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The Neural Mechanisms Of Conformity Across Socioeconomic Status And Development

Christopher N. Cascio
University of Pennsylvania, ccascio@upenn.edu

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Abstract

Social influence is omnipresent, explicitly and implicitly influencing people's preferences and behaviors. Recently, neuroscientists have begun to contribute to our understanding of social influence, providing insight into mental processes that occur in real time without the need for participant introspection. The current dissertation aims to build our understanding of social influence by examining the neural mechanism that underlie receiving feedback about others' preferences, as well as the mechanisms that underlie conformity to others' preferences. In order to examine these relationships, the current dissertation examined four questions. First, we examined which neural mechanisms underlie processing social feedback and conformity across 249 people, making it the largest study of social influence in the brain to date. Next, we examined whether SES (high versus low) moderates neural mechanisms associated with social influence processing and conformity. Third, we examined whether development (adolescents versus young adults) moderates neural mechanisms associated with social influence. Finally, we examined whether the relationship between SES and social influence processing and conformity is different depending on developmental trajectories. Results from the current dissertation provide robust evidence for a core set of brain systems involved in conflict detection and mentalizing that are implicated in social influence across groups. We address previous methodological limitations stemming from diverse methods employed to study social influence across different past studies of influence. In addition, we begin to show evidence that socio-demographic factors and development may moderate the neural bases of social influence. Taken together the findings from the current dissertation advance our understanding of social influence by providing evidence for a set of core mechanisms involved in social influence. We do not find robust evidence for differences in neural processing associated with socio-demographic factors, but highlight some subtle differences and discuss possibilities for future neuroimaging research that can more definitively address commonalities and differences across groups.

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THE NEURAL MECHANISMS OF CONFORMITY ACROSS SOCIOECONOMIC STATUS AND DEVELOPMENT

Christopher N. Cascio

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Supervisor of Dissertation

____

Emily Falk, Associate Professor of Communication

Graduate Group Chairperson

____

Joseph Turow, Robert Lewis Shayon Professor of Communication

Dissertation Committee

Joseph N. Cappella, Gerald R. Miller Professor of Communication

Robert C. Hornik, Wilbur Schramm Professor of Communication

THE NEURAL MECHANISMS OF CONFORMITY ACROSS SOCIOECONOMIC STATUS AND DEVELOPMENT

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ABSTRACT

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Christopher N. Cascio

Emily B. Falk

Social influence is omnipresent, explicitly and implicitly influencing people's preferences and behaviors. Recently, neuroscientists have begun to contribute to our understanding of social influence, providing insight into mental processes that occur in real time without the need for participant introspection. The current dissertation aims to build our understanding of social influence by examining the neural mechanism that underlie receiving feedback about others' preferences, as well as the mechanisms that underlie conformity to others' preferences. In order to examine these relationships, the current dissertation examined four questions. First, we examined which neural mechanisms underlie processing social feedback and conformity across 249 people, making it the largest study of social influence in the brain to date. Next, we examined whether SES (high versus low) moderates neural mechanisms associated with social influence processing and conformity. Third, we examined whether development (adolescents versus young adults) moderates neural mechanisms associated with social influence. Finally, we examined whether the relationship between SES and social influence processing and conformity is different depending on developmental trajectories. Results from the current dissertation provide robust evidence for a core set of brain systems involved in conflict detection and mentalizing that are implicated in social influence across groups. We address previous methodological limitations stemming from diverse methods employed to study social influence across different past studies of influence. In addition, we begin to show evidence that socio-demographic factors and development may moderate the neural bases of social influence. Taken together the findings from the current dissertation advance our understanding of social influence by providing evidence for a set of core mechanisms involved in social influence. We do not find robust evidence for differences in neural processing associated with socio-demographic factors, but highlight some subtle differences and discuss possibilities for future neuroimaging research that can more definitively address commonalities and differences across groups.

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CHAPTER 1. INTRODUCTION AND OVERVIEW

Introduction

Social influence is omnipresent, often explicitly or implicitly influencing people's preferences and behaviors. Although people are often unaware or underestimate the strength of social influence, research has demonstrated its influence on preferences and behaviors across a variety of circumstances (for a review, see Cialdini & Goldstein, 2004). For example, social influence has been shown to affect alcohol use (Huang et al., 2014; Osgood et al., 2013), smoking (Fujimoto, Unger, & Valente, 2012; Harakeh & Vollebergh, 2012; Schaefer & Haas, 2013), drug use (Tucker, De La Haye, Kennedy, Green, & Pollard, 2014), risky sexual behaviors (Romer et al., 1994), diet (Matera, Nerini, & Stefanile, 2013; Stok, Ridder, Vet, & Wit, 2014), cyberbullying (Hinduja & Patchin, 2013), and physical activity (Simpkins, Schaefer, Price, & Vest, 2013). Therefore, gaining a better understanding of the underlying mechanisms that drive social influence is of great interest across many fields, including communication, psychology, public health, marketing, economics, political science, and sociology.

