The Pennsylvania State University

The Graduate School

College of the Liberal Arts

THE NEURAL CIRCUITRY UNDERLYING THE PEER BIAS IN FACE RECOGNITION IN EMERGING ADULTS

A Thesis in

Psychology

by

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Submitted in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science

August 2018

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ABSTRACT

Our previous developmental work indicates that emerging adults, individuals ages 18-25 years, have a peer bias in their face recognition abilities (Picci & Scherf, 2016). Specifically, they exhibit superior recognition for peer faces compared to faces from other developmental groups. Little is known about how the underlying neural circuitry is organized to support this peer bias behavior. Here, we examined neural activation in emerging adults as they viewed faces from a wide range of developmental groups while they were scanned with fMRI. The face categories included children, early puberty adolescent face, late puberty adolescent face, emerging adult (i.e., peer), and parent-age faces. For each participant, we individually defined regions of interest (ROI) bilaterally using each face category contrasted with objects (e.g., child faces-objects, emerging adult faces-objects). We quantified each ROI in terms of the magnitude of response to each category of faces, the number of active voxels, and the locus of activation. We found that the right FFA1 activation was largest in volume when defined by emerging adult faces than by any other face categories. In addition, the emerging adult defined right FFA1 region was in a more anterior location compared to the other face defined FFA ROIs, particularly in comparison to the child-face defined FFA1. Finally, each of the face category defined FFA1 ROIs exhibited a unique profile of activation, which suggest that the bilateral fusiform gyri appear to encode information about the developmental stage of a face in separate, but overlapping, patches of tissue. In sum, the findings suggest that the peer bias in emerging adult face recognition behavior may be subserved by disproportionally larger activation of neural tissue located in an anterior part of the FFA1 (but not FFA2) compared to that elicited by other kinds of faces.

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ACKNOWLEDGEMENTS

I would like to express tremendous gratitude to my advisor, Dr. Suzy Scherf, for her unconditional support, guidance, and encouragement throughout the entirety of my master's thesis project. I would also like to sincerely thank the members of my committee, Dr. Koraly Perez-Edgar and Dr. Reginald Adams, for their invaluable feedback and advice. Your support has enabled me to make valuable progression on my critical thinking, scientific writing, and presentation skill. I would also like to acknowledge PSU Psychology Department and Social, Life, and Engineering Sciences Imaging Center for supporting this experiment. I would also like to give my many thanks to my colleagues in the Lab of Developmental Neuroscience, Giorgia Picci, Natalie Motta-Mena, Dan Elbich, for your involvement in experiment procedure, data collection, and advice on data analysis. I would also like to show my appreciation to the undergraduate research assistants, Marlaina Laubach, Sara Albert, and Naomi Franklin, for your help in data collection.

Chapter 1

Introduction

Face recognition is an important ability for human beings to identify our caregivers, peers, and potential romantic partners. Evidence shows that humans exhibit strong biases (i.e., superior recognition) for specific kinds of faces, including faces from our own species (e.g., Dufour, Pascalis, & Petit, 2006; Scott & Monesson, 2009), race (e.g., Anzures, Quinn, Pascalis, Slater, & Lee, 2010; Hayden, Bhatt, Zieber, & Kangas, 2009), and gender (e.g., Armony & Sergerie, 2007; Wright & Sladden, 2003). These biases also change over the course of the life time and with particular kinds of experience (Hills & Lewis, 2011; Lebrecht, Pierce, Tarr, & Tanaka, 2009). These fine-tuned adjustments in the face processing system are considered to be evolutionarily and socially adaptive for human being's ability to promptly identify motivationally significant faces in complicated social contexts (Farroni et al., 2005; Pascalis & Bachevalier, 1998; Pascalis, de Haan, & Nelson, 2002; Scott & Fava, 2014).

The current study focused on identifying the underlying neural circuitry supporting one of the most important face recognition biases, the peer bias, in emerging adulthood. This bias represents the ability to recognize individual unfamiliar faces from one's peer group, which was often defined based on age, more accurately and faster than from other developmental periods or ages (e.g., Anastasi & Rhodes, 2006; Bäckman 1991; Fulton & Bartlett, 1991; Perfect & Moon, 2005; Scherf & Scott, 2012; Wright & Stroud, 2002). Empirical behavioral studies showed that the peer bias in face recognition is comparable in younger and older adults (e.g., Wright & Stroud, 2002), and strongest in middle adulthood (e.g., Anastasi & Rhodes, 2006). However, one of the limitations in these previous studies is that they did not have a clear theoretical framework about peer bias and usually used age to define peer bias.. Although age can be part of the definition, it is difficult to think about age as an in-group identifier. For example, toddlers were expected to have an age bias for other toddler-aged faces even though they likely experience parent-aged faces more often. Empirical studies actually showed that, children did not exhibit superior performance for their own-aged faces compared to other aged faces in an old/new recognition memory task for different age faces (Anastasi & Rhodes, 2005). In this case, using age to define bias can only answer a question about whether there's a bias but fail to answer what the actual bias for developmental groups is.

In contrast, Social Development Task (SDT) theoretical framework not only defines the direction of bias in face recognition behavior across developmental groups but also what is the bias for individuals at different developmental groups using peer bias as a in/out-group identifier. Specifically, this theoretical framework suggests that there's no peer bias but parent-aged bias in face recognition in infancy and childhood, and influenced by pubertal development, peer bias begins to emerge during adolescence and continue to develop into early adulthood. These changing patterns of biases reflect how the visuoperceptual system changes to accommodate social developmental tasks at different developmental stages (Picci & Scherf, 2016; Scherf & Scott, 2012). The most recent developmental work supports SDT perspective by showing that 5 to 8-year-old children failed to exhibit a peer bias in face recognition (Picci & Scherf, 2016). Instead,

children showed a caregiver bias in which they exhibit superior recognition of adult female faces. In contrast, adolescents did not exhibit a caregiver bias but an emerging peer bias, which includes superior recognition for faces of a similar age and pubertal status as their own. Importantly, this study also revealed a strong peer bias in emerging adults between the ages of 18-25 years. However, it is still largely unknown how the underlying neural circuitry that supports face recognition is organized to accommodate this bias. In the current study, I will focus on this core question.

In this section, I first reviewed the current prominent theoretical frameworks aimed at explaining peer bias in face recognition and the literature associated with the behavioral and neural evidence on peer bias. Second, I presented the rationale, goals, as well as the predictions of the current study.

Theory Foundations of Peer Bias in Face Recognition

The social importance of face recognition bias has motivated a great amount of studies to explore the kinds of faces that are relatively more important for us to remember and recognize compared to other faces, and the underlying mechanisms that motivate and support our biased performance.

One explanation that has been used previous to explain biases in face recognition behavior is the Contact Hypothesis, which emphasizes the role of experience in the formation of biases in face recognition behavior. The Contact Hypothesis proposes that people have differential experience in interacting with different faces. As a result, perceivers develop superior recognition of faces exposed to them relative to other faces (e.g., Meissner & Brigham, 2001). Specifically, within Contact Hypothesis theoretical framework, a lack of contact with certain kind of face results in a lack of perceptual expertise with this kind of face, which results in deficiency. This deficiency potentially reflects in differential processing mechanisms. From this perspective, greater expertise with a certain kind of face allows those faces to be processed in a configural manner while other faces will be processed in a feature-based manner. Another perspective within Contact Hypothesis is representational model in which facial features are suggested to have normally distributed in a population. Faces with greater exposure, such as same-race faces, will be represented much more frequently, allowing for a more diffuse distribution of facial exemplar. In such way, more familiar face will activate the representation of exemplar and be processed more sufficiently. In other word, perspectives within Contact Hypothesis consistently consider experience/familiarity with face as the most critical factor that predict the directionality and content of bias in face recognition.

Another theory that can be used to explain bias in face recognition is Social Cognitive Theory (SCT). At the core of this theoretical framework is perceiver's tendency to think of outgroup member in categorical manner while think of ingroup member in a more individuated manner. Categorical thinking involves a reliance on social membership such as gender, race, age while individuation relies on processing the unique characteristics of target. Within this theoretical framework, the feature-selection model suggests individuated processing of ingroup member drive perceivers to search for identity-relevant facial characteristics to further recognize a face. Nevertheless, the tendency to categorically think of outgroup members leads to search for categoryspecifying facial features that shared by the same group (MacLin & Malpass, 2001; Levin et al., 1996, 2000). The ingroup/outgroup model with SCT suggests that the perceiver first determines whether the face belongs to ingroup or outgroup and then only those faces belong to ingroups elicit relatively deep processing (Sporer 2001). Similarly, cognitive disregard model suggests that perceivers only rely on social category information in processing. Rather than processing each individual equally, some characteristics that is not motivationally relevant enough will be ignore and perceptually disregarded. The categorization-individuation model, posits that categorization evoke perceptual homogenization effects which results in insufficiency of face recognition (Hugenberg et al., 2010). On the other hand, motives to individuate also play an important role in bias in face recognition but expertise with a certain kind of face (i.e., more exposure) will improve recognizing this kind of face.

The common limitation of Contact Hypothesis and Social Cognitive Theory is that these two prominent theories were originally based on empirical evidence on own race recognition bias and cannot simply generalized to explain all the biases in face recognition behavior. As a result, these theoretical frameworks failed to account for the developmental trajectory of peer bias in face recognition behavior. For example, In the study of Ebner & Johnson (2009), the relation between adults' self-reported frequency of contact with one's own and other age groups (younger and older adults) was explored. Results showed that the frequency of contact with own or other age groups failed to predict own-age effects in their face recognition task. These findings related to the peer bias in face recognition are inconsistent with the predictions of the Contact Hypothesis in which experience/familiarity is sufficient enough to form bias. On the other hand, at the core of Social Cognitive Theory is the salience of same and cross race faces which is believed to have a great impact on the development of bias. However, within this theoretical framework, either category of face (e.g., same race and cross race) can be identified as salient in certain context (Young and colleagues 2010; Hugenberg et al., 2010, for review). As a result, Social Cognitive Theory is not parsimonious enough to explain which face (e.g., peer or non-peer) is biased in face recognition behavior.

As far as I know, there's only one theoretical framework currently that is specifically designed to explain the development of peer bias in face recognition. Within this developmental theory framework, Social Development Tasks at different developmental stage are suggested to influence the kinds of information that people disproportionately encode and thus remember in faces (SDT; Scherf & Scott, 2012). Developmental tasks are salient measures by which adaptation to life can be judged (Masten et al., 1995). For example, the tasks differ in infancy and young adulthood. Specifically, forming a close attachment with primary caregiver in early infancy is the most important developmental task while obtaining autonomy from parent and social reorientation toward peers to form close friendship and romantic relationship is the most critical developmental task in early adulthood. Successfully mastering developmental tasks in one period is associated with mastery in a host of behaviors and developmental tasks in the next developmental period (Roisman et al., 2004). Scherf and Scott argue that specific social developmental tasks fundamentally influence the 'computational goals' (Marr & Vision, 1982) of the face processing system, which are an instantiation of the solutions to these developmental tasks and ultimately reflected in the bias of face recognition (Scherf & Scott, 2012). A great amount of empirical studies has supported this theoretical framework. For example, behavioral studies showed that infants have a

preference to their caregivers' faces (e.g., Rennels & Davis 2008; Bushnell et al., 1989; Lavelli et al., 2002), adolescents and emerging adults have a preference to their own-age peer bias (e.g., Picci & Scherf 2016). Therefore, the current study was driven and guided by social developmental task theoretical framework to study the peer bias in face recognition.

