.823	15	.007			
	70-79	.828	15	.009			
	80-89	.785	18	.001			
Interest	20-29	.871	18	.019	1.347	6, 110	.243
	30-39	.883	19	.024			
	40-49	.850	17	.011			
	50-59	.749	15	.001			
	60-69	.891	15	.070			
	70-79	.923	15	.216			
	80-89	.908	18	.081			

Table 4
Shapiro-Wilk Tests of Normality & Levene's Test of Homogeneity of Variance for Discrete Emotions – Prosodic Identification

Emotion	Age Group	Shapiro-Wilk Test of Normality			Levene Test of Homogeneity of Variance		
		Statistic	df	p	Statistic	df	p
Anger	20-29	.624	18	< .001	4.115	6, 110	.001
	30-39	.713	19	< .001			
	40-49	.678	17	< .001			
	50-59	.844	15	.014			
	60-69	.561	15	< .001			
	70-79	.840	15	.012			
	80-89	.886	18	.033			
Sad	20-29	.601	18	< .001	3.309	6, 110	.005
	30-39	.772	19	< .001			
	40-49	.809	17	.003			
	50-59	.840	15	.012			
	60-69	.799	15	.004			
	70-79	.883	15	.051			
	80-89	.855	18	.010			
Fear	20-29	.752	18	< .001	.209	6, 110	.973
	30-39	.753	19	< .001			
	40-49	.855	17	.013			
	50-59	.806	15	.004			
	60-69	.896	15	.082			
	70-79	.839	15	.012			
	80-89	.862	18	.013			
Unpleasant Surprise	20-29	.862	18	.013	2.242	6, 110	.044
	30-39	.887	19	.028			
	40-49	.868	17	.021			
	50-59	.896	15	.082			
	60-69	.817	15	.006			
	70-79	.734	15	.001			
	80-89	.875	18	.021			
Pleasant Surprise	20-29	.849	18	.008	.580	6, 110	.745
	30-39	.866	19	.012			
	40-49	.878	17	.030			
	50-59	.876	15	.041			
	60-69	.840	15	.013			
	70-79	.867	15	.031			
	80-89	.871	18	.018			
Happy	20-29	.726	18	< .001	1.402	6, 110	.220
	30-39	.836	19	.004			
	40-49	.806	17	.002			
	50-59	.876	15	.041			
	60-69	.872	15	.037			
	70-79	.768	15	.001			
	80-89	.739	18	< .001			

Table 4 (cont.)

Task	Age Group	Statistic	<i>df</i>	<i>p</i>	Statistic	<i>df</i>	<i>p</i>
Disgust	20-29	.875	18	.022	.594	6, 110	.734
	30-39	.862	19	.011			
	40-49	.848	17	.010			
	50-59	.806	15	.004			
	60-69	.866	15	.030			
	70-79	.891	15	.070			
	80-89	.812	18	.002			
Interest	20-29	.803	18	.002	1.103	6, 110	.365
	30-39	.799	19	.001			
	40-49	.855	17	.013			
	50-59	.888	15	.063			
	60-69	.874	15	.038			
	70-79	.761	15	.001			
	80-89	.877	18	.023			

Table 5
Shapiro-Wilk Tests of Normality & Levene's Test of Homogeneity of Variance for Discrete Emotions – Lexical Word Identification

Task	Age Group	Shapiro-Wilk Test of Normality			Levene Test of Homogeneity of Variance		
		Statistic	df	p	Statistic	df	p
Anger	20-29	Unable to calculate			2.940	5, 93	.017
	30-39	.452	19	< .001			
	40-49	.385	17	< .001			
	50-59	.413	15	< .001			
	60-69	.394	15	< .001			
	70-79	.713	15	< .001			
	80-89	.651	18	< .001			
Sad	20-29	.520	18	< .001	7.545	6, 110	< .001
	30-39	.507	19	< .001			
	40-49	.262	17	< .001			
	50-59	.658	15	< .001			
	60-69	.667	15	< .001			
	70-79	.816	15	.006			
	80-89	.750	18	< .001			
Fear	20-29	.786	18	.001	1.249	6, 110	.287
	30-39	.779	19	.001			
	40-49	.703	17	< .001			
	50-59	.815	15	.006			
	60-69	.761	15	.001			
	70-79	.896	15	.082			
	80-89	.850	18	.008			
Unpleasant Surprise	20-29	.457	18	< .001	5.631	6, 110	< .001
	30-39	.536	19	< .001			
	40-49	.385	17	< .001			
	50-59	.525	15	< .001			
	60-69	.525	15	< .001			
	70-79	.630	15	< .001			
	80-89	.747	18	< .001			
Pleasant Surprise	20-29	.253	18	< .001	2.933	6, 110	.011
	30-39	.422	19	< .001			
	40-49	.678	17	< .001			
	50-59	.603	15	< .001			
	60-69	.525	15	< .001			
	70-79	.758	15	.001			
	80-89	.786	18	.001			
Happy	20-29	.520	18	< .001	2.738	6, 110	.016
	30-39	.685	19	< .001			
	40-49	.678	17	< .001			
	50-59	.709	15	< .001			
	60-69	.413	15	< .001			
	70-79	.782	15	.002			
	80-89	.768	18	.001			

Table 5 (cont.)