Recently, neuroscientists have begun to contribute to our understanding of social influence, providing insight into mental processes that occur in real time without the need for participant introspection and potentially circumventing certain social desirability biases (Lieberman, 2010). Neuroimaging studies suggest that under different circumstances, neural systems associated with reward and positive subjective valuation (Campbell-Meiklejohn, Bach, Roepstorff, Dolan, & Frith, 2010; Zaki, Schirmer, & Mitchell, 2011), conflict monitoring and social distress or pain (Berns, Capra, Moore, & Noussair, 2010; Klucharev, Hytönen, Rijpkema, Smidts, & Fernández, 2009), and considering the mental states of others (i.e., mentalizing) (Cascio, O'Donnell, Bayer, Tinney, & Falk, 2015; Welborn et al., 2015) are key processes associated with processing social feedback, as well as preference and behavior change in response to social influence. These findings offer a new perspective on social influence research and using this information in conjunction with findings from other methodologies (e.g., self-report surveys) will give researchers a more holistic understanding of social influence.

Socioeconomic status

Not all groups are equally susceptible to social influence, however, and may be influenced through different pathways. One potential moderator of the neural mechanisms associated with social influence is SES. It has been well established that SES is associated with health and health behavior disparities, ranging from smoking (Hiscock, Bauld, Amos, Fidler, & Munafo, 2012; Patrick, Wightman, Schoeni, & Schulenberg, 2012), to diet (Hanson & Chen, 2007), physical activity (Hanson & Chen, 2007), cardiovascular disease (Clark, DesMeules, Luo, Duncan, & Wielgosz, 2009), diabetes (Agardh, Allebeck, Hallqvist, Moradi, & Sidorchuk, 2011), cancer (Hystad, Carpiano, Demers, Johnson, & Brauer, 2013; Uthman, Jadidi, & Moradi, 2013), and ultimately mortality (Nandi, Glymour, & Subramanian, 2014). Although this influence is complex, and the relationship between SES and these important outcomes of interest is attributed in part to social and physical environments[1], psychological factors likely play important roles as well (Alexander, Entwisle, & Olson, 2001; Chen & Miller, 2013).

Even from a young age differences can be found between those from high and low SES backgrounds on behavioral measures of executive functions (Hughes & Ensor, 2005; Lipina, Martelli, & Colombo, 2005; Lipina, Martelli, Vuelta, Injoque-Ricle, & Colombo, 2004; Mezzacappa,

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[1] Note: Currently, several models have attempted to explain how SES influences outcomes such as health and health behaviors across the lifespan (Pollitt, Rose, & Kaufman, 2005). Among these models, several core mechanisms seem to be implicated, including the influence that SES has on psychological resources (e.g., stress and emotion regulation), physical wellbeing (e.g., sedentary behaviors, diet, substance use), physiology (e.g., physiological dysregulation, altered cortical development, cellular damage (Cohen, Janicki-Deverts, Chen, & Matthews, 2010), and susceptibility to social influence (Chen & Miller, 2013; Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012; Spielberg et al., 2015), particularly during childhood and adolescence (Cohen et al., 2010). Although all of these factors, in addition to affordance and adequacy of health care (Cohen et al., 2010), may separately contribute to the link between SES and health, they are also interrelated. For example, having a lower ability to regulate psychological stress may lead an individual to use substances in order to help alleviate stress. This is beyond the scope of this dissertation, however, the multiple influences on outcomes will be kept in mind as we address questions of SES and decision-making.

2004; Rhoades, Greenberg, Lanza, & Blair, 2011). For example, children as young as 6 to 14 months from homes that do not meet basic needs (e.g., inadequate dwelling conditions, overcrowding) already begin to show decreased performance on the *A-not-B* task, an early predictor of executive functioning in comparison to children from homes where basic needs are met (Lipina et al., 2005). Similarly, research examining exposure to low SES environments during early childhood and adolescence and executive functioning, including working memory, goal setting, set-shifting, and inhibitory control finds that those from lower SES backgrounds display decreased performance in comparison to those from higher SES backgrounds (Hughes & Ensor, 2005; Lipina et al., 2004; Mezzacappa, 2004; Rhoades et al., 2011).

Critical to the current set of studies, such psychological influences can be traced to the brain, wherein social environments train the brain to respond differently and adaptively according to circumstances and cultural norms (Chen & Miller, 2013; Tost, Champagne, & Meyer-Lindenberg, 2015). Although this research is relatively new, neuroscientists have begun to examine how SES influences neural functioning, particularly among regions involved in executive functioning (for reviews, see; (Hackman, Farah, & Meaney, 2010; Lawson et al., 2014)), which are important for a wide range of outcomes (Barkin, 2013; Bull & Scerif, 2001; Keilp et al., 2013; Snyder, 2013). For example, those from lower compared to higher SES backgrounds have shown neural differences in regions associated with working memory during a rule learning task (Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012) and regions associated with inhibitory control during an inhibition task (Spielberg et al., 2015). These differences in the brain have been linked less efficient performance on these tasks (Sheridan et al., 2012; Spielberg et al., 2015), however, differences in the brain can also reveal alternative mechanisms that lead to equivalent performance. For example, research has shown that high and low SES have different neural responses on an auditory attention task where those from lower SES backgrounds allocate greater neural resources to distracting information, however, these studies did not find behavioral differences (D'Angiulli, Herdman, Stapells, & Hertzman, 2008; Stevens, Lauinger, & Neville, 2009). Thus, even in the absence of behavioral differences in conformity, those from different