What is Emerging Adulthood and Why studied

Emerging adulthood was proposed as a new conception of development period in industrialized countries from the late teens through the twenties, with a focus on ages 18 to 25 (Arnett 2010). During this developmental period, many young adults obtain different levels of education and training for the purpose of occupational career. Most importantly, this developmental period is a critical transitioning period for individual who are at their late adolescence learn how to conduct the roles and obligations as adult. The social developmental tasks for emerging adults are to obtain some degree of autonomy and independence from parent, build up various close relationships including friendship and romantic relationships with peers. Empirical studies showed that these salient social developmental tasks, especially social competence with peers in emerging adulthood, predict future success in their work and romantic competence 10 years later (Roisman et al., 2004).

Within Social Developmental Task theoretical framework, specific developmental tasks fundamentally influence the computational goals of individual's perceptual system. As a result, biases in face-processing at different developmental stages self-organize as developmental task through infancy to emerging adulthood. To explore the end point of this self-organization in face-processing behavior, I studied whether there's a peer bias in

face recognition behavior in emerging adulthood and what is the neural circuitry develop to support this peer bias. This study will be part of my developmental project aims at investigating the developmental trajectory of bias in face recognition across life-span and how brain is fine-tuned to support these biases in order to full-fill different developmental tasks over time.

fMRI Studies of Face Processing and the Age Bias

A growing body of neuroimaging research on face processing has been investigated during the past decades. One of the most well-known early findings about the neural circuitry of face processing is fusiform face area (FFA). This brain region, which is located in the fusiform gyrus, is preferentially activated by faces compared to other kinds of visual stimuli, such as common objects (Kanwisher, McDermott, & Chun, 1997). However, Haxby et al., (2000) proposed a face recognition network model that includes multiple disparate neural regions. To date, neuroimaging studies now consider face processing abilities as being subserved by regions comprising a core and extended network. The core set regions in this distributed network includes the fusiform gyrus (FFA1, FFA2, and pFG), the occipital face area (OFA), inferior occipital gyrus (OFA), and posterior superior temporal sulcus (pSTS); the extended set regions, on the other hand, are primarily comprised of amygdala, ventromedial prefrontal cortex (vmPFC), and anterior temporal lole (ATL; Haxby et al., 2000). Further, previous brain-behavior correlation evidence showed that the activation of the regions within this core and extended network is highly correlated to the face recognition performance (e.g., Elbich & Scherf, 2017). For example, a piece of neural evidence reported an increase in the

activation in the area of right FFA, which is considered as FFA1 recently (Grill-Spector & Weiner, 2014) as a function of recognition behavior. This evidence was further supported by other brain-behavior studies (e.g., Aylward et al., 2005; Huang et al., 2014; Passarotti, Smith, DeLano, & Huang, 2007; Yovel & Kanwisher, 2005). Our recent work also indicates that the activation of amygdala is also related to face-recognition behavioral performance (Elbich & Scherf, 2017).

As far as we know, there are only two functional magnetic resonance imaging (fMRI) studies that investigated the neural basis associated with (to some degree) peer bias in face recognition. In this study of Golarai et al., (2015), two groups of participants (children: 7-11 years old; adults: 18-40 years old) engaged in a 1-Back task with 6 kinds of stimuli, adult age and child age faces, familiar and novel objects, and familiar and novel scenes. The multi-voxel patterns analysis (MVPA) with stimulus classification in ventral temporal cortex (VTC) as a measure revealed an interaction between groups and face category. That is, the classifier could decode the activation patterns more accurately for adult compared to child faces in the right and left ventral temporal cortex. In children, there was no difference in the accuracy of the classifier across the two kinds of faces. The authors suggested that both of the recent and cumulative experience, along with the relatively greater social significance of adult-like face explain the observation of larger own-age preference in the distributed VTC representations for adult faces in adults. Previous study has provided us a chance to better understand the neural circuitry of peer face recognition. However, this evidence is largely based on one brain region rather than considering distributed network of face recognition including core (e.g., FFA2, FFA1, pFG) and extended regions (e.g., amygdala, pSTS, ATL). Further, this study recruited

participants with wide range of age (18-40 years), therefore, precluding our ability to attribute the neural responsiveness to a specific developmental age (Marusak, Carré, & Thomason, 2013). Emerging adults (ages 18-25 years) are in a very different life stage with different social developmental tasks than are 30-40 year old adults. Emerging adults are generally not married and raising children while 30-40 year old adults are and these different developmental life stages and associated tasks (e.g., raising children) may shape face recognition biases in an importantly different ways. Another fMRI study relevant to peer face recognition compared the neural activation in response to age and gender categorization of unfamiliar faces in adults (Wiese et al., 2012). In this study, participants were asked to categorize young and old faces. Even the age of young face stimuli is appropriately match to the age of participants (mean age = 23 years), there was no significant main effect of young face compared to old face in any brain regions of distributed face recognition network. In sum, the current existing literature on the neural circuitry underlying peer bias in face recognition is largely unknown and there is no consistency across studies.

Rationale and Goals of Current Study

The current study recruited emerging adult participants aged at 18-22 years old who were asked to recognize faces from various developmental stages (i.e., child, earlypuberty adolescent, late-puberty adolescent, emerging adult, and parent-age face) in and outside the fMRI scanner to explore the neural mechanisms underlying peer bias in face recognition. Multiple reasons motivated us to choose emerging adults. First, previous studies did not consider emerging adulthood as a special developmental stage that is

distinct from the adulthood broadly known. We call for attention to this special developmental stage since it is a period in which emerging adult continues to dramatically build up their own distinct social relationship with peers, seek or form own romantic experience with mates, which is broadly different from later adulthood (Arnett et al., 2000). Also, this is an important transitioning stage that post-adolescence individual keeps socially orientating from parents toward peer. The social developmental tasks in emerging adulthood is believed to keep reorganizing the computational goal of emerging adult's face recognition system (Scherf et al., 2012), resulting in measurable preference (i.e., bias) for peer faces (i.e., emerging adult face in the current study) compared to other faces, at behavioral and neural levels. As a result, I hypothesize that there should be a developmental continuum with regard to peer bias in face recognition behavior from adolescence to adulthood. Narrowing down participants' age and looking at this special developmental stage may help to consider the behavioral and neural responsiveness within a certain development context and especially contribute to understanding the developmental continuum of peer face recognition behavior.

Previously behavioral or neuroimaging studies focusing on the own-age face bias in adults usually compare adult faces to younger faces in which facial structure and feature are obviously different from that of adult face (i.e., there is no sexual dimorphism). It is possible that the peer bias found in these previous studies was due to these differences in face morphology across these two different developmental groups, rather than in true recognition bias. In our study, comparing emerging adults' recognition abilities for emerging adult faces and parent-aged faces that are also sexually mature already as are emerging adult faces, will facilitate our understanding of the peer bias by ruling out the confounding effect of sexual dimorphism in faces. In addition, another strength of including parent-aged face in the current study is that we can directly test whether emerging adults socially orientate from parents toward peers by comparing these peer face to parent-aged face.

In general, by comparing the faces at different developmental stages (i.e., child, early puberty adolescent, late puberty adolescent, emerging adult, and parent-age face), this study is focusing on the peer bias of face recognition in a specific developmental stage (i.e., emerging adult) at behavioral and neural levels. This design would provide us a chance to understand how recognition of a certain face (e.g., child, early adolescent, late adolescent, emerging adult, and parent-age face) transforms across age by collecting other group's behavioral and neural data in future. The central goals of the current work are threefold. First, the current study aimed at further replicating our previously developmental findings about peer bias in face recognition in emerging adults. Second, the current study focuses on the distinct neural response to faces representing different developmental status (i.e., child, early puberty adolescent, late puberty adolescent, emerging adult, and parent-age faces) in emerging adults to explore the neural circuitry underlying peer bias in face recognition. The current study expects to provide information about how social developmental tasks may potentially drive the transformation in neural circuitry (rather than experience proposed by Contact *Hypothesis*) from a developmental perspective. To further demonstrate the relation between brain and behavior, the present study included not only neural magnitude but also neural size in the evaluation of correlation between core and extended network and multiple behavior performance (see **Method** part). As far as we know, this is the first

study that collects neural data of recognizing multiple faces representing different developmental stages. This would highly enhance our possibility to look at how brain system supports the recognition of a certain face is fine-tuned across development by using cross-sectional design (i.e., multiple participant groups) in the future. Lastly, I am also particularly interested in how this bias at behavioral and neural level relates to relationship quality in emerging adulthood.

Based on our previously developmental work (Picci & Scherf. 2016), I predicted that emerging adults would exhibit peer bias compared to other faces, even compared to parent-aged faces that are also sexually mature. Driven by social developmental task theoretical framework, I predicted that peer face (i.e., emerging adult face) would elicit larger activation in the distributed face recognition network compared to other faces in order to support this bias. I would also predict that the neural activation in response to peer face is associated with behavioral results and the relationship quality with peers.

Chapter 2

Method

General Methodology

Participants

A total of 31 emerging adult participants were recruited in the current study initially (age range = 18-22 years; M = 19.33 years, S.D = 1.29; 16 females). These participants were primarily recruited through the Psychology Department undergraduate subject pool or via fliers on campus. Emerging adulthood is characterized by a high degree of demographic diversity and still lacks of an inclusive definition. The characteristic of emerging adulthood includes, but not limited to, aged from 18-25 years, totally sexual mature, longer participation in postsecondary education after adolescence, engaging premarital sex and experience, living outside of families for most of time (Arnett 2000). We used the following criteria largely based on the definition suggested by Arnett (2000) to recruit participants: first, participants were college students (freshmen and sophomore in the current study) at The Pennsylvania State University; second, participants did not have a full time job (i.e., fully or partially financial dependent); third, participants were not married or parents; lastly, participants were living outside of family for most of time (i.e., fully or partially autonomic). This information was embedded in screening procedure that used to inspect participant's qualification on MRI scanning.

Neither the participants nor their first-degree relatives had any medical history of neurological or psychiatric disorders, learning disabilities or developmental disorders. Participants had concussion history were excluded. The participants were all right handed and had normal or corrected normal vision. Written informed consent was obtained before the experiment began using the procedures approved by the Internal Review Board of The Pennsylvania State University. Participants were paid with credits from subject pool or 50-60 dollars.

Stimuli

Face Recognition Behavioral Task

The stimuli consisted of a total of 150 gray-scaled images of faces with neutral and/or happy expressions (see Figure. **1-1**), which included 30 images for each face condition (i.e., child, early puberty adolescent face, late puberty adolescent face, emerging adult, and parent-aged faces). Images were acquired from several face stimuli databases, including the NimStim (Tottenham et al., 2009), Karolinska (Lundqvist, Flykt, & Öhman, 1998), NIMH-ChEFS (Egger et al., 2011), and JimStim (Tanaka & Pierce, 2009). In addition, approximately half of images of the later puberty adolescent face and some of the parent-aged faces were taken at the Pennsylvania State University.

All images were gray-scaled and presented on a black background. Image size and luminance were standardized across images; however, the face shape and size were allowed to vary naturally within image size to reflect naturally occurring variance in faces.



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Figure 1-1: Stimuli Examples by Developmental Group of Face Recognition Behavioral Task.

fMRI Task Stimuli

Face Category Stimulation Task. This task was composed of short color videos representing 6 conditions (child faces, early puberty adolescent faces, late puberty adolescent faces, emerging adult faces, parent-aged faces, and objects). These freely available videos were downloaded from Youtube.com. The stimuli in each condition consist of approximately 24-30 different actors across both genders expressing 2 different emotion valences, positive (happy, joyful, or enthusiastic) and negative (angry, scared, or crying). Specific faces (4 to 6 images) were randomly assigned to each block and edited using iMovie software. Luminance of the videos was standardized across conditions.