Task	Age Group	Statistic	<i>df</i>	<i>p</i>	Statistic	<i>df</i>	<i>p</i>
Disgust	20-29	.253	18	< .001	12.834	6, 110	< .001
	30-39	.616	19	< .001			
	40-49	.611	17	< .001			
	50-59	.284	15	< .001			
	60-69	.413	15	< .001			
	70-79	.663	15	< .001			
	80-89	.601	18	< .001			
Interest	20-29	Unable to calculate			6.972	6, 110	< .001
	30-39	.362	19	< .001			
	40-49	.533	17	< .001			
	50-59	.667	15	< .001			
	60-69	.413	15	< .001			
	70-79	.783	15	.002			
	80-89	.662	18	< .001			

Table 6
Shapiro-Wilk Tests of Normality & Levene's Test of Homogeneity of Variance for Discrete Emotions – Lexical Sentence Identification

Task	Shapiro-Wilk Test of Normality				Levene Test of Homogeneity of Variance		
	Age Group	Statistic	df	p	Statistic	df	p
Anger	20-29	.614	18	< .001	.997	6, 110	.431
	30-39	.803	19	.001			
	40-49	.809	17	.003			
	50-59	.806	15	.004			
	60-69	.734	15	.001			
	70-79	.881	18	.050			
	80-89	.836	18	.005			
Sad	20-29	.373	18	< .001	7.945	6, 110	< .001
	30-39	.591	19	< .001			
	40-49	.262	17	< .001			
	50-59	.525	15	< .001			
	60-69	.284	15	< .001			
	70-79	.828	18	.009			
	80-89	.662	18	< .001			
Fear	20-29	.705	18	< .001	.500	6, 110	.807
	30-39	.804	19	.001			
	40-49	.815	17	.003			
	50-59	.823	15	.007			
	60-69	.749	15	.001			
	70-79	.868	18	.031			
	80-89	.855	18	.010			
Unpleasant Surprise	20-29	.614	18	< .001	3.519	6, 110	.003
	30-39	.774	19	< .001			
	40-49	.611	17	< .001			
	50-59	.716	15	< .001			
	60-69	.761	15	.001			
	70-79	.718	15	< .001			
	80-89	.823	18	.003			
Pleasant Surprise	20-29	.457	18	< .001	2.478	6, 110	.028
	30-39	.733	19	< .001			
	40-49	.632	17	< .001			
	50-59	.630	15	< .001			
	60-69	.790	15	.003			
	70-79	.815	15	.006			
	80-89	.866	18	.015			
Happy	20-29	.642	18	< .001	1.640	6, 110	.143
	30-39	.733	19	< .001			
	40-49	.738	17	< .001			
	50-59	.763	15	.001			
	60-69	.709	15	< .001			
	70-79	.744	15	.001			
	80-89	.780	18	.001			

Table 6 (cont.)

Task	Age Group	Statistic	<i>df</i>	<i>p</i>	Statistic	<i>df</i>	<i>P</i>
Disgust	20-29	.669	18	< .001	2.493	6, 110	.027
	30-39	.647	19	< .001			
	40-49	.770	17	.001			
	50-59	.728	15	.001			
	60-69	.525	15	< .001			
	70-79	.812	15	.005			
	80-89	.815	18	.002			
Interest	20-29	.699	18	< .001	.862	6, 110	.526
	30-39	.684	19	< .001			
	40-49	.752	17	< .001			
	50-59	.748	15	.001			
	60-69	.748	15	.001			
	70-79	.846	15	.015			
	80-89	.831	18	.004			

Table 7
*Shapiro-Wilk Tests of Normality & Levene's Test of Homogeneity of Variance for
 Nonemotional Control Tasks*