SES backgrounds may use different brain systems when conforming to social feedback. Likewise, different environments train the brain to function differently. When differences in performance on laboratory tasks are observed this may be a result of different learned cognitive approaches to different environments, which could also be associated with differential recruitment of brain regions to perform such tasks. For example, those from very low SES backgrounds may need to pay more attention to what is happening in the environment more than someone from a higher SES environment, perhaps due to safety reasons or to achieve similar goals. In other words, differences that may hinder performance on researcher-defined performance metrics, may stem from adaptive behaviors in the real world. Bringing these ideas together, in the current dissertation, we explore the idea that SES may moderate brain regions associated with executive function during social influence, and seek to determine whether behavioral and neural indices of responsiveness to SES are observable between participants who are similar in the level of success they have achieved (e.g., college students) but who grew up in families with parents of different educational backgrounds. Some evidence suggests that even with milder differences in SES, differences in brain pathways to cognitive function occur (Cascio, O'Donnell, Simons-Morton, Bingham, & Falk, 2017; Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009; Stevens et al., 2009), whereas other evidence suggests that more extreme forms of deprivation may be required to show effects (Kim et al., 2013; Liberzon et al., 2015; Luby et al., 2013; Sripada, Swain, Evans, Welsh, & Liberzon, 2014).

It is important to understand the mechanisms of social influence across SES because the effect of norms (Cialdini & Goldstein, 2004) and social influence (Brechwald & Prinstein, 2011) on behavior is well documented, as is the disproportionate presence of social influence on risk behaviors in lower SES communities (Cohen, Janicki-Deverts, Chen, & Matthews, 2010). However, neural mechanisms of social influence have primarily been studied in relatively high SES individuals, leaving open the question of whether the neural mechanisms of influence are similar across SES groups. If they are similar, this would suggest that differential exposure to influence is the main driver of effects. If they differ, however, this would suggest an additional set of pathways through which SES groups may be differentially influenced by the social environment and may offer additional opportunities for tailoring interventions.

One potential way in which those from different SES backgrounds may be differentially influenced by the social environment may be attributed to regions in the brain associated with executive function, which develop differently depending on high and low SES environments (Czernochowski, Fabiani, & Friedman, 2008; D'Angiulli et al., 2008; Kishiyama et al., 2009; Stevens et al., 2009). Differences witnessed between those from higher and lower SES backgrounds in regions associated with inhibitory control (Spielberg et al., 2015) may be one system that is relevant to processing social feedback and conformity. For example, conformity likely involves the ability to inhibit one's predominant preference prior to conforming to the preferences of others. Thus, one's SES environment may shape which processes contribute to inhibitory control or those from different SES backgrounds may use inhibitory control processes at different times, depending on social cues that are important to one's environment. It is also possible, however, that people across SES backgrounds could show similar patterns of response in relation to social influence, if some basic and robust mechanisms support social influence across groups and contexts. We expand on this rationale in Chapter 3.

Development

A second potential moderator of the neural mechanisms associated with social influence may be related to developmental differences in the brain pathways to social influence. Current research examining neural mechanisms associated with social influence has independently been carried out using adolescent (Berns et al., 2010; Cascio, O'Donnell, et al., 2015; Welborn et al., 2015) and adult (Berns et al., 2005; Klucharev et al., 2009; Zaki et al., 2011) samples. One study directly compared adolescents and adult decisions related to driving decisions in a video game in the presence and absence of peers (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011), however, no prior studies that we are aware of have directly compared the neural correlates of normative influence in the brain across development. Thus, a direct comparison of the differences in social influence processing between adolescents and adults has not been examined. This is important given the increased importance placed on social relationships (Gardner & Steinberg, 2005) and increase in peer influenced risk taking (Steinberg, 2008) during adolescence. For example, conforming to social influences during adolescence has been associated with an increase in risky behaviors (Allen, Porter, & McFarland, 2006; Chein et al., 2011; Gardner & Steinberg, 2005), such as adolescent drug use (Andrews, Tildesley, Hops, & Li, 2002), alcohol use (Urberg, Değirmencioğlu, & Pilgrim, 1997), risky sexual behaviors (Romer et al., 1994), and risky driving (Simons-Morton et al., 2011; Simons-Morton, Lerner, & Singer, 2005). Risk taking in adolescence can also promote positive outcomes related to learning new things and meeting new people (Telzer, 2016). Thus, identifying neural differences between adolescents and adults may give researchers additional insight into why adolescents are more likely to engage in different behaviors in response to social influence compared to adults (Steinberg, 2008).

One potential way in which adolescents may differ in how they process social feedback compared to adults may be attributed to the developing brain. Research has demonstrated that during adolescence affective systems mature more rapidly compared to slower maturing prefrontal cortex regions involved in cognitive control (Steinberg, 2008). In addition, research on adolescence suggests that more mature subcortical structures, including the ventral and dorsal striatum, can help facilitate emotion regulation (Masten et al., 2009; Pfeifer et al., 2011). Thus, we explored whether adolescents may be more likely to process social feedback through affective processing regions within the limbic system (social pain, reward sensitivity systems), compared to adults who may show greater activity in cognitively oriented regions of prefrontal and temporal cortex (mentalizing, and self-processing systems). Although we do not find strong evidence for this distinction, we do find evidence consistent with greater variability in adolescent neural processing of social influence.