Because we did not know the pubertal status of the actors in these videos, we acquired an estimate of their developmental status by asking emerging adults (independent group; N = 49) to rate the relative sexual maturity of the faces using a 1-5 points scale that mirrors the Tanner pubertal development scale (as in Picci & Scherf,

2016). The scale was anchored using pre-pubescent 'baby' face for the lowest ranking as '1' and a sexually mature 'grown-up' face for the highest ranking as '5' point in the scale are given to participants. Parent-aged faces were not included in this assessment since they are already sexually mature. The rating scores for all faces were submitted to a repeated-measures analysis of variance (ANOVA) with face category as the withinsubject factor. A Greenhouse-Geisser correction was applied because the assumption of sphericity was violated. There was a significant main effect for face category, F(1.16,(55.54) = 273.58, p < 0.0001, $\eta^2 = 0.85$. Bonferroni-adjusted pairwise comparisons indicated that the rating score for emerging adult face $(4.22 \pm 0.08; \text{Mean} \pm \text{S.E})$ was significantly larger than the rating score for late puberty adolescent face $[3.41 \pm 0.05]$; Mean \pm S.E; p < .001, see Figure 2-1; CI of mean difference = (0.60, 1.02)], rating score for late puberty adolescent face was also significantly larger than that of early puberty adolescent face $[2.62 \pm 0.06;$ Mean \pm S.E; p < .001; CI of mean difference = (0.71, 0.89)]. Lastly, the rating score for early puberty adolescent face was also significantly larger than the rating score for child $[1.91 \pm 0.08;$ Mean \pm S.E; p < .001; CI of mean difference = (0.57, 0.86)]. Bonferroni-adjusted comparisons were used as I didn't have prior knowledge of the direction of comparison. These results indicate that the movies containing faces for Face Category Stimulation Task were appropriately categorized by developmental status.



Figure 2-1. Pairwise Comparisons on Maturation Scores and Confidence Intervals of Each Face Category for Face Category Stimulation Task. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, and EA represents emerging adult face condition.

Further, the emotional intensity between these five conditions (child, early puberty adolescent face, late puberty adolescent face, emerging adult, and parent-age face) was also assessed before scanning by another different group of participants (N = 30) whose age range is similar to the age range of participants involved in scanning. Participants were showed a neutral video (rated as 1) and an intense emotional video (rated as 5) before assessment and instructed to rate the emotional intensity of each video from 1 to 5. One-way repeated-measures analysis of variance (ANOVA) on the rating score was conducted using the face category as within subject factors. A Greenhouse-Geisser correction was applied when sphericity could not be assumed. There was no

difference in the emotion intensity between these conditions and any difference between conditions observed in this task would not resulted by the difference in emotion intensity.



Figure **2-2.** Pairwise Comparisons on Emotion Intensity Scores and Confidence Intervals of Each Face Categories for Face Category Stimulation Task. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, EA represents emerging adult face condition and PA represents parent-aged face condition.

Face Identity Memory Task. The faces (5 conditions: child, early puberty adolescent face, late puberty adolescent face, emerging adult, and parent-aged faces) used in the Face Identity Memory Identity Task were selected from several existing databases CAFE (LoBue & Thrasher, 2014), JimStim (Tanaka 2009), NIMH-ChEFS (Egger, et al., 2011), Center for Vital Longevity (Minear & Park, n.d.), NimStim (Tottenham, et al., 2009), Karolinska (Lundqvist, Flykt, & Öhman, 1998). Common objects (inanimate objects) are downloaded from Internet. The size, color, and luminance of the facial and object images were controlled by software.

To confirm that we correctly categorize these faces by developmental status, another group of participants (N = 36) were recruited to assess the sexual maturity of

these faces using the same procedure described above. Parent-aged faces were also not included in the assessment. One-way repeated-measures analysis of variance (ANOVA) on the rating score was conducted using the face category as within subject factors. A Greenhouse-Geisser correction was applied because the assumption of sphericity was violated. Repeated-measure ANOVA on the rating score revealed a significant main effect for the face category, F(2.08, 72.88) = 1540.84, p < 0.0001, $\eta^2 = .978$. Bonferroni-adjusted pairwise comparisons indicated that the rate score for emerging adult face $(4.44 \pm 0.05; \text{mean} \pm \text{S.E})$ was significantly larger than the rating score for late puberty adolescent face $[3.55 \pm 0.07; \text{ mean} \pm \text{S. E}; p < .001, \text{ see Figure 2-3}; CI of mean$ difference = (0.80, 1.00)], rating score for late puberty adolescent face was also significantly larger than that of early puberty adolescent face $[2.50 \pm 0.07; \text{mean} \pm \text{S. E}; p$ < .001; CI of mean difference = (0.93, 1.16)], and rating score for early puberty adolescent face was also significantly larger than the rating score for child face $[(1.21 \pm$ 0.04; mean \pm S. E; p < .001; see Figure 2-3; CI of mean difference = (1.15, 1.42)). Bonferroni-adjusted comparisons were used as I didn't have prior knowledge of the comparison directions. These results indicate that the face stimuli used in Face Identity Memory Identity Task in scanner were appropriately categorized by developmental statuses.



Figure **2-3**. Pairwise Comparisons on Emotion Intensity Scores and Confidence Intervals of Each Face Categories for Face Identity Memory Identity Task. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, EA represents emerging adult face condition and PA represents parent-aged face condition.

Experiment Procedures

fMRI Studies

Prior to scanning, all participants were placed in a mock MRI scanner for approximately 30 minutes and practiced being still during scanning. It has been demonstrated that this procedure is highly effective at acclimating participants to the scanner environment and minimizing motion artifact and anxiety during scanning (see Scherf et al., 2015).

Face Category Stimulation Task. This task was used to elicit activation in response to the different face categories, particularly in the fusiform gyri, but also throughout more distributed regions in the face-processing network (Gobbini & Haxby, 2007). It was also used to define functional regions of interest (ROIs) so that the neural

responses in the Face Identity Memory Identity Task could be evaluated independently. The order of the stimulus blocks was randomized for each participant during scanning. It was a passive viewing task in which participants were instructed to keep still and focus on the videos shown on the screen. There were two different runs of the task. Each run began and ended with a 12-second fixation block. Following the first fixation block, there was a 12-second block of patterns. In each run, there were three 16-second blocks of each of the 6 conditions (i.e., child, early puberty adolescent face, late puberty adolescent face, emerging adult, parent-age adult face, and object; see Figure **3-1**). Six-second fixation blocks) were interleaved between the task blocks. Each run lasted 7 minutes and 12 seconds.



Child Early Pubertal Late Pubertal Emerging adult Parent-aged

Figure **3-1.** Stimuli Examples by Developmental Group of Face Category Stimulation Task.

Face Identity Memory Task. This was also a block design task in which faces from all 5 developmental groups were presented to participants in 12-second blocks, with interleaved 6-second fixation blocks. The task began and ended with a 12-second fixation block. Following the first fixation block, there was a 12-second block of patterns. We presented 6 blocks of each of the five faces categories (pre-pubescent children, early puberty adolescent face, late puberty adolescent face, emerging adult, parent-age adult). The order of blocks was randomized for each participant. Within each block, 12 images were each presented for 800ms followed by a 200 ms fixation. Two identities in each stimulus block were repeated, the order of which was counterbalanced across blocks. Participants were instructed to press a button when they saw the same face repeats. During scanning, Accuracy and reaction time as indexes of task performance were collected. The duration of this task is 9 minutes and 36 seconds.

Neuroimaging Protocol

Participants were scanned using a Siemens 3T Trio MRI with a 12-channel head coil at the Social, Life, and Engineering Imaging Center at Penn State University. During the scanning session, the stimuli were displayed to participants via a rear-projection screen. Functional EPI images were acquired in 34 3mm-thick slices that were aligned approximately 30° perpendicular to the hippocampus, which is effective for maximizing signal-to-noise ratios in the medial temporal lobes (Whalen et al., 2008). This scan protocol allowed for complete coverage of the medial and lateral temporal lobes, frontal, and occipital lobes. For individuals with very large heads, part of the superior parietal lobe was not scanned. The scan parameters were as follows; TR = 2000 ms; TE = 25; flip angle = 80°, FOV = 210 x 210, 3mm isotropic voxels. Anatomical images were also collected using a 3D-MPRAGE with 176 1mm³, T1-weighted, straight sagittal slices (TR = 1700; TE = 1.78; flip angle = 9°; FOV = 256).

The Network of Relationships Social Provision Version

In order to explore whether the peer bias in face recognition behavior and the corresponding neural circuitry underlying this bias has any relation with emerging adult's social adaptation. The Network of Relationships (NRI) Social Provision Version (Furman & Buhrmester, 1985) was administered to each participant after scanning. The present version of the NRI assesses 10 relationship qualities, which include Support dimension that is comprised of seven qualities: (a). Companionship, (b). Instrumental Aid, (c). Intimate Disclosure, (d). Nurturance, (e). Affection, (f). Admiration, (g). Reliable Alliance. Negative Interactions is comprised of two qualities: (a). Conflict and (b). Antagonism. Each participant rated each of these qualities in their relationships with (a). mother or step-mother, (b). father or step-father, (c). sibling, (d). relatives, (e) boy/girlfriend, (f). same-sex friend, (g). other-sex friend, and (h). extra person.

Face Recognition Behavioral Task

Followed by the survey, participants performed a behavioral task outside the scanner immediately following the scan. Face recognition abilities were measured in a developmentally sensitive old/new recognition paradigm by using a computerized game (Picci & Scherf, 2016). In this test, participants were required to identify whether each face in a set of 20 faces (10 are targets, and 10 are distractors) were new or old after studying 10 target faces. The tasks were presented in a counterbalanced blocked design with each block containing one of the five face categories (i.e., child, early puberty adolescent face, late puberty adolescent face, emerging adult, and parent-aged faces).

Participants first completed a practice phase, which consists of an abbreviated version of the task. At the end of practice, participants were instructed to try to remember the person rather than the picture to encourage participants to create an invariant representation of the face identity. The portions of task include encoding, delay, and recognition in the context of a movie theatre scenario. During the encoding phase, participants were presented with 10 target faces and told that these are faces of people who are 'going to a movie'; face expressions are neutral. All participants had 2000 ms to encode each face. In the delay phase, all participants watched a trailer for a movie (approximately 1.5 minutes for each condition). During the test phase, participants were presented with the 10 target faces together with 10 faces as distractors that were all smiling. By showing participants perceptually transformed images of the target faces (i.e., different facets) during the test phase, we are able to assess participants' invariant representation of face identity rather than image-specific memory. The faces are presented for 3000 ms for participants and participants were instructed to make a 'yes' or 'no' response by pressing keyboard. Participants were encouraged to complete the task as quickly, accurately as possible.

Data Analysis

Imaging Data Analysis

Preprocessing. Imaging data are analyzed in Brain Voyager QX system (Version 2.3; Brain Innovation, Maastricht, The Netherlands). Preprocessing of functional data included 3D-motion correction, and filtering out low frequencies (3 cycles). Only participants who exhibited maximum motion of less than 2/3 voxel in all six directions

(i.e., no motion greater than 2.0 mm in any direction on any image) were included in the fMRI analyses. For each participant and each task, the time-series images for each brain volume were analyzed separately for condition differences (e.g., child, early puberty adolescent face, late puberty adolescent face, emerging adult face, parent-age face in the Face Category Stimulation Task) in a fixed-factor GLM (general linear model). Each condition was defined as a separate predictor with a box-car function adjusted for the delay in hemodynamic response. The time-series images are then spatially normalized into Talairach space. The functional images were not spatially smoothed in order to preclude false positive error (see Grill-Spector & Weiner, 2014).