Task	Shapiro-Wilk Test of Normality				Levene Test of Homogeneity of Variance		
	Age Group	Statistic	df	p	Statistic	df	p
Word Discrimination (Nonemotional)	20-29	.930	18	.192	.263	6, 110	.953
	30-39	.882	19	.023			
	40-49	.966	17	.743			
	50-59	.928	15	.258			
	60-69	.873	15	.037			
	70-79	.961	15	.703			
	80-89	.946	18	.366			
Word Identification (Nonemotional)	20-29	.817	18	.003	1.941	6, 110	.080
	30-39	.830	19	.003			
	40-49	.694	17	< .001			
	50-59	.728	15	.001			
	60-69	.843	15	.014			
	70-79	.857	15	.022			
	80-89	.813	18	.002			
Sentence Identification (Nonemotional)	20-29	.930	18	.197	3.409	6, 110	.004
	30-39	.944	19	.311			
	40-49	.920	17	.151			
	50-59	.925	15	.231			
	60-69	.948	15	.497			
	70-79	.920	15	.194			
	80-89	.926	18	.164			
Visual Matrices	20-29	.483	18	< .001	3.339	6, 108	.005
	30-39	.588	19	< .001			
	40-49	.490	17	< .001			
	50-59	.638	13	< .001			
	60-69	.606	15	< .001			
	70-79	.836	15	.011			
	80-89	.683	18	< .001			
Benton Facial Recognition	20-29	.935	18	.234	3.755	6, 109	.002
	30-39	.896	19	.041			
	40-49	.828	17	.005			
	50-59	.924	15	.219			
	60-69	.896	14	.098			
	70-79	.886	15	.059			
	80-89	.955	18	.506			

Table 7 (cont.)

Task	Age Group	Statistic	<i>df</i>	<i>P</i>	Statistic	<i>df</i>	<i>p</i>
Intonation Contours	20-29	.645	18	< .001	5.023	6, 109	< .001
	30-39	.840	19	.005			
	40-49	.938	17	.294			
	50-59	.803	15	.004			
	60-69	.894	15	.078			
	70-79	.848	15	.016			
	80-89	.782	17	.001			
Benton Phoneme Discrimination	20-29	.775	18	< .001	5.968	6, 110	< .001
	30-39	.839	19	.004			
	40-49	.893	17	.052			
	50-59	.860	15	.024			
	60-69	.906	15	.117			
	70-79	.920	15	.190			
	80-89	.935	18	.237			
Beck Depression Inventory	20-29	.726	18	< .001	2.180	6, 110	.050
	30-39	.747	19	< .001			
	40-49	.690	17	< .001			
	50-59	.817	15	.006			
	60-69	.810	15	.005			
	70-79	.727	15	<.001			
	80-89	.913	18	.098			

Table 8

Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Identification Task with Age as a Continuous Variable

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.440	11.673	< .001					
Constant				75.483	7.548		10.000	< .001
Letter Cancellation Time				-.094	.038	-.215	-2.459	.016
WAIS-R Information				.682	.213	.285	3.203	.002
WAIS-R Block Design				.139	.121	.124	1.144	.255
WMS-R Logical Memory I				.052	.317	.027	.165	.870
Pure Tone Threshold Composite				1.739	1.680	.114	1.035	.303
Age (continuous)				-.265	.080	-.422	-3.306	.001

Table 9

Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Identification Task with Age as a Continuous Variable

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.506	15.238	< .001					
Constant				43.222	10.270		4.208	< .001
Letter Cancellation Time				-.022	.052	-.034	-.416	.678
WAIS-R Information				.631	.290	.182	2.177	.032
WAIS-R Block Design				.200	.165	.123	1.213	.228
WMS-R Logical Memory I				.698	.432	.248	1.617	.109
Pure Tone Threshold Composite				-5.648	2.285	-.254	-2.471	.015
Age (continuous)				-.262	.109	-.289	-2.409	.018

Table 10

Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Identification Task with Age as a Continuous Variable

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.478	13.620	< .001					
Constant				69.130	7.151		9.667	< .001
Letter Cancellation Time				-.039	.036	-.091	-1.078	.284
WAIS-R Information				.902	.202	.384	4.470	< .001
WAIS-R Block Design				.090	.115	.081	.779	.437
WMS-R Logical Memory I				.619	.301	.325	2.057	.042
Pure Tone Threshold Composite				-1.281	1.591	-.085	-.805	.423
Age (continuous)				-.164	.076	-.266	-2.156	.033

Table 11

Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Sentence Identification Task with Age as a Continuous Variable

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.533	16.978	< .001					
Constant				58.125	8.011		7.256	< .001
Letter Cancellation Time				-.077	.041	-.151	-1.902	.060
WAIS-R Information				1.309	.226	.471	5.790	< .001
WAIS-R Block Design				-.020	.129	-.015	-.153	.878
WMS-R Logical Memory I				.487	.337	.216	1.445	.151
Pure Tone Threshold Composite				1.251	1.783	.070	.702	.484
Age (continuous)				-.234	.085	-.321	-2.753	.007

Table 12

Multiple Regression with Auditory Acuity, Cognition, and Age for Facial Discrimination Task with Age as a Continuous Variable

	R^2	F	$p(F)$	B	$SE B$	β	t	$p(t)$
Model	.336	7.530	< .001					
Constant				77.615	5.211		14.895	< .001
Letter Cancellation Time				-.018	.026	-.063	-.666	.507
WAIS-R Information				.390	.147	.257	2.651	.009
WAIS-R Block Design				-.026	.084	-.037	-.310	.757
WMS-R Logical Memory I				.231	.219	.188	1.056	.294
Pure Tone Threshold Composite				-2.113	1.160	-.218	-1.822	.071
Age (continuous)				-.083	.055	-.209	-1.502	.136