Socioeconomic status by development

Finally, although peer influenced risk taking during adolescence and health behavior disparities among low SES individuals have been broadly related to social environmental factors (Albert, Chein, & Steinberg, 2013; Carroll-Scott et al., 2013), research has not yet addressed whether development (adolescence versus adulthood) and SES (low versus high) interact to influence neural mechanisms associated with susceptibility to social influence. Although this interaction has not been explored in the context of social influence, work related adverse environmental conditions suggests that stress may influence the brains of adults and children in different ways. For example, early childhood stress from lower SES environments, neglect, and physical abuse have been associated with decreased amygdala and hippocampus volume, which can lead to issues with emotion regulation (Hanson et al., 2015). However, new onset post-traumatic stress syndrome in adults does not have the same influence on hippocampal volume (Bonner et al., 2001). Findings such as these may suggest that SES influences on neural functioning are not uniform across development. Understanding whether neural mechanisms that underlie social influence differ depending on SES, and whether those neural differences are consistent versus different across development is an important step in our understanding social influence, SES, and development. We explore whether such patterns might exist, even in the absence of severe deprivation.

Dissertation overview

The current dissertation aims to build our understanding of social influence by examining the neural mechanism that underlie receiving social feedback, as well as the mechanisms that underlie conformity. In addition, the current dissertation aims to build on our understanding of the relationship between SES, development, and the brain by further elucidating the neural mechanisms associated with social influence in relation to these key variables. Specifically, the current dissertation will first meta-analyze a series of studies on social influence across groups to identify regions robustly associated with social influence, and then examine whether SES and development moderate how the brain responds to social cues and guides action in response to social influence. Details regarding the operationalization of SES are reported in chapter 3 and development in chapter 4.

The current dissertation will focus on two important aspects of social influence by focusing on the neural mechanisms associated with viewing or processing social feedback (referred to in the remainder of the dissertation as *processing*), as well as the neural mechanisms associated with conforming to social feedback (referred to in the remainder of the dissertation as *conformity*). In order to examine these relationships the current dissertation will answer 4 questions. Study 1 will examine which neural mechanisms underlie processing social feedback and conformity across 249 people, making it the largest study of social influence in the brain to date. Study 2 will examine whether SES (high versus low) moderates neural mechanisms associated with social influence processing and conformity. Study 3 will examine whether development (adolescents versus adults) moderates neural mechanisms associated with social influence. Finally, study 4 will examine whether the relationship between SES and social influence processing and conformity is different depending on developmental trajectories.

CHAPTER 2. NEURAL CORRELATES OF SOCIAL INFLUENCE

Introduction

Social influence impacts a wide range of important preferences and behaviors (Cialdini & Goldstein, 2004; Higgs, 2015; Mead, Rimal, Ferrence, & Cohen, 2014; Stok, de Vet, de Ridder, & de Wit, 2016). Neuroscience has built on the long history of social science research examining conformity and compliance by examining neural mechanisms associated with social influence. These studies offer new insight into neural processes as they occur in real time without the need for participant introspection. Thus, even if participants are unaware or do not necessarily know the reasons why they were susceptible to social influence, neuroimaging methods can capture cognitive processes taking place at the time of influence.

Current neuroimaging studies have suggested the involvement of several core systems in social influence processing and conformity, including social pain/conflict detection (Berns et al., 2005; Klucharev et al., 2009; Tomlin, Nedic, Prentice, Holmes, & Cohen, 2013), positive valuation/reward (Campbell-Meiklejohn et al., 2010; Zaki et al., 2011), mentalizing (Cascio, O'Donnell, et al., 2015; Welborn et al., 2015), and self-processing networks (Mason, Dyer, & Norton, 2009). Although these neural networks have been suggested as core processes relevant to social influence (Cascio, Scholz, & Falk, 2015; Izuma, 2013), studies report divergent findings. One difficulty in understanding the neural processes that drive social influence is that most studies to date of social influence have been small, and use heterogeneous methods. For example, some studies compare receiving divergent social feedback to no social feedback, and some compare to receiving convergent social feedback. Second, some studies account for whether participants change their preferences/ratings (i.e., are actually influenced) and some studies only compare social feedback types and then look at aggregate levels of conformity. Finally, there is substantial heterogeneity in the demographic groups studied across existing studies, making it difficult to know whether observed differences stem from differences in methods or underlying populations.

As one example, research by Welborn et al., (2015) finds that activity in mentalizing regions during social feedback that a person is misaligned with the preferences of others compared to a no social feedback condition is associated with conformity. However, when comparing social feedback that a person is misaligned with the preferences of others to social feedback that a person is aligned with the preferences of others, Klucharev and colleagues (2009) did not observe activity in the regions found by Welborn and colleagues (2015), but instead observed that neural activity in a different set of regions associated with conflict detection were associated with conformity. Thus, although the two tasks studied by the teams appear very similar on the surface, social influence is defined differently, and the researchers observe key differences in mentalizing and conflict detection regions. More broadly, variability in how neuroimaging tasks define social influence makes it is difficult to determine which regions are unique to initially processing social feedback, and which are associated with behavioral conformity. The two example studies described here differed in the within-subject control condition that was compared to receiving divergent peer feedback (Welborn (2015) used “no feedback” and Klucharev (2009) used “peers agree”). Thus, it is difficult to know whether convergent versus no social feedback are equivalent control conditions or whether these conditions involve different process, which may lead to different conclusions regarding neural activity associated with social influence. In addition, these two example studies differ in sample populations (adolescents versus adults), which to our knowledge have not been directly compared to understand whether the two populations process social information in the same way. Similar comparisons can be made across the extant literature on “social influence” or “conformity” in the brain.