Subject- and Group-level GLM Maps. For each subject, the time series images were submitted to GLM. Functional activation maps for each face condition (i.e., child, early puberty adolescent face, late puberty adolescent face, emerging adult, and parentaged face) were obtained based on the contrast [face - object], which was corrected for false positive activation using the False Discovery Rate of q < 0.10 (Genovese et al. 2002). For example, the child face-related activation would be defined by the following contrast (child faces – objects), whereas the emerging adult face-related activation would be defined by (emerging adult faces – objects). This resulted in 5 whole-brain corrected functional maps for each participant from which I could define individual ROIs. In other words, for each functional region, I defined a child, early puberty adolescent face, late puberty adolescent face, FFA1- emerging adult, FFA1- parent aged face). Followed by this, each participant's face category maps were combined to create a group-level activation map using the False Discovery Rate of q < .01. This resulted in 5 group-level functional activation maps including child face > object, early puberty adolescent face > object, late puberty adolescent face > object, emerging adult face > object, and parent-aged face > object.

ROI Identification

To evaluate neural magnitude, size, and loci, the functional profile of categoryselective activation was determined in *individually defined* ROIs for each participant. The face-related activation within ROIs of both the core (e.g., FFA, OFA, STS) and extended (e.g., amygdala, vmPFC, PCC, anterior temporal lobe) face processing regions for each participant in each hemisphere were defined. Multiple face patch ROIs were defined. The cluster of contiguous voxels nearest the classically defined FFA (i.e., lateral to the midfusiform sulcus) in the middle portion of the gyrus was identified as the medial FFA (FFA1; Weiner et al., 2014). Functional activation anterior to this ROI is defined as the anterior FFA in the current study (FFA2; Weiner et al., 2014). Moreover, the activation posterior to this classically defined FFA will be defined as the posterior FFA (i.e., pFG). The region defined as posterior FFA (pFFA) in the current study is sporadically identified as the IOG/OFA in previous studies (e.g., Grill-Spector & Weiner, 2014); however, there is still controversy about the locus of the OFA and whether there are multiple OFAs in the inferior occipital gyrus (Pitcher, Walsh, & Duchaine, 2011). Consequently, the current study defined the OFA as the set of contiguous voxels on the lateral surface of the occipital lobe closest to our previously defined adult group level coordinates (x, y, z)coordinates: 50, -66, -4; Scherf et al. 2007). The pSTS was defined as the set of contiguous voxels within the horizontal posterior segment of the superior temporal

sulcus. The anterior temporal lobe ROI was defined as the cluster of voxels nearest the coordinates reported previously in studies of individual face recognition (right: 35, -3, -25; left: -26, -6, -27; Mur, Ruff, Bodurka, Bandettini, & Kriegeskorte, 2010). The PCC was defined as the cluster of voxels in the posterior cingulate gyrus above the splenium of the corpus callosum near the coordinates reported previous in studies of face processing (*x*, *y*, *z* coordinates: 0, -51, 23; Schiller, Freeman, Mitchell, Uleman, & Phelps, 2009). The vmPFC in the current study was defined as the cluster of voxels in the medial portion of the superior frontal gyrus ventral to the cingulate gyrus near coordinates reported in previous studies of social components of face processing (*x*, *y*, *z* coordinates: 0, 48, -8; Schiller et al. 2009). The amygdala in the current study was defined as the entire cluster of face-selective voxels within the structure.

Quantifying Regions of Interest

Previous neural evidence on face recognition is largely based on the calculation of neural magnitude in related brain regions. However, studies revealed that the neural size of the brain regions, when functional data are not smoothed, can also provide important information about the extend of the local distributed representation (Golarai et al., 2010; Scherf, Behrmann, Humphreys, & Luna, 2007; Weiner & Grill-Spector, 2011). For example, previously developmental neuroimaging studies associated with the emerging topography in the ventral visual pathway reported an age-related increase in the functional size of FFA and OFA from childhood to adulthood (Golarai et al., 2010; Scherf et al., 2007). Further, our recent work also found that the neural size within network (e.g., FFA) was significantly associated with face recognition behavioral
performance and more regions of face recognition network were associated with face recognition behavior while using neural size compared to neural magnitude (Elbich & Scherf, 2017). All of these neural findings consistently indicate that the functional neural size may be a particularly sensitive and potentially better index for face recognition ability. Therefore, not only neural magnitude but also neural size of the core and extended face recognition network were taken into consideration in the current study.

The ROIs were quantified in terms of the beta weights (i.e., neural magnitude) and the total number of significantly active voxels (i.e., neural size) as aforementioned. To compute the magnitude of face category selectivity within each region, separate ROIbased GLMs were conducted for each participant in each ROI to generate the resulting beta weights. Face selectivity for each condition was computed by submitting these beta weights to the following difference score: Face – Object (e.g., child-object, emerging adult-object). Participants with no identifiable voxels in an ROI were excluded from the analysis of *neural magnitude*, given that no ROI-based GLM could be computed. For the analysis of *neural size*, a score of 0 was entered if a participant did not exhibit any significantly active voxels for a given ROI.

To evaluate individual variability in the loci of these ROIs, following (Müller, Kleinhans, Kemmotsu, Pierce, & Courchesne, 2003), this study calculated the distance in stereotactic space between the midpoint of each individually defined ROI and the midpoint of the appropriate group-defined ROI in each individual of the respective group. For example, the midpoint of child-object right FFA1 occurred at the coordinates (39, -50, -18). For Participant 1, the midpoint of his/her individually defined child-object right FFA1 ROI occurred at the coordinates (39, -47, 20), resulting in a distance of 15.3 mm, calculated as follows:

$$\sqrt{(2^2 + 3^2 + 2^2)} = 4.12$$

This computation is roughly equivalent to calculating the geometric mean of the differences; however, it preserves the pooled distance in the original units (mm). To compare group differences in these scores, they were submitted to separate paired-samples *t*-tests for each ROI in each hemisphere and only individuals with definable ROIs were included in this analysis. In sum, three neural indexes including neural magnitude, neural size, as well as loci, were taken into analysis for any definable ROIs.

Neural Signal Extraction from Face Identity Memory Task

Next, to test whether there is a peer bias in the emerging adult face defined ROIs in this task, independently defined ROIs from each participant obtained from Face Category Stimulation Task was overlaid on their respective GLM maps from the Face Identity Memory Identity Task. Beta weights for each face condition from this map were extracted from within each participant's independently defined ROIs (emerging adult face – object). These beta weights were submitted to a planned comparison to evaluate the differences in neural magnitude between emerging adult face and other faces.

Also, the accuracy (ACC) and reaction time (RT) for each face category were extracted and submitted to separate repeated-measures ANOVA with the face category (5 levels) as within-subject factor to test whether there were any differences in ACC and RT between face categories.

General Statistical Analysis for Imaging Data

The dependent measures of neural activation include neural magnitude, neural size of activation within each ROI, as well as invariability of ROI activated by faces. Each dependent measure was evaluated for violations of normality and outliers before statistical analysis. Any dependent measure violated normality or was positively skewed was corrected by using an appropriate transformation. Theory-driven planned paired sample *t*-test were conducted to compare the differences between emerging adult face (i.e., peer face) and other faces since I am interested in the neural circuitry supporting peer bias in emerging adult in the current study. Further, based on social reorientation theory, the neural response to peer face is expected to be larger than that of parent-aged face. Hence, planned paired sample *t*-test comparing peer face and parent-aged face were also conducted. Since the default *p*-values of paired-sample *t*-test were two-tailed, we adjusted the p values to 1-tailed by p/2. The reasons why we conducted paired sample ttest rather than omnibus ANOVA with Bonferroni correction are as follow: First, this study is theoretically driven by existing theoretical frameworks proposed by Scherf & Scott (2012), as well as previously developmental finding (Picci & Scherf, 2016) rather than simply exploring neural representation of each face category. Second, omnibus ANOVA with Bonferroni correction is more concerned with the general null hypothesis, which is rarely of interest to researchers (Perneger 1998). It adjusts statistical significance for the numbers of test and direction of comparison, highly increasing the likelihood of type II error. All neural results were based on 1-tailed p values since we theoretically hypothesized there was a peer bias compared to other faces in the activation of neural profile. In other word, the emerging adult face elicited a larger neural magnitude or

neural size compared to other faces. If there was any significant result with reversed direction (i.e., emerging adult face < other faces), we took it as insignificant since it was out of our interests.

The current study not only focused on the difference in the neural indexes of the core and extended face recognition network but also the brain-behavior relationship. Hence, correlation between dependent measures was assessed by Pearson product-moment correlation. The current study evaluated the brain-behavior relations by using linear regressions in which the behavioral data from face recognition behavioral task (out of scanner) and Face Identity Memory Identity Task (in scanner) were considered as the potential predictors of each measure of neural activation (both of neural magnitude, and neural size). For each of the significant correlations found in the regression analyses, the robustness of the correlation in separate bootstrap analyses using 1000 iterations was evaluated.

The Network of Relationships Social Provision Version

Separate repeated measures ANOVA were conducted to test whether there were any differences in Support and Negative Interaction using the relationship category as within-subject variable. A Greenhouse-Geisser correction was applied when the assumption of sphericity was violated. Bonferroni-adjusted comparisons were used since we did not have specific prediction about the directions of comparison.

Behavioral Data Analysis

Face Recognition Behavioral Task Analysis. Normality and residual analysis were employed before difference test, separately for each condition. First, any participant whose overall accuracy in this task was below chance (i.e., 50%) was excluded. Then, any data value that beyond ± 2 standard deviation (i.e., S.D) of the mean for each face category was winsorized at 2 standard deviations above or below the mean, as appropriate (Dixon & Tukey, 1968). The current study used A' sensitivity as an index of peer face recognition bias. A' sensitivity ranges from 0 to 1, with higher scores reflecting better performance. The current study computed A' sensitivity rather than accuracy is because it accounts for response biases in signal and noise distributions that are nonparametric (Zhang & Mueller, 2005). A' sensitivity was based on the hit rate (H) and false alarm rate (F) and was calculated for each participant as follows:

$$A = \begin{cases} \frac{3}{4} + \frac{H - F}{4} - F(1 - H) & \text{if } F \le .5 \le H; \\ \frac{3}{4} + \frac{H - F}{4} - \frac{F}{4H} & \text{if } F \le H \le .5; \\ \frac{3}{4} + \frac{H - F}{4} - \frac{1 - H}{4(1 - F)} & \text{if } .5 < F \le H. \end{cases}$$

First, to evaluate whether the current study replicated the peer bias in face recognition behavior found in our previous study (Picci & Scherf, 2016), the current study used the same planned contrast to compare the A' sensitivity on emerging adult face and the averaged A' sensitivity on child, early puberty adolescent face, late puberty adolescent face. Specially, the A' sensitivity scores on parent-aged face were not included in this analysis since our previous study did not include this face category. Second, a planned contrast was conducted to compared the A' sensitivity on emerging adult face and the average A' sensitivity of other face categories used in the current study (i.e., child, early puberty adolescent face, late puberty adolescent face, and parent-aged face) to further test whether the peer bias in face recognition behavior exists in emerging adults. Further, a planned contrast was also conducted to compared the A' sensitivity on emerging adult face and parent-aged face to test the social orientation theory which suggests that individual transition their attention from parents to their peers. Driven by this theory, a larger A' sensitivity on peer face (i.e., emerging adult face) compared to parent-aged face was expected. All behavioral results were based on 1-tailed *p* values since because I had a clear prediction about the directionality of the effect I am interested, guided by the Social Developmental Task theoretical framework (e.g., emerging adult face).