Table 13

Multiple Regression with Auditory Acuity, Cognition, and Age for Prosodic Discrimination Task with Age as a Continuous Variable

	R^2	F	$p(F)$	B	$SE B$	β	t	$P(t)$
Model	.124	2.106	.049					
Constant				96.728	3.399		28.459	< .001
Letter Cancellation Time				-.020	.017	-.128	-1.173	.243
WAIS-R Information				-.007	.096	-.009	-.077	.939
WAIS-R Block Design				-.013	.055	-.033	-.244	.808
WMS-R Logical Memory I				.014	.143	.021	.100	.920
Pure Tone Threshold Composite				-.228	.756	-.041	-.302	.763
Age (continuous)				-.034	.036	-.150	-.942	.349

Table 14
Multiple Regression with Auditory Acuity, Cognition, and Age for Lexical Word Discrimination Task with Age as a Continuous Variable

	R^2	F	$P(F)$	B	$SE B$	β	t	$P(t)$
Model	.439	11.641	< .001					
Constant				55.471	5.977		9.281	< .001
Letter Cancellation Time				.029	.030	.082	.944	.347
WAIS-R Information				.869	.169	.459	5.155	< .001
WAIS-R Block Design				.195	.096	.220	2.029	.045
WMS-R Logical Memory I				.163	.251	.106	.649	.518
Pure Tone Threshold Composite				.543	1.330	-.124	-.970	.334
Age (continuous)				-.061	.063	-.124	-.970	.334

Figure 1
Normal and Detrended Normal P-P Plots for Facial Identification

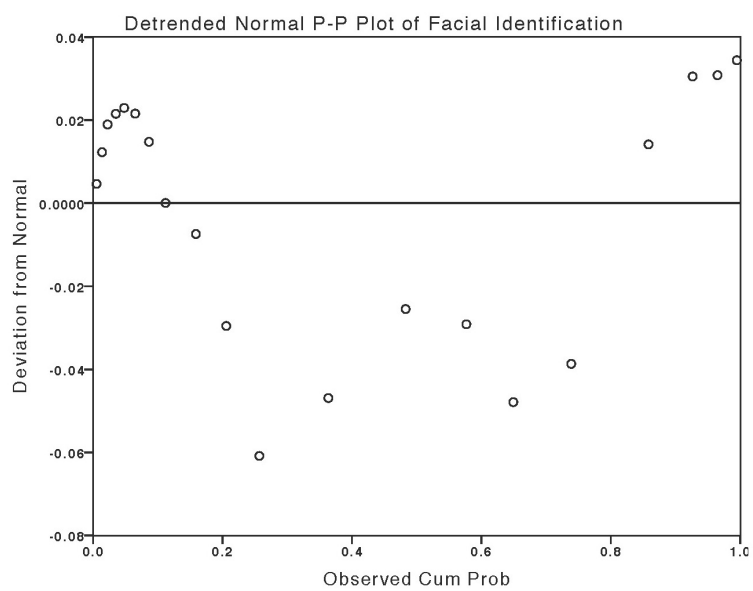
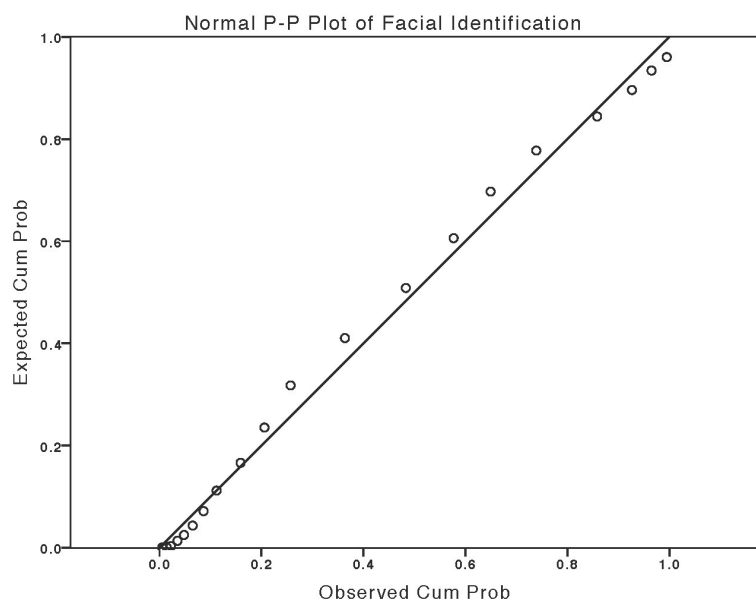