Therefore, the aim of this study is to expand and clarify our understanding of the neural processes involved in social influence by conducting a large scale functional magnetic resonance imaging (fMRI) study that explores the neural mechanisms associated with social influence by: 1) examining which brain networks most consistently respond to social norms that suggest a person is misaligned with the group (processing); 2) examining which brain networks most consistently respond to social norms that suggest a person is aligned with the group (processing); and 3) examining which brain networks are most central to conforming to social influence (conformity).

Neural pathways to social influence

Social pain/conflict detection network. One account of why we conform in response to social influence is our desire to maintain group harmony (Cialdini & Goldstein, 2004). This account of social influence suggests that in order to maintain cohesion within a group people need to be able to detect, whether consciously or unconsciously, when their preference or behavior conflicts with the group. Detecting misalignment with the group may trigger neural alarm systems (Berns et al., 2010; Tomlin et al., 2013), which may motivate individuals to conform or comply with the group (DeWall, 2010). In this way, conforming may alleviate distress, establish group acceptance, and maintain group harmony. This account suggests that neural regions associated with conflict detection or social pain drive social influence processing (i.e., understanding that others' views differ from one's own) and conformity (updating one's own behavior or preferences to align with the group). Studies that support this account have found that increased activity in the dorsal anterior cingulate (dACC), supplementary motor area (SMA) and anterior insula (AI), regions implicated in conflict detection (Botvinick, Cohen, & Carter, 2004; Garavan, Ross, Murphy, Roche, & Stein, 2002) and social pain (Eisenberger & Lieberman, 2004; Eisenberger, Lieberman, & Williams, 2003), are associated with updating opinions in response to being misaligned with group members (Berns et al., 2010; Klucharev et al., 2009; Tomlin et al., 2013). Stronger causal support for this account comes from work by Klucharev and colleagues (2011), who demonstrated that down regulation, or disruption of the posterior medial frontal cortex (pMPF), overlapping with the dACC and SMA, using transcranial magnetic stimulation (TMS) decreased susceptibility to social influence (Klucharev, Munneke, Smidts, & Fernández, 2011). The authors suggest that these regions are involved in prediction error involved in reinforcement learning. In this context, prediction error refers to the difference between expected and obtained outcomes (Schultz, 2006), which guides learning and future decisions. For example, in a conformity context, a person may anticipate that others would share similar preferences, however finding out others diverge from your own opinion may lead to activity in neural regions involved in conflict detection, which may signal a prediction error, and prompt behavior change. These results provide strong evidence that core regions including the dACC and SMA are involved in social influence. Taken together, these studies provide evidence for the involvement of social pain or conflict detection regions (referred to as conflict detection throughout the rest of the dissertation) in social influence processing and conformity, through direct manipulation of social influence in the scanner and using TMS.

Positive valuation/reward network. In addition to the involvement of conflict monitoring and social pain, social influence processing and conformity may be attributed to the positive value placed on relationships with others (Baumeister & Leary, 1995) or changes in value of the stimuli (Zaki et al., 2011), thus motivating preference or behavior change in response to social influence through social rewards and punishments (Falk, Way, & Jasinska, 2012). Changing preferences or behaviors in response to social feedback may be motivated by expected or experienced reward attributed to social belonging or to changes in perceived value of the underlying stimuli (Ruff & Fehr, 2014). Consistent with these accounts of social influence, studies of conformity have demonstrated that activity in regions implicated in reward and positive valuation (Bartra, McGuire, & Kable, 2013), including the ventral medial prefrontal cortex (VMPFC) and ventral striatum (VS), have been associated with social influence (Campbell-Meiklejohn et al., 2010; Zaki et al., 2011). This account of social influence has also been extended to predict conformity outside of the neuroimaging environment. In other words, individual differences in sensitivity of the brain's reward system were associated with greater conformity to the specific norms expressed by peers in a different context (Beard et al., under review). Overall, these studies suggest that social influence involves neural mechanisms associated with positive valuation or reward processing (referred to as reward sensitivity throughout the rest of the dissertation).