Chapter 3

Results

Neuroimaging Results

Face Category Stimulation Task

Neural size of Face Category Stimulation Task. Each definable ROI provides five values that represent the volumes of activation to each face category, in which a score of 0 was entered if a participant did not have any significantly active voxels for that face category within ROI. Since the measures of the size of activation violated normal distribution, the measure of the size of activation was corrected using a square root transformation and all analysis using the neural size of activation were performed on these transformed values. Since the current study predicted that the activation to emerging adult face would elicit larger neural volume within face process neural network, 1-tailed *p* value was set for this analysis. The results showed that emerging adult face significantly induced a larger volume than other faces in right FFA [t (30) = 1.899, p < 0.05, 95% *CI* of the mean difference = (0.67, 10.53); 1-tailed] and parent-aged face in right FFA [t (30) = 2.283, p < 0.05, 95% *CI* of the mean difference = (1.73, 11.43)]. Emerging adult face also activated a larger volume in left FFA compared to parent-aged face [t (30) = 2.05, p < 0.05, 95% *CI* of the mean difference = (0.98, 9.78); 1-tailed].



Figure 4-1. Pair Comparisons on Neural Sizes Activated by Face Conditions.

Neural Magnitude of Face Category Stimulation Task. In the very beginning of ROIs definition, we tried to individually define all the ROIs from the core and extended face recognition network, which include bilateral FFA2, FFA1, pFG, OFA, pSTS, vmPFC, PFC, amygdala, as well as ATL, using each face category contrasted with object (16 x 5 ROIs/participant). However, there was a lot of missing data because very few participants had whole-brain corrected significant activation in all 80 ROIs. As a result,

we focused our analyses on the most informative and sensitive ROIS based on our previous work, which indicates that individual differences in face recognition behavior are associated with the neural responses to faces in bilateral FFA1, anterior temporal lobe, and the amygdala (Elbich & Scherf, 2017). Hence, we focused understanding whether there is a bias to encode peer faces in these 6 regions (right and left).

A non-parametric difference test, Friedman test was conducted within each ROI to evaluate whether there was a difference in the number of definable regions as a function of condition. The results showed that there were no significant differences in the number of identifiable ROIs for any region related to face category (all p > 0.05; Table 1-

1).

Table 1-1. The Numbers of Participants Who Had Significant ROIs. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, EA represents emerging adult face condition, and PA represents parent-aged face condition.

	Child	EP	LP	EA	PA
rFFA1	28 (31)	26 (31)	28 (31)	26 (31)	27 (31)
lFFA1	27 (31)	26 (31)	25 (31)	24 (31)	24 (31)
rAmygdala	5 (31)	12 (31)	10 (31)	7 (31)	8 (31)
lAmygdala	7 (31)	8 (31)	11 (31)	8 (31)	10 (31)
rATL	12 (31)	18 (31)	13 (31)	12 (31)	10 (31)
lATL	13 (31)	14 (31)	12 (31)	12 (31)	10 (31)

FFA1 was the only ROI in which there was sufficient data to do an analysis of the neural magnitude differences as a function of face category. Within the rFFA1 defined by **child face-object (Figure 5-1. a)**, the magnitude elicited by child faces was significantly larger than the average magnitude of other faces [t(27) = 2.35, p < 0.05, 95% *CI* of mean difference = (0.03, 0.20); 1-tailed] and the magnitude elicited by early puberty adolescent face [t(27) = 5.21, p < 0.0001, 95% *CI* of mean difference = (0.15, 0.30); 1-tailed].

Within the rFFA1 defined by early puberty adolescent face-object (Figure 5-1. b), there was no significant difference between the neural magnitudes of early puberty adolescent face and other faces. Within the rFFA1 defined by late puberty adolescent face-object (Figure 5-1. c), the magnitude elicited by late puberty adolescent face was significantly larger than the average magnitude of other faces [t (27) = 3.58, p < 0.001, 95% CI of mean difference = (0.09, 0.25); 1-tailed]; also, the magnitude elicited by late puberty adolescent face was significantly larger than the magnitude elicited by child face [t (27) = 3.58, p < 0.001, 95% CI of mean difference = (0.10, 0.28); 1-tailed], early puberty adolescent face [t (27) = 4.17, p < 0.0001, 95% CI of mean difference = (0.13, 0.33); 1-tailed], emerging adult face [t(27) = 2.20, p < 0.05, 95% CI of mean difference = (0.03, 0.24); 1-tailed], parent-aged face [t (27) = 3.09, p < 0.005, 95% CI of mean difference = (0.08, 0.28); 1-tailed]. Within the rFFA1 defined by emerging adult face**object (Figure 5-1.d)**, the magnitude elicited by emerging adult face was significantly larger than the average magnitude of other faces [t(25) = 2.67, p < 0.05, 95% CI of mean difference = (0.05, 0.25); 1-tailed]; also, the magnitude elicited by emerging adult face was significantly larger than the magnitude elicited by child face [t (25) = 3.24, p < 0.005, 95% CI of mean difference = (0.09, 0.30); 1-tailed], early puberty adolescent face [t (25) = 4.76, p < 0.0001, 95% CI of mean difference = (0.17, 0.35); 1-tailed], parentaged face [t (25) = 2.41, p < 0.05, 95% CI of mean difference = (0.05, 0.29); 1-tailed]. Within the rFFA1 defined by parent-aged face-object (Figure 5-1.e), the magnitude elicited by parent-aged face was significantly larger than the average magnitude of other faces [t(26) = 2.54, p < 0.05, 95% CI of mean difference = (0.04, 0.17); 1-tailed]; also, the magnitude elicited by parent-aged face was significantly larger than the magnitude

elicited by child face [t (26) = 2.17, p < 0.05, 95% CI of mean difference = (0.03, 0.22); 1-tailed], early puberty adolescent face [t (26) = 4.18, p < 0.0001, 95% CI of mean difference = (0.11, 0.28); 1-tailed].





Figure **5-1**. Pair Comparisons on Neural Magnitude from Face-Object Defined rFFA1.

Within the IFFA1 defined by child face-object (Figure 6-1. a), the magnitude elicited by child face was significantly larger than the average magnitude of other faces [t (26) = 3.89, p < 0.001, 95% CI of mean difference = (0.10, 0.25); 1-tailed], the magnitude elicited by early puberty adolescent face [t(26) = 4.33, p < 0.0001, 95% CI of mean difference = (0.12, 0.29); 1-tailed], the magnitude elicited by late puberty adolescent face [t(26) = 2.09, p < 0.05, 95% CI of mean difference = (0.03, 0.20); 1tailed], the magnitude elicited by emerging adult face [t (26) = 2.43, p < 0.05, 95% CI of mean difference = (0.04, 0.23); 1-tailed], the magnitude elicited by parent-aged face [t (26) = 2.85, p < 0.01, 95% CI of mean difference = (0.08, 0.30); 1-tailed]. Within the IFFA1 defined by early puberty adolescent face-object (Figure 6-1. b), there was also no significant difference between the neural magnitudes of early puberty adolescent face and other faces. Within the IFFA1 defined by late puberty adolescent face-object (Figure 6-1. c), the magnitude elicited by late puberty adolescent face was significantly larger than the average magnitude of other faces [t(24) = 4.62, p < 0.001, 95% CI of mean difference = (0.13, 0.30); 1-tailed]; also, the magnitude elicited by late puberty

adolescent face was significantly larger than the magnitude elicited by child face [t (24) =3.49, p < 0.005, 95% CI of mean difference = (0.09, 0.26); 1-tailed], early puberty adolescent face [t(24) = 4.49, p < 0.0001, 95% CI of mean difference = (0.17, 0.39); 1tailed], emerging adult face [t(24) = 2.25, p < 0.05, CI of mean difference = (0.06, 0.29); 1-tailed], parent-aged face [t(24) = 3.77, p < 0.005, CI of mean difference = (0.13, 0.36); 1-tailed]. Within the IFFA1 defined by emerging adult face-object (Figure 6-1. d), the magnitude elicited by emerging adult face was significantly larger than the average magnitude of other faces [t(23) = 2.67, p < 0.001, 95% CI of mean difference = (0.07, (0.27); 1-tailed]; also, the magnitude elicited by emerging adult face was significantly larger than the magnitude elicited by child face [t (23) = 3.24, p < 0.005, 95% CI of mean difference = (0.08, 0.30); 1-tailed], early puberty adolescent face [t (23) = 4.76, p < 0.0001, 95% CI of mean difference = (0.14, 0.35); 1-tailed], parent-aged face [t (23) = 2.41, p < 0.05, CI of mean difference = (0.02, 0.29); 1-tailed]. Within the IFFA1 defined by parent-aged face-object (Figure 6-1. e), the magnitude elicited by child face was significantly larger than the average magnitude of other faces [t(23) = 3.18, p < 0.005, 95% CI of mean difference = (0.04, 0.14); 1-tailed]; also, the magnitude elicited by parent-aged face was significantly larger than the magnitude elicited by child face [t(23)] = 2.28, p < 0.05, 95% CI of mean difference = (0.03, 0.21); 1-tailed], early puberty adolescent face [t (23) = 3.56, p < 0.005, 95% CI of mean difference = (0.10, 0.39);1tailed].



IFFA1 Bias for LP Faces





IFFA1 Defined by Emerging Condition





c.



Object



Face Condition



Face Condition



-1.0



EA Face



IFFA1 Defined by Child Condition

tude

Magnitude











IFFA1 Bias for EP Faces



IFFA1 Bias for Child Faces



Other Faces





Figure **6-1**. Pair Comparisons on Neural Magnitude from Face-Object Defined IFFA1.

In sum, with the exception of the early puberty adolescent face defined FFA, each of face category defined FFA ROIs exhibited a unique profile of activation. For example, child face elicited larger neural magnitude compared to other faces in FFA defined by child-object comparison. It should be noted that the voxel selection for ROIs definition was at the basic category level (i.e., face category – object), while the comparisons between magnitudes was at a subordinate level in which faces as visual category. These slightly different or overlapping voxels defined at basic level also have sensitivity at subordinate level for different developmental group's faces.

To address the question about how different the populations of voxels defined by each face category contrasted to object really are, I computed a group level GLM analysis for each kind of face-related activation to compare the relative overlap or lack thereof. The group-level activation maps indicate that the emerging adult face defined FFA1 region is in fairly distinct location compared to the right FFA1 defined by the other face categories. The group-level activation map also shows that compared to object, all face categories except early puberty adolescent face elicited a significant activation in right FFA (Figure 7-1). Noticeably, the rFFA defined by emerging adult face (shown as yellow) is located in a more anterior location than other neural patches elicited by other face categories.



Figure 7-1. Result of Group-level GLM. The yellow spot inside the red circle represents the activation map of rFFA1 defined by emerging adult face-object. Group-level GLM activation map was projected onto a representative structural brain and thresholded at p < .01.

Variability in Location. To further explore whether different neural patches located within FFA respond to different faces contained different developmental statues information, the distance in stereotactic space between the midpoint of each individually defined FFA and the midpoint of the appropriate group-defined ROI in each individual was calculated (see Table 2; Muller et al., 2003).

To compare face conditions in these scores, they were submitted to separate paired-samples *t*-tests for each ROI in each hemisphere and only individuals with definable ROIs were included in this analysis. This was only computed for the right and left FFA ROIs since (a). A unique profile of activation was found in each face category defined FFA ROIs; (b). group-level analysis map shows the emerging face defined ROIs activation potentially distinguish from other face category defined ROIs activation. The result showed that the spatial variability was significantly higher in the emerging adult face defined right FFA than child face but not other kind of faces, t (24) = 1.81, p < 0.05 (1-tailed).