Figure 2
Normal and Detrended Normal P-P Plots for Prosodic Identification

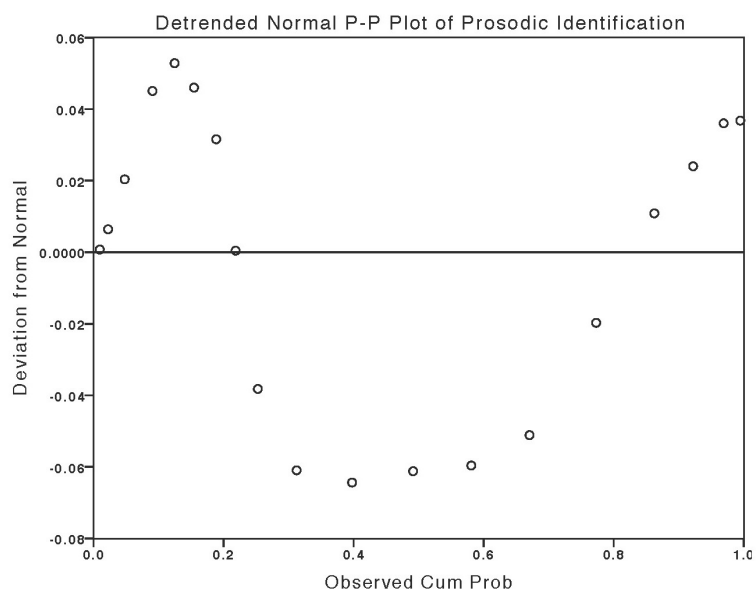
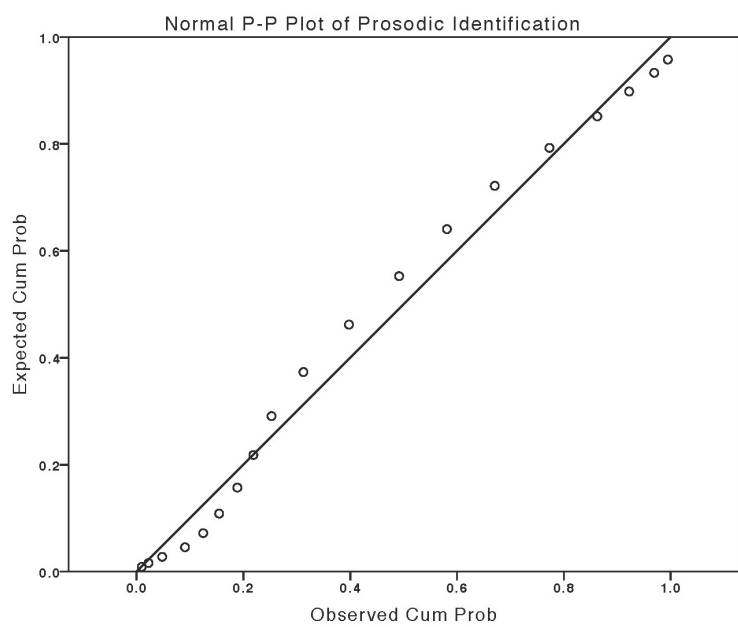