Mentalizing network. Next, both sensitivity to social rewards and social threats require considering the mental states of others (i.e., mentalizing). Thus, social influence may be associated with cognitive processing such that the more a person considers the mental states of others the more likely they are to conform. However, increased mentalizing may also take the form of counter arguing and therefore could suggest that those who are more likely to mentalize are less likely to conform. A small number of studies have begun to find evidence for the role of mentalizing in relation to social influence processing and conformity (Cascio, O'Donnell, et al., 2015; Welborn et al., 2015). For example, research by Cascio and colleagues (2015) examined neural activity when processing social feedback, finding that activity in the temporoparietal junction (TPJ) was associated with processing divergent social feedback compared to convergent social feedback (Cascio, O'Donnell, et al., 2015). In addition, research by Welborn and colleagues (2015) examined conformity when making preferences about art work, finding that activity in the TPJ and dorsomedial prefrontal cortex (DMPFC) was associated with processing peer feedback compared to no social feedback (Welborn et al., 2015). Similar to the previous study, mentalizing activity was associated with social feedback that was divergent from the participant. Overall, these studies suggest that considering the mental states of others, or perceiving how others want you to behave may be associated with social influence.

The current study

The current study aims to expand and clarify our understanding of social influence processing and conformity by conducting a large scale fMRI study that examines the neural mechanisms associated with social influence by: 1) examining which brain networks most consistently respond to social norms that suggest a person is misaligned with the group (processing); 2) examining which brain networks most consistently respond to social norms that suggest a person is aligned with the group (processing); and 3) examining which brain networks are most central to conforming to social influence (conformity).

Methods

Eligible participants were recruited across 5 studies, including two adolescent samples (N_{smple1} = 78, $N_{sample2}$ = 104) and three young adult samples ($N_{sample3}$ = 59, $N_{sample4}$=43, $N_{sample5}$ = 34). Participants in samples 1 and 2 were 16-17 adolescent males recruited from the Michigan Driver License Records through the University of Michigan Transportation Research Institute as part of a series of larger studies examining adolescent driving behavior (Simons-Morton et al., 2014). Samples 3 and 4 included young adults recruited from the University of Pennsylvania and surrounding Philadelphia, PA community. Sample 5 included young adults recruited from the University of Michigan. All participants were right-handed, did not suffer from claustrophobia, were not currently taking any psychoactive medications, had normal (or corrected to normal) vision, and did not have metal in their body that was contraindicated for fMRI.

Study design

After participants gave assent (for adolescents) or consent (for young adults) to participate in the study, they completed a number of self-report online survey measures and made initial ratings on a set of mobile game apps for our social influence task prior to the fMRI scan. These ratings served as the baseline measure of participant preferences. Next, during the fMRI scanning session participants completed the social feedback version of the social influence task, where participants rerated the same apps they rated prior to the scan, however, were shown peer feedback during the scanning session. Finally, they completed additional post-scan online survey measures. Although the broader study designs and procedures differed across the individual studies, the target task and procedures (i.e., social influence task) were similar across all studies; details are given in the task section below.

Social influence task

We developed a social influence task for the fMRI environment to examine neural correlates of social influence on decisions about what to recommend to others. The task elicits neural processes associated with sharing online recommendations for a mobile game website and manipulates social feedback regarding the recommendations of peers. The task stimuli consist of real puzzle based game app titles, images and their associated descriptions acquired from the iTunes App Store. Actual apps from the App Store were used in order to maximize external validity and engagement for the target participants (young adults), maintain a sense of realism and present a product that adolescents and young adults are likely to buy and rate online in real life. As part of the task, participants were exposed to information that was available at the

App Store-- game titles, logos, and brief descriptions of the games. Games from one category (puzzle based games) were used in order to reduce strong preferences for one particular game genre over another (e.g., shooter game versus sports games) and all game descriptions were limited to a consistent two sentence structure (e.g., Zombie Grandmother: "*Fight your way through the army of the Undead blasting them with fireballs, cutting ropes, and breaking chains. Defeat your main target, the Zombie Grandmother*!").

Participants completed two rounds of the social influence task. First, an initial set of recommendation intentions were recorded during a pre-scan session in which participants learned about the games. During the initial rating session participants were asked to give their preliminary recommendations on 80[2] mobile game apps (previously unknown to the participants) in response to a prompt asking "*how likely would you be to recommend the game to a friend*". Participants rated the games on a 1 to 5 Likert scale, where 1 represented "*wouldn't recommend*" and 5 represented "*would recommend*". The 80 trials were randomly ordered within participants (figure 2.1).

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[2] Note: Sample 3 participants made ratings for 60 mobile phone apps but other elements of the task were the same.

Figure 2.1. Social influence task (initial ratings, made before the fMRI scan)

Round 1: **Pre-scan** baseline ratings

Zombie Granny

Fight your way through the army of the Undead blasting them with fireballs, cutting ropes, and breaking chains. Defeat your main target, the Zombie Grandmother!

Wouldn't Recommend 1 2 3 4 5 Would Recommend

Initial Exposure to Game App
(Randomly Ordered)

Zombie Granny

Fight your way through the army of the Undead blasting them with fireballs, cutting ropes, and breaking chains. Defeat your main target, the Zombie Grandmother!