ROIs	Face	N	X (Mean ± SE)	Y (Mean ± SE)	Z (Mean ± SE)
	Condition				
rFFA1	Child	27	39 (3)	-51 (7)	-17(4)
	Early puberty adolescent face	26	39 (4)	-50 (7)	-18 (4)
	Late puberty adolescent face	28	38 (3)	-50 (8)	-17(4)
	Emerging adult	27	39 (4)	-51 (8)	-17 (4)
	Parent-aged	26	38 (4)	-52 (7)	-18 (4)
lFFA1	Child	27	-37 (15)	-50 (8)	-18 (4)
	Early puberty adolescent face	26	-39 (4)	-51 (9)	-18 (3)
	Late puberty adolescent face	26	-40 (3)	-48 (8)	-19 (3)
	Emerging adult	25	-39 (3)	-51 (9)	-18 (3)
	Parent-aged	23	-40 (3)	-50 (8)	-17 (3)

Table 2-1. Mean Coordinates of FFA1 ROIs across Face Conditions.

Face Identity Memory Task in Scanner

Behavioral Results. There were no differences in accuracy or reaction time to remember faces in any of the 5 face category conditions (all p > .10)

Neural Magnitude Result. The central goal of these analyses it to evaluate whether there is a peer bias in the profile of the neural magnitude responses in the facerelated ROIs defined by emerging adult face activation from the Face Category Simulation Task. We have started to work on these analyses but have encountered some technical difficulties that we do not quite understand yet. Specifically, all the beta weights in the individually defined ROIs are negative, which suggests that there is a problem with co-registration or in the pre-processing of the data. We have ongoing quality control measures that we are implementing to evaluate the problem.

Behavioral Result

Unfortunately, there was an experimenter error and only 4 out of 5 face conditions were recorded. Only 21 out of 31 participants were willing to come back for performing behavioral task again. The interval between first visit and second visit varied from 1 to 5 months. We recruited 21 more participants for this behavioral task using the same criteria. As a result, there was 42 participants in final sample for behavioral session in this study (age range = 18-22 years; M = 19.43 years, S.D = 1.47; 26 females). 3 of these 42 participants were recruited in data analysis since their overall accuracy were below chance (i.e., 50%).

Our previous developmental work indicates that peer bias in face recognition emerges from adolescence to emerging adulthood. Specifically, emerging adult groups (18-25 years) exhibit superior recognition for peer faces compared to faces from other developmental groups. To evaluate whether this study could replicate the emerging adults' peer bias in face recognition found in previous study, a same planned paired *t*-test was used to compare the A' sensitivity for emerging adult face to the average A' sensitivity for the other 3 face categories (child, early puberty adolescent face, and late puberty adolescent face; Picci & Scherf, 2016). The result showed that the A' sensitivity for emerging adult face (0.70 ± 0.03 ; mean \pm S.E) was not significantly larger than the averaged A' sensitivity for other face categories [0.67 ± 0.02 ; mean \pm S.E; Figure 8-1 .b; t (39) = 1.17, n.s.]. Further, a paired *t*-test was also used to compare the A' sensitivity for emerging adult face to the averaged A' sensitivity for all the other face categories (child, early puberty adolescent face, late puberty adolescent face, and parent-aged face). The result showed that A' sensitivity for emerging adult face (0.70 ± 0.03 ; mean \pm S.E) was not significantly larger than the A' sensitivity for other 4 face categories $(0.70 \pm 0.03;$ mean \pm S.E), t(39) = 1.03, n.s (see Figure 8-1.c). In order to test social orientation theory, which suggests that individual, has a shift from parent to peer in terms of social behavior, a paired *t*-test comparing the A' sensitivity of parent-aged face and peer face was conducted. Result showed that A' sensitivity for peer face $(0.70 \pm 0.03; \text{ mean} \pm \text{S.E})$ in emerging adults was not significantly larger than the A' sensitivity for parent-aged face [$(0.69 \pm 0.03; \text{ mean} \pm \text{S.E})$; Figure 8-1. d]. However, paired *t*-test showed that A' sensitivity of emerging adult face $(0.70 \pm 0.03; \text{ mean} \pm \text{S.E})$ was significant larger than the A' sensitivity for parent-aged face [$(0.69 \pm 0.03; \text{ mean} \pm \text{S.E})$; Figure 8-1. d]. However, paired *t*-test showed that A' sensitivity of emerging adult face $(0.70 \pm 0.03; \text{ mean} \pm \text{S.E})$ was significant larger than the A' sensitivity for late adolescent face $(0.63 \pm 0.03; \text{ mean} \pm \text{S.E})$, t(38) = 1.97, p < 0.05 (see Figure 8-1. e).



Figure **8-1**. Result of Behavioral Task. a). Overall sensitivity to each face category, EP represents early puberty adolescent face and LP represents late puberty adolescent face condition; b). Planned contrast between the sensitivities to peer face (i.e., emerging adult face) and other faces except parent-aged face; c). Planned contrast

between the sensitivities to peer face (i.e., emerging adult face) and all other faces; d). Planned contrast between the sensitivities to peer face (i.e., emerging adult face) and parent-aged face; e). Planned contrast between the sensitivities to peer face (i.e., emerging adult face) and late puberty adolescent face.

NRI Social Provision Version Assessment

As Table **3** shows how participants responded regarding supportive and negative interactions with mother and father figures, siblings, same- and opposite-sex friends, and romantic partners. The results revealed a significant primary effect for the relationship category, F(2.88, 86.47) = 5.37, p < 0.005, $\eta^2 = .15$. Bonferroni-adjusted pairwise comparisons indicated that the relationship with mother ($11.47 \pm .34$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with other-sex friend ($9.24 \pm .56$; mean \pm S.E; p < .005). In addition, the relationship with same-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with same-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with same-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with same-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with same-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with same-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with other-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with other-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with other-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive, compared to the relationship with other-sex friend ($10.86 \pm .52$; mean \pm S.E) was seen as significantly more supportive.

The repeated measures ANOVA on Negative Interaction score revealed a significant main effect for the relationship category, F(3.27, 98.15) = 7.73, p < 0.001, $\eta^2 = .21$. Consistent with developmental task predictions, Bonferroni-adjusted pairwise comparisons indicated that participants reported significantly less negative interactions with same-sex friends ($4.84 \pm .34$; mean \pm S.E) than mother (p < .001) and less negative interaction with other-sex friends ($4.47 \pm .39$; mean \pm S.E) than mother (p < .005) and father (p < .05). Lastly, participants reported significantly less negative interactions with other-sex friends ($6.19 \pm .52$; mean \pm S.E; p < 0.05).

Relationship Category	Support	Negative Interaction	
	$(Mean \pm S.E)$	$(Mean \pm S.E)$	
Mother/Step-mother	$11.47 \pm .31$	$6.86 \pm .49$	
Father/Step-father	$10.21 \pm .57$	$6.15 \pm .55$	
Romantic Partner	$11.43 \pm .47$	$6.19 \pm .52$	
Same-sex Friend	$10.86 \pm .52$	$4.84 \pm .34$	
Other-sex Friend	9.24 ± .56	4.47 ± .39	

Table 3-1. Overall Descriptive Result of NRI Social Provision Version.

One of the goals of the current study is to look at whether the peer bias in face recognition behavior and the corresponding neural circuitry supporting this bias has any relation with emerging adult's social adaptation. Since face represents one of the most important social information that enables individuals explore their environment and form relationship with others, we were interested in how this bias in face recognition would contribute to their social relationship network. However, we are still thinking the best way to relate this relationship data to behavioral and neuroimaging data in a theoretically driven way rather than p hacking.

Chapter 4

General Discussion

The central goals of the current work are threefold. First, the current study aimed at replicating the peer bias in face recognition behavior in emerging adults found in previous study. Second, I am particularly interested in the distinct neural response to faces representing different developmental status (i.e., child, early adolescent, late adolescent, emerging adult, and parent-age faces) in adulthood to explore the neural circuitry of peer bias in face recognition. Last, I tended to look at the relation between the behavior, neural circuitry, and social network in emerging adults. To do so, 31 typically developing emerging adults were recruited to complete Face Category Stimulation and Face Identity Memory task while scanning, NRI Social Provision survey and Face Recognition behavioral task after scanning. Extra 21 participants were recruited for Face Recognition behavioral task.

This study partially replicated our previously developmental work by showing that emerging adults were better at recognizing peer faces compared to late puberty adolescent faces. Overwhelmingly, the neural results of the present study suggest that the peer bias in emerging adult face recognition behavior may be subserved by disproportionally larger activation of fusiform area (FFA1) in terms of neural magnitude, size, as well as location. As such, the current study first indicates that the FFA1 may be a critical brain region that supports the peer bias behavior in face recognition in emerging adults.

Peer Bias in Face Process Behavior in Emerging Adults

Previous developmental work revealed that emerging adults were better at recognizing their peer faces compared to other developmental status faces (i.e., child, early puberty adolescent face, and late puberty adolescent face; Picci & Scherf 2016). However, the present study did not replicate this finding. I did not find the A' sensitivity to emerging adult face was larger than that of other faces (i.e., child, early puberty adolescent face, and late puberty adolescent face) using the same statistical method. I did not find the A' sensitivity to emerging adult face was larger than that of other faces including parent-aged face either. The reason behinds this inconsistence may lie in the participants' age difference. The age range of emerging adult group in our previous study was 18 to 24 (mean = 19.97, S.D = 2.40) while the age range of participant in this study is 18 to 22 (mean = 19.43, S.D = 1.47). Older emerging adult may be more sensitive to emerging adult faces used in the current study. Also, the sample in the current study was primarily comprised of college undergraduate students while the sample in our previous study was comprised of graduate student and adult work outside campus. Arnet (2000) suggested that there's a lot of demographic difference between emerging adult individuals. Moreover, the gender of participants in the current sample for behavioral task was not totally balanced. As a result, it is critical to include a more diversity sample with larger age range for investigating emerging adult's peer bias in face recognition behavior. In future, I will continue to collect more data for this goal.

The finding of the present study showed that emerging adults also had a greater A' sensitivity to peer face compared to other faces (i.e., child, early puberty adolescent face, late puberty adolescent face, **and parent-aged face**). In this study, Further,

emerging adults were better at recognizing peer face compared to late puberty adolescent face. This rule out the possibility that peer bias in emerging adult was induced by the cumulative experience. These emerging adult participants have just been through late puberty developmental stage but did not show any sensitivity to late puberty adolescent faces. If experience resulted in the bias in face recognition, the late puberty adolescent face would elicit an equal sensitivity as peer face (i.e., emerging adult face) as these emerging adult participants just went through this developmental stage. This somehow suggest that peer bias in face recognition is not due to experience but potentially motived by social development task which drives individual to encode new social information from a face (Scherf et al., 2012 & 2013).

In general, these results somehow indicate that emerging adults have peer bias in face recognition behavior. Noticeably, our findings indicate this peer bias is not about experience with face. We suggest that specific developmental task in emerging adulthood (e.g., forming intimacy with peers and obtaining autonomy from parent) fundamentally impact the computational goal of the perceptual system, consequently influences how emerging adults perceive and process peer faces.

Neural Circuitry underlying Peer Bias in FFA1

We planned to defined ROIs throughout the whole distributed face recognition network. However, it turned out that FFA1 is the only region that was consistently activated by different face categories. Three different aspects of FFA1, including size, loci, and magnitude, consistently provide evidence on the mechanism of FFA1 underlying peer bias in face recognition in emerging adults.