Figure 3
Normal and Detrended Normal P-P Plots for Lexical Word Identification

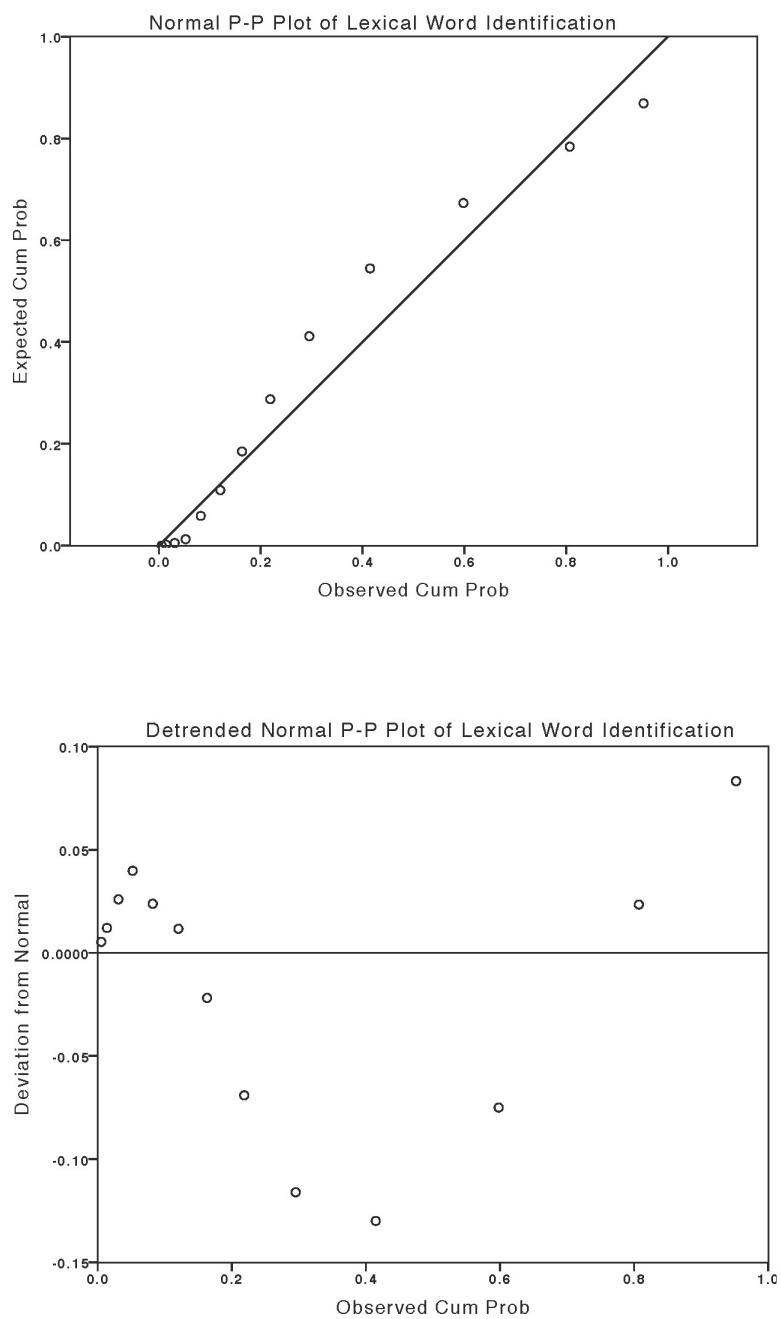


Figure 4
Normal and Detrended Normal P-P Plots for Lexical Sentence Identification

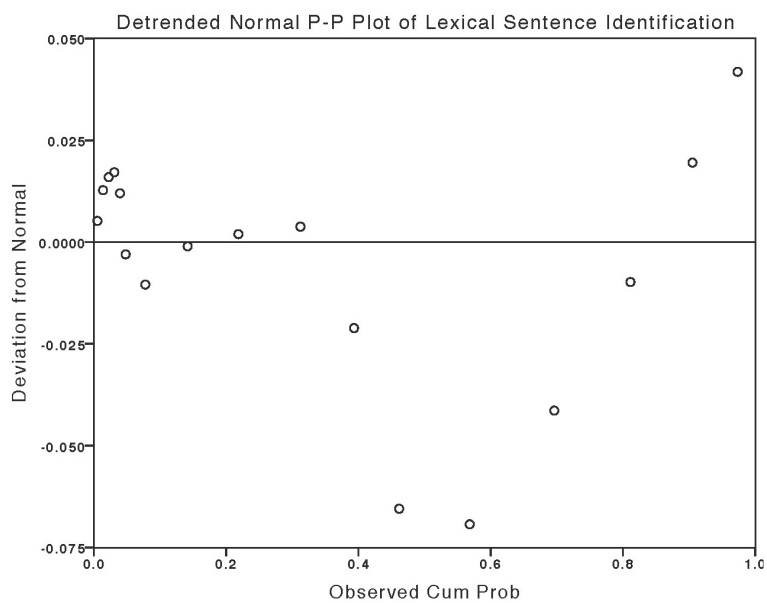
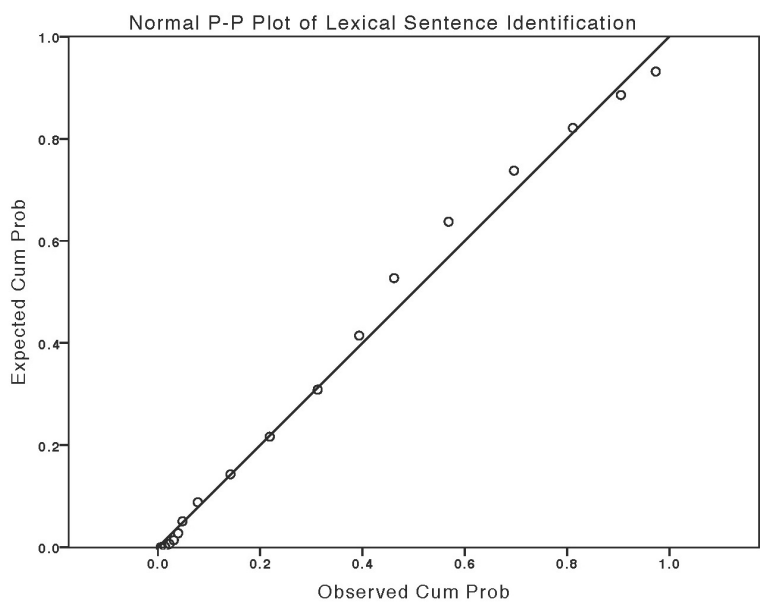