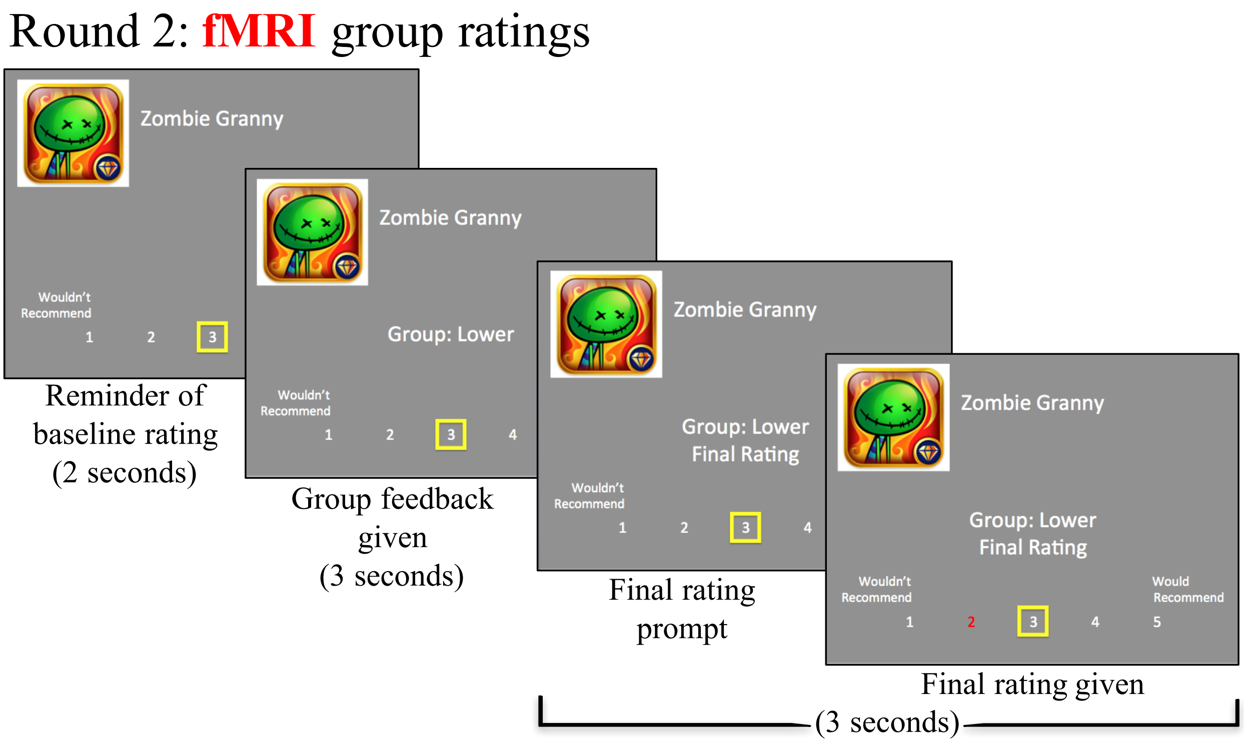
Wouldn't Recommend 1 2 3 4 5 Would Recommend

Baseline Rating of Game App Given

Note: Example of initial pre-scan phase of the social influence task. Recommendations were self-paced, giving the participant time to read the title, game description, and view the logo. Once a recommendation was made the rating score was highlighted in red and then the next trial started.

Next, during the fMRI session participants completed a second round of the social influence task, which occurred approximately 40 minutes after the participant made the initial recommendation ratings. Participants were told that they would be re-rating the same 80 mobile game apps to be recorded for a review website, however this time participants would be shown the title, logo, and a reminder of how they initially rated the game. Participants were instructed that they would then be shown information about whether their peers in the study were more likely, less likely, or equally likely to recommend the games to others, but that for some games, we had not yet collected recommendation information from others, so no peer recommendation information was available. Peer group recommendations were pseudo randomly computer generated in order to maintain 20 trials for each feedback type (15 trials for sample 3). Finally, participants were instructed that they would be given an opportunity to update their initial recommendations if they wished, and to lock in a final response in the scanner. In other words, during the fMRI portion of the task, each game rating block consisted of three parts. Consistent with these instructions, in the scanner, participants first saw a reminder of the game using the title and logo along with a reminder of how they initially rated the game (2 seconds). Next participants were exposed to manipulated peer group recommendations relative to their own, within subjects (*different*, *same, or not rated*; 3 seconds). Finally, participants were asked to lock in a final recommendation for each game for the website (3 seconds; figure 2.2).

Figure 2.2. Social influence task (group ratings)



Note: Example of the fMRI peer group feedback phase of the social influence task. Participants initially saw the game app (logo and tittle) along with their initial recommendation (boxed in yellow). Next, participants saw the peer group feedback (*higher, lower, same,* or *not rated*), followed by a final rating prompt. Once a final recommendation was made the rating score was highlighted in red.

In addition, we took several steps to increase the plausibility of the task: participants were told that we were conducting a marketing study in order to understand how relatively unknown apps become popular given that when they are introduced on sites such as iTunes there is generally very little information to make purchasing decisions. Also, participants were specifically told that we were interested in how they made their recommendations based on exposure to limited information and that we wanted them to give their recommendations for their peers as they would on the type of mobile game site from which the app descriptions were originally pulled.