First of all, we found that the neural size in right FFA1 activation in response to emerging adult face was significantly larger than other face categories. When functional data was not smoothed, the size of the activation region can sufficiently provide critical information about the extent of neural representation (Elbich & Scherf, 2017; Scherf, Behrmann, Humphreys, & Luna, 2007). Previous studies have found that the increased activation size of FFA was significantly associated with face recognition behavior improvement. For example, Golarai and colleagues (Golarai et al., 2007; Golarai, Liberman, Yoon, & Grill-Spector, 2010) found that the volume of face-selective activations in the right FFA was significantly positively related to face recognition memory performance, but not object or place memory performance. Our recent neuroimaging work also found that the size of right FFA was positively associated with face recognition ability (Elbich & Scherf, 2017). In addition, studies showed that there is a developmental difference in size of face selective activation in FFA from childhood to adulthood (Golarai et al., 2010; Peelen, Glaser, Vuilleumier, & Eliez, 2009; Scherf et al., 2007). All these findings suggest that the activation size of FFA is particularly sensitive to individual difference in face recognition behavior at different developmental stages. Combined with our behavioral findings that emerging adults have specific peer bias in face recognition, our finding of neural size indicates that the larger neural size activated by emerging adult face may reflect the peer bias in face recognition in emerging adults. In addition, consistent with our behavior finding that A' sensitivity is larger to peer face compared to parent-aged face, we also found that the neural size of emerging adult face is larger than that of parent-aged face. However, it should be noted that there was no behavior-neural response correlation in the current study. I planned to correlate these two

variables but there was an experimenter error in recording, resulting in no enough individual variation for me to conduct this analysis. Future studies focusing on the relation between neural size of FFA and peer bias in emerging adult group are needed.

Second, we found that the emerging adult defined FFA ROI was in a more anterior location compared to the other face category defined ROIs, particularly in comparison to the child-face defined FFA ROI. This finding potentially suggests that different neural patches within FFA are responsible for encoding different developmental status of a face. Most of conventional fMRI studies defined ROIs in a general way and only compared the beta weights without specifying whether the loci of each ROI patch in a same region are different. This information is critically important to understand whether specifically different neural voxels in a same brain region are responsible for processing different information. For example, Scherf and colleagues (2010) found that high functioning autism group and typically developing group have different location of the face-selective activation, and this activation of functioning autism group tends to be located in traditionally object-selective region, suggesting face processing in individuals with autism is more akin to object processing in typically developing individuals. Therefore, the neural patches of FFA1 defined by emerging adult face is located in a different space may represent how brain is organized and differentiated from other voxels encoding other facial information.

Third, we observed the neural magnitude of bilateral FFA1 elicited by peer faces in emerging adults was significantly larger than other faces. As far as we know, there are only two fMRI studies relevant to peer bias in face recognition in adults. One of the researches did not find adult face elicited significantly larger neural magnitude in FFA

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than older faces in adult participants (Wiese et al., 2012). Another research using multivoxel pattern analysis revealed a higher decoding accuracy in ventral temporal cortex for own-age face than other age face in adults (18-40 years old). The authors suggested that the recent and cumulative experience, as well as social significance of adult-like face together result in larger own-face preference in neural representation. However, it should be noted that in this study, the own-age face stimuli were all young adult faces, which are not completely and appropriately matched to the developmental status of participants. As a result, it limits our ability to fully attribute this neural responsiveness to peer bias in face recognition in a specific developmental group. The current study employed facial stimuli (sexually mature emerging adult face) appropriately matched on the developmental status of participants to explore the neural circuitry underlying *peer bias* in face recognition. Our result suggests that FFA1 may subserve the peer bias in face recognition in emerging adult group. Further, this neural representation in FFA1 is not related to recent or cumulative experience (i.e., familiarity) since the neural magnitude elicited by emerging adult face in this defined ROI was significantly larger than that elicited by parent-aged face. Within developmental task theoretical framework, we reason that the developmental task in emerging adulthood (i.e., forming relationship with peers) fundamentally change the computational goal of neural circuitry underlying face recognition.

In addition, the results of the present study showed that each of the face category defined FFA1 ROIs exhibited a unique neural profile of activation. Specifically, certain face elicited a larger neural magnitude within the bilateral FFA1 defined by this face category with the exception of early puberty adolescent face (see Figure **5-1 & 6-1**). It

should be noted that the ROIs identification was at basic level (i.e., emerging adult face > object) and the comparison between beta weights conducted in the present study was at subordinate level (e.g., emerging adult face > other faces). This indicates that the ROIs identification at basic level may be also sensitive to subordinate level except early puberty adolescent face. These findings associated with these five face categories with different developmental status may extend to different subordinate level contrasts such as gender, attractiveness of face in future studies. Further, these results also lead researchers to think about the role and organization of FFA in future.

It should be noted that this set of findings was not reflective of any doubledipping conduct in which the effect size becomes more significant when one selects voxels using a factor of interest and then estimates the effect size related to that same factor of interest again in those same voxels (Kriegeskorte, Lindquist, Nichols, Poldrack, & Vul, 2010; Vul, Harris, Winkielman, & Pashler, 2009). In the current study, we compared the beta weights *between face categories* extracted from the FFA1 regions defined by each face category *contrasted with object*. As a result, this set of findings reflects FFA1 encodes developmental statues of a face rather than the overestimated effect introduced by double-dipping misconduct. Further, if this set of findings was resulted from effect size overestimation, the neural magnitude of each face category should be significantly larger than that of the other face categories within the FFA1 ROI defined by that face category. However, we did not observe early puberty adolescent face elicited significantly larger neural magnitude compared to other faces within the FFA1 ROI defined by early puberty adolescent face. On the other hand, the maturity assessment on stimuli indicates that early puberty adolescent faces employed in the current study

were distinguishable from other face categories (Figure **2-1**). Future studies should look at which brain region is capable to encode this kind of developmental status information.

In sum, the neural results of the present study preliminarily indicate that the information about developmental status of a face is differentially represented in the configuration of FFA1. A more anterior part of FFA1 is capable of differentiating peer face from other faces, in terms of magnitude and size.

Limitations and Future Directions

Though the present study provides a substantial contribution to the current literature in multiple ways, there are some caveats to note. First, one of the limitations of this study is the lack of the correlation between behavioral results and neural response. I collected behavioral data, intending to explore whether the neural circuitry that encodes peer bias information relates to peer bias face recognition behavior. However, due to some errors in experimental recording, some of the behavioral data was lost. As a result, there was no enough power for me to conduct the correlational analysis. Further researches should be more focusing on demonstrating the relation between FFA1 and peer bias in face recognition in emerging adult. Multi-voxel patterns analysis investigating the representational content of regions provides us fine-grained spatialpattern information about how small chunks of voxel in a region differentially decode inputs (Mur, Bandettini, & Kriegeskorte, 2008). Our next step is to see whether we have enough data to conduct this kind of analysis and look at whether the peer face recognition in emerging adults is decoded by FFA1 in a different pattern compared to other developmental status faces. Secondly, in order to explore and delineate how neural

circuitry encodes the information about developmental status of a face, face stimuli with a comprehensive range of developmental status were used while scanning in the current study. However, long scanning duration potentially saturated participant and decreased the blood-oxygen-level dependent imaging signal. Based on this, future studies should take the balance between signal acquisition and the question of interests into consideration. Lastly, only bilateral FFA1 regions were consistently activated across participants and could be analyzed in the present study. Therefore, it is still an open question that whether the FFA1 is the only region that capable to decode developmental status information contained in a face and subserve emerging adults' peer bias in face recognition. I will continue to work on this data to seek whether there is any way to improve the data analysis.

Conclusion

The present study represents the first study that includes faces with wide range of different developmental status to explore the neural circuitry encodes this kind of information. The present study replicates the most recent developmental study associated with peer bias in face recognition behavior by showing that emerging adults are better recognizing peer face compared to other developmental groups' faces including child face, early puberty adolescent face, late puberty adolescent face, as well as parent-aged face, at behavioral level. Neuroimaging results of the current study suggest that bilateral FFA1 regions, which found to be related to face recognition behavior in previous studies, enable to differentiate the information about developmental status of a face. Further, the neural magnitude and neural size elicited by peer faces (i.e., emerging adult face) stand

out from the neural magnitude and neural size of other faces with different developmental status. This whole set of findings implicates that the peer bias in emerging adult face recognition behavior may be subserved by disproportionally larger activation (i.e., magnitude or size) of neural tissue located in a more anterior part of the FFA1. This study represents a novel contribution to knowledge about how neural circuitry underlying face processing is organized to form peer bias in face recognition behavior.

Appendix

Figure Legends

Figure 1-1.: Stimuli Examples by Developmental Group of Face Recognition Behavioral Task.

Figure 2-1. Pairwise Comparisons on Maturation Scores and Confidence Intervals of Each Face Category for Face Category Stimulation Task. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, and EA represents emerging adult face condition.

Figure 2-2. Pairwise Comparisons on Emotion Intensity Scores and Confidence Intervals of Each Face Categories for Face Category Stimulation Task. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, EA represents emerging adult face condition and PA represents parent-aged face condition.

Figure 2-3. Pairwise Comparisons on Emotion Intensity Scores and Confidence Intervals of Each Face Categories for Face Identity Memory Identity Task. EP represents early puberty adolescent face condition, LP represents late puberty adolescent face condition, EA represents emerging adult face condition and PA represents parent-aged face condition. **Figure 3-1.** Stimuli Examples by Developmental Group of Face Category Stimulation Task.

Figure 4-1. Pair Comparisons on Neural Sizes Activated by Face Conditions.

Figure 5-1. Pair Comparisons on Neural Magnitude from Face-Object Defined rFFA1.

Figure 6-1. Pair Comparisons on Neural Magnitude from Face-Object Defined IFFA1.

Figure 7-1. Result of Group-level GLM. The yellow spot inside the red circle represents the activation map of rFFA1 defined by emerging adult face-object. Group-level GLM activation map was projected onto a representative structural brain and thresholded at p < .01.

Figure 8-1. Result of Behavioral Task. a). Overall sensitivity to each face category, EP represents early puberty adolescent face and LP represents late puberty adolescent face condition; b). Planned contrast between the sensitivities to peer face (i.e., emerging adult face) and other faces except parent-aged face; c). Planned contrast between the sensitivities to peer face (i.e., emerging adult face) and all other faces; d). Planned contrast between the sensitivities to peer face (i.e., emerging adult face) and all other faces; d).

Reference:

Anastasi, J., & Rhodes, M. (2005). An own-age bias in face recognition for children and older adults. *Psychonomic Bulletin & Review*, *12*(6), 1043.

Anastasi, J., & Rhodes, M. (2006). Evidence for an own-age bias in face

recognition. North American Journal of Psychology, 8(2), 237-252.

Anzures, G., Quinn, P. C., Pascalis, O., Slater, A. M., & Lee, K. (2010).

Categorization, categorical perception, and asymmetry in infants' representation of face race. *Developmental Science*, *13*(4), 553-564.

Armony, J. L., & Sergerie, K. (2007). Own-sex effects in emotional memory for faces. *Neurosci Lett*, *426*(1), 1-5.

Arnett, J. J. (2000). Emerging adulthood: A theory of development from the late teens through the twenties. *American Psychologist*, *55*(5), 469-480.

Aylward, E. H., Park, J. E., Field, K. M., Parsons, A. C., Richards, T. L., Cramer, S.

C., & Meltzoff, A. N. (2005). Brain activation during face perception: Evidence of a developmental change. *J Cogn Neurosci*, *17*(2), 308-19.

Bäckman, L. (1991). Recognition memory across the adult life span: The role of prior knowledge. *Memory & Cognition*, *19*(1), 63-71.

Dufour, V., Pascalis, O., & Petit, O. (2006). Face processing limitation to own species in primates: A comparative study in brown capuchins, tonkean macaques and humans. *Behav Processes*, *73*(1), 107-13. doi:10.1016/j.beproc.2006.04.006

Dixon, W. J., & Tukey, J. W. (1968). Approximate behavior of the distribution of Winsorized t (Trimming/Winsorization 2). *Technometrics*, 10, 83–98.

Ebner, N., & Johnson, M. (2009). Young and older emotional faces: Are there age group differences in expression identification and memory? *Emotion*, *9*(3), 329-339.