Figure 5
Normal and Detrended Normal P-P Plots for Facial Discrimination

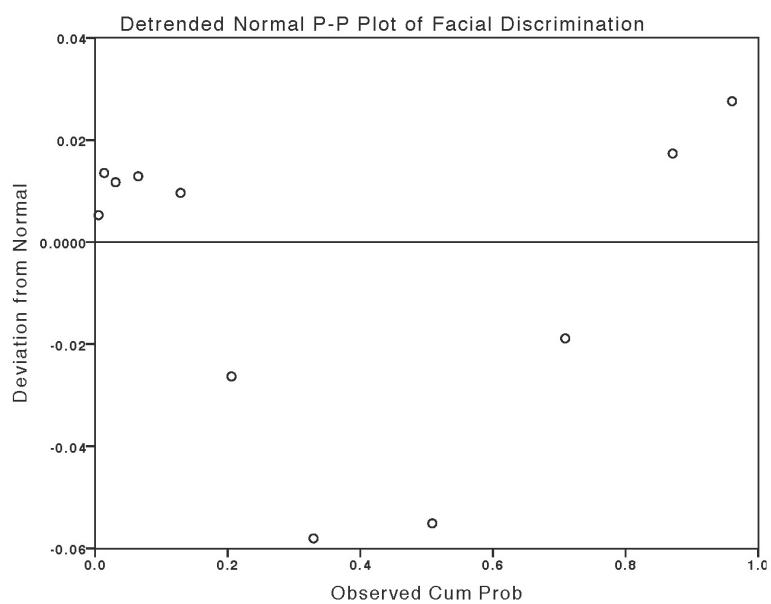
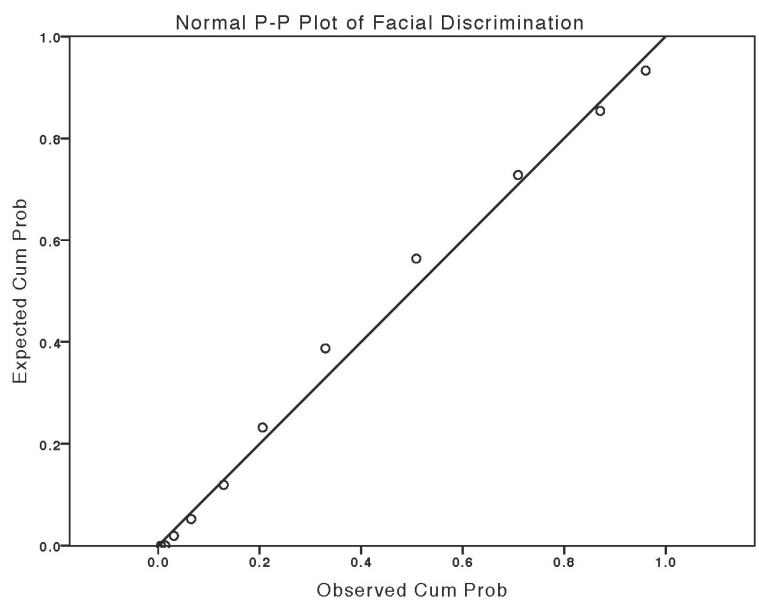