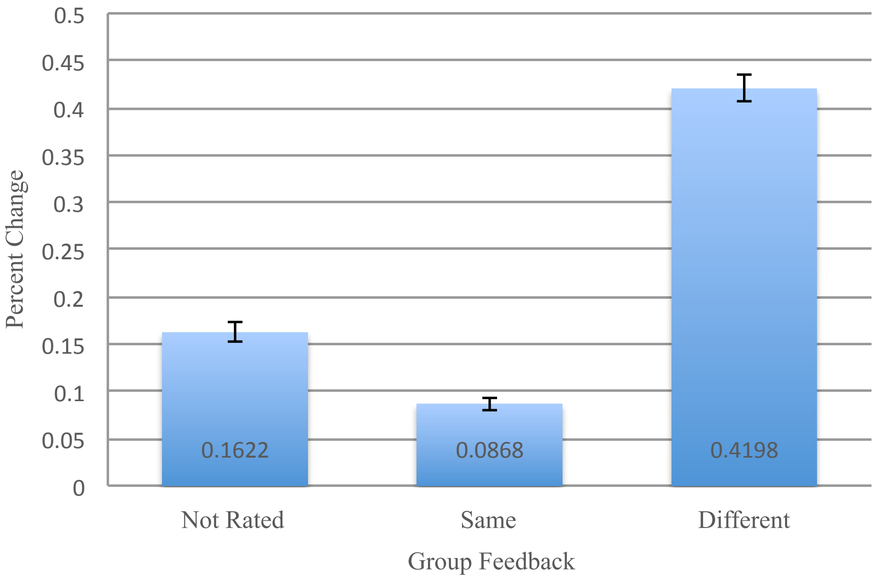
fMRI data acquisition

Imaging data for samples 1, 2, and 5 were acquired using a 3 Tesla GE Signa MRI scanner. Functional images were recorded using a reverse spiral sequence (TR = 2,000 ms, TE = 30 ms, flip angle = 90°, 43 axial slices, FOV = 220 mm, slice thickness = 3 mm; voxel size = 3.44 mm x 3.44 mm x 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = .86 mm x .86 mm x 3.0 mm) and high-resolution T1-weighted images (spoiled gradient echo; 124 slices; slice thickness = 1.02 mm x 1.02 mm x 1.2 mm) for use in coregistration and normalization. Imaging data for samples 3 and 4 were acquired using a 3 Tesla Siemens Trio scanner. Functional images were recorded using a reverse spiral sequence (TR = 1,500 ms, TE = 25 ms, flip angle = 70°, 54 axial slices, FOV = 200 mm, slice thickness = 3 mm; voxel size = 3.0 mm x 3.0 mm x 3.0 mm). We also acquired high-resolution T1-weighted images (MPRAGE; 160 slices; slice thickness = 0.9 x 0.9 x 1.0 mm) for use in coregistration and normalization.

Manipulation check

Differences in peer group feedback. A repeated measures analysis of variance (ANOVA) was run to examine whether there were significant differences in the proportion of time participants changed their recommendations in response to group feedback (*not rated*, *same*, and *different*). Results indicated that the three feedback conditions were significantly different from one another ($F(2,270)=296.23$, $p<.001$), such that participants changed their recommendation most often when receiving *different* feedback ($M = 41.98\%$, $SD = 22.35\%$), compared to the *same* ($M = 8.68\%$, $SD = 11.19\%$; $F(1,271)=578.53$, $p<.001$) or no social feedback ($M = 16.22\%$, $SD = 17.10\%$; $F(1,271)=89.23$, $p<.001$) (figure 2.3).

Figure 2.3. Recommendation change



Note: Proportion of time participants changed their recommendation in response to peer group feedback. Significant differences were found between feedback conditions (*not rated*, *same*, and *different*). Error bars represent stand errors of the mean.

Data analyses

Quality checking. Quality checking of the brain data was done prior to the preprocessing step and after to ensure results are not driven by abnormalities related to data acquisition or preprocessing (e.g., scanner artifacts). All brain images were visually inspected for signal dropout or other abnormal data. In addition, motion parameters from SPM were examined and no runs displaying greater than 3mm (translation) or 2 degrees (rotation) of head movement during a task run were used. Overall, a total of 13 participants from sample 2 did not participate in the fMRI portion of the study and 56 participants across samples 1-5 were excluded due to excess head motion, poor image quality, or inability to create the contrasts of interest due to behavioral results (sample 1=11, sample 2=25, sample 3=10, sample 4=2, and sample 5=8). Thus, the final fMRI sample size included 249 participants.

Preprocessing. Functional data was pre-processed and analyzed using Statistical Parametric Mapping (SPM8, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). To allow for the stabilization of the BOLD signal, the first four volumes (eight seconds) of each run were discarded prior to analysis. Functional images were despiked using the 3dDespike program as implemented in the AFNI toolbox. Next, data were corrected for differences in the time of slice acquisition using sinc interpolation; the first slice served as the reference slice. Data was then spatially realigned to the first functional image. We then co-registered the functional and structural images using a two-stage procedure. First, in-plane T1 images were registered to the mean functional image. Next, high-resolution T1 images were registered to the in-plane image. After coregistration, high-resolution structural images were skull-stripped using the VBM8 toolbox for SPM8 (http://dbm.neuro.uni-jena.de/vbm), and then normalized to the skull-stripped MNI template provided by FSL (“MNI152_T1_1mm_brain.nii”). Finally, functional images were smoothed using a Gaussian kernel (8 mm FWHM).

Statistical Modeling. Data were modeled at the single subject level using the general linear model