Elbich, D. B., & Scherf, S. (2017). Beyond the FFA: Brain-behavior correspondences in face recognition abilities. *NeuroImage*, *147*, 409-422.

Egger, H. L., Pine, D. S., Nelson, E., Leibenluft, E., Ernst, M., Towbin, K. E., & Angold, A. (2011). The NIMH child emotional faces picture set (nimh-chefs): A new set of children's facial emotion stimuli. *International Journal of Methods in Psychiatric Research*, *20*(3), 145-156. doi:10.1002/mpr.343

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguana, D., & Csibra, G. (2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *PNAS*.

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G.
(2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *Proc Natl Acad Sci U S A*, *102*(47), 17245-50.

Fulton, A., & Bartlett, J. C. (1991). Young and old faces in young and old heads: The factor of age in face recognition. *Psychology and Aging*, *6*(4), 623.

Furman, W., & Buhrmester, D. (1985). Children's perceptions of the qualities of sibling relationships. *Child Development*, *56*(2), 448-61.

Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia*, 45(1), 32-41. doi:10.1016/j.neuropsychologia.2006.04.015

Gabrieli, J. D., & Grill-Spector, K. (2007). Differential development of high-level visual cortex correlates with category-specific recognition memory. *Nat Neurosci*, *10*(4), 512-

Golarai, G., Ghahremani, D. G., Whitfield-Gabrieli, S., Reiss, A., Eberhardt, J. L.,
Golarai, G., Hong, S., Haas, B. W., Galaburda, A. M., Mills, D. L., Bellugi, U., . . . Reiss, A. L. (2010). The fusiform face area is enlarged in williams syndrome. *J Neurosci*, *30*(19), 6700-12. doi:10.1523/JNEUROSCI.4268-09.2010

Golarai, G., Liberman, A., & Grill-Spector, K. (2015). Experience shapes the development of neural substrates of face processing in human ventral temporal cortex. *Cerebral Cortex.* doi:10.1093/cercor/bhv314

Grill-Spector, K., & Weiner, K. S. (2014). The functional architecture of the ventral temporal cortex and its role in categorization. *Nat Rev Neurosci.* doi:10.1038/nrn3747

Hayden, A., Bhatt, R., Zieber, N., & Kangas, A. (2009). Race-based perceptual asymmetries underlying face processing in infancy. *Psychonomic Bulletin & Review*, *16*(2), 270-275. doi:10.3758/PBR.16.2.270

Haxby, J., Hoffman, E., & Gobbini, M. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*(6), 223-232.

Hills, P. J., & Lewis, M. B. (2011). The own-age face recognition bias in children and adults. *Q J Exp Psychol (Hove)*, *64*(1), 17-23. doi:10.1080/17470218.2010.537926

Huang, L., Song, Y., Li, J., Zhen, Z., Yang, Z., & Liu, J. (2014). Individual differences in cortical face selectivity predict behavioral performance in face recognition. *Front Hum Neurosci*, *8*, 483. doi:10.3389/fnhum.2014.00483

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *J Neurosci*, *17*(11), 4302-11.

Kriegeskorte, N., Lindquist, M., Nichols, T., Poldrack, R., & Vul, E. (2010).

Everything you never wanted to know about circular analysis, but were afraid to ask. *Journal of Cerebral Blood Flow & Metabolism*, *30*(9), 1551-1557.

Lebrecht, S., Pierce, L. J., Tarr, M. J., & Tanaka, J. W. (2009). Perceptual otherrace training reduces implicit racial bias. *PLoS One*, *4*(1), e4215.

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H., Hawk, S. T., & van

Knippenberg, A. (2010). Presentation and validation of the radboud faces database. *Cognition and Emotion*, *24*(8), 1377-1388.

LoBue, V., & Thrasher, C. (2014). The child affective facial expression (CAFE)

set: Validity and reliability from untrained adults. Frontiers in Psychology, 5, 1532.

Lundqvist, D., Flykt, A., & Öhman, A. (1998). The karolinska directed emotional faces (KDEF). *CD ROM From Department of Clinical Neuroscience, Psychology Section, Karolinska Institutet*, 91-630.

MacLin, O. H., & Malpass, R. S. (2001). Racial categorization of faces: The ambiguous race face effect. *Psychology, Public Policy, and Law*, *7*(1), 98. https://doi.org/10.1037/1076-8971.7.1.98

Marr, D., & Vision, A. (1982). A computational investigation into the human representation and processing of visual information. *WH San Francisco: Freeman and Company*.

Marusak, H. A., Carré, J. M., & Thomason, M. E. (2013). The stimuli drive the response: An fmri study of youth processing adult or child emotional face stimuli. *Neuroimage*, *83*, 679-89. doi:10.1016/j.neuroimage.2013.07.002

Minear, M., & Park, D. C. (n.d.). A lifespan database of adult facial stimuli. Behavior Research Methods, Instruments, & Computers, 36(4), 630-633 Mur, M., Bandettini, P., & Kriegeskorte, N. (2008). Revealing representational content with pattern-information fMRI--an introductory guide. *Social Cognitive and Affective Neuroscience*, *4*(1), 101-109.

Mur, M., Ruff, D., Bodurka, J., Bandettini, P., & Kriegeskorte, N. (2010). Face-Identity change activation outside the face system: "Release from adaptation" may not always indicate neuronal selectivity. *Cerebral Cortex*, *20*(9), 2027-2042.

Müller, R. A., Kleinhans, N., Kemmotsu, N., Pierce, K., & Courchesne, E. (2003). Abnormal variability and distribution of functional maps in autism: An FMRI study of visuomotor learning. *Am J Psychiatry*, *160*(10), 1847-62.

Pascalis, O., & Bachevalier, J. (1998). Face recognition in primates: A cross-species study. *Behavioural Processes*, *43*(1), 87-96.

Pascalis, O., de Haan, M., & Nelson, C. A. (2002). Is face processing speciesspecific during the first year of life? *Science*, *296*(5571), 1321-3.

doi:10.1126/science.1070223

Passarotti, A. M., Smith, J., DeLano, M., & Huang, J. (2007). Developmental differences in the neural bases of the face inversion effect show progressive tuning of face-selective regions to the upright orientation. *Neuroimage*, *34*(4), 1708-22.

Peelen, M. V., Glaser, B., Vuilleumier, P., & Eliez, S. (2009). Differential development of selectivity for faces and bodies in the fusiform gyrus. *Dev Sci*, *12*(6), F16-25.

Perfect, T. J., & Harris, L. J. (n.d.). Adult age differences in unconscious transference: Source confusion or identity blending? *Memory & Cognition*, *31*(4), 570-580.

Perfect, T. J., & Moon, H. (2005). The own-age effect in face recognition.

Measuring the Mind: Speed, Control, and Age, 317-340.

Pitcher, D., Walsh, V., & Duchaine, B. (2011). The role of the occipital face area in the cortical face perception network. *Exp Brain Res*, *209*(4), 481-93. 1

Roisman, G. I., Masten, A. S., Coatsworth, D. J., & Tellegen, A. (2004). Salient and Emerging Developmental Tasks in the Transition to Adulthood. *Child Development*, 75(1), 123–133. https://doi.org/10.1111/j.1467-8624.2004.00658.x

Scherf, K., Behrmann, M., Humphreys, K., & Luna, B. (2007). Visual categoryselectivity for faces, places and objects emerges along different developmental trajectories. *Developmental Science*, *10*(4), F15-F30. doi:10.1111/j.1467-

7687.2007.00595.x

Scherf, K. S., & Scott, L. S. (2012). Connecting developmental trajectories: Biases in face processing from infancy to adulthood. *Developmental Psychobiology*, *54*(6), n/a. doi:10.1002/dev.21013

Scherf, K. S., Behrmann, M., & Dahl, R. E. (2012). Facing changes and changing faces in adolescence: A new model for investigating adolescent-specific interactions between pubertal, brain and behavioral development. *Dev Cogn Neurosci*, *2*(2), 199-219. doi:10.1016/j.dcn.2011.07.016

Scherf, K. S., Smyth, J. M., & Delgado, M. R. (2013). The amygdala: An agent of change in adolescent neural networks. *Hormones and Behavior*, *64*(2), 298-313. doi:10.1016/j.yhbeh.2013.05.011

Schiller, D., Freeman, J. B., Mitchell, J. P., Uleman, J. S., & Phelps, E. A. (2009). A neural mechanism of first impressions. *Nat Neurosci*, *12*(4), 508-14.

Scott, L. S., & Monesson, A. (2009). The origin of biases in face perception. *Psychol Sci*, *20*(6), 676-80.

Scott, L. S., & Fava, E. (2014). The own-species face bias: A review of developmental and comparative data. *Visual Cognition*.

Sporer, S. (2001). Recognizing faces of other ethnic groups: An integration of theories. *Psychology, Public Policy, and Law*, 7(1), 36. https://doi.org/10.1037/1076-8971.7.1.36

Thomaz, C. E., & Giraldi, G. A. (2010). A new ranking method for principal components analysis and its application to face image analysis. *Image and Vision Computing*, *28*(6), 902-913. doi:10.1016/j.imavis.2009.11.005

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., . . . Nelson, C. (2009). The nimstim set of facial expressions: Judgments from untrained research participants. *Psychiatry Res*, *168*(3), 242-9.

Vul, E., Harris, C., Winkielman, P., & Pashler, H. (2009). Puzzlingly high correlations in fmri studies of emotion, personality, and social cognition. *Perspectives on Psychological Science*, *4*(3), 274-290.

Weiner, K. S., & Grill-Spector, K. (2011). Neural representations of faces and limbs neighbor in human high-level visual cortex: Evidence for a new organization principle. *Psychol Res.* doi:10.1007/s00426-011-0392-x

Weiner, K. S., Golarai, G., Caspers, J., Chuapoco, M. R., Mohlberg, H., Zilles, K., .
. . Grill-Spector, K. (2014). The mid-fusiform sulcus: A landmark identifying both
cytoarchitectonic and functional divisions of human ventral temporal cortex. *Neuroimage*, *84*, 453-65. doi:10.1016/j.neuroimage.2013.08.068

Wiese H., Kloth N., Gullmanr D., Reichenbach J., & Schweinberger S., (2012) Perceiving age and gender in unfamiliar faces: An fMRI study on face categorization. *Brain and Cognition*. 78(2), 163-168

Whalen, P. J., Johnstone, T., Somerville, L. H., Nitschke, J. B., Polis, S., Alexander,
A. L., . . . Kalin, N. H. (2008). A functional magnetic resonance imaging predictor of
treatment response to venlafaxine in generalized anxiety disorder. *Biol Psychiatry*, *63*(9),
858-63. doi:10.1016/j.biopsych.2007.08.019

Wright, D. B., & Stroud, J. N. (2002). Age differences in lineup identification accuracy: People are better with their own age. *Law and Human Behavior*, *26*(6), 641-654.

Wright, D. B., & Sladden, B. (2003). An own gender bias and the importance of hair in face recognition. *Acta Psychologica*, *114*(1), 101-114. doi:10.1016/S0001-6918(03)00052-0

Yarkoni, T. (2009). Big correlations in little studies: Inflated fmri correlations reflect low statistical powercommentary on vul et al.(2009). *Perspectives on Psychological Science*, *4*(3), 294-298.

Young, S., Bernstein, M., & Hugenberg, K. (2010). When Do Own-Group Biases in Face Recognition Occur? Encoding versus Post-Encoding. *Guilford Publications*, *28*(2), 240–250.

Yovel, G., & Kanwisher, N. (2005). The neural basis of the behavioral faceinversion effect. *Curr Biol*, *15*(24), 2256-62. doi:10.1016/j.cub.2005.10.072