Figure 6
Normal and Detrended Normal P-P Plots for Prosodic Discrimination

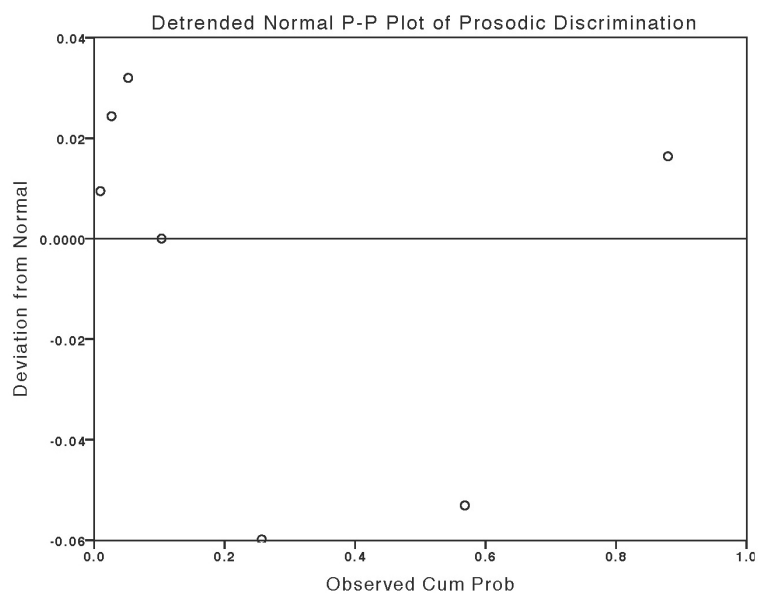
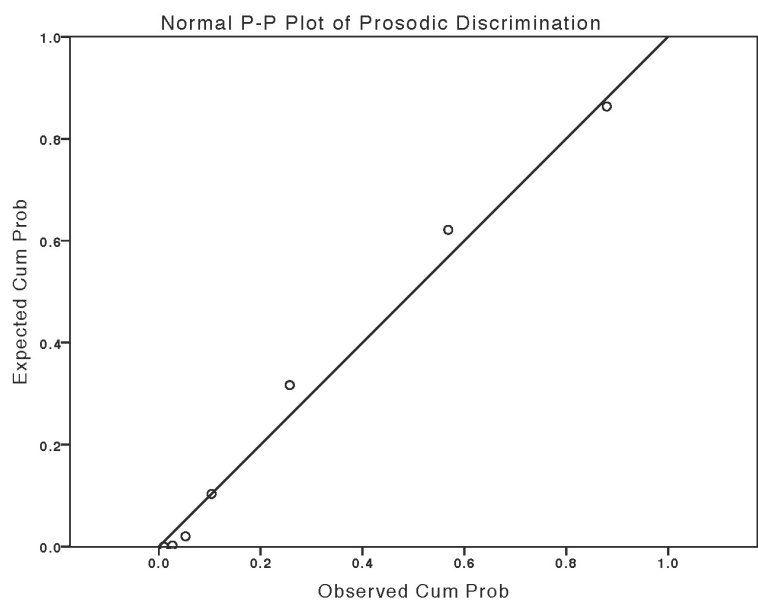
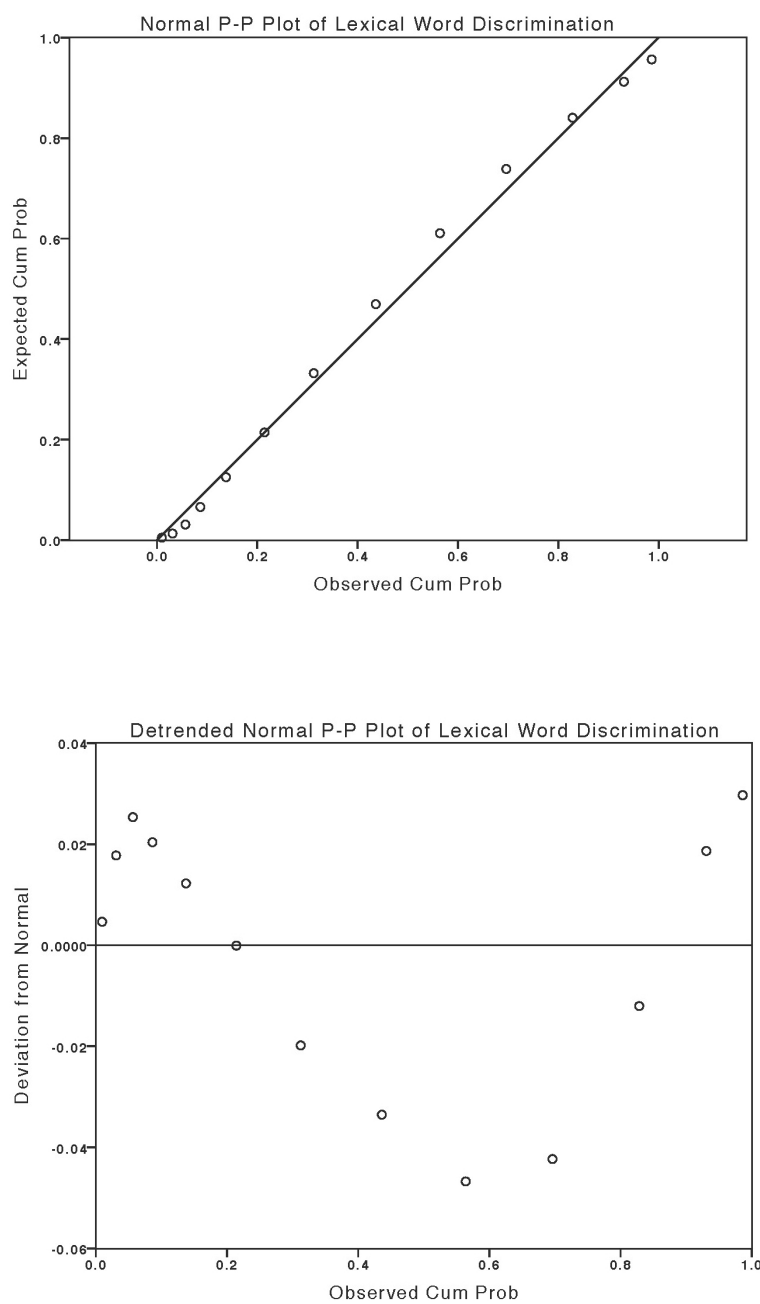


Figure 7
Normal and Detrended Normal P-P Plots for Lexical Word Discrimination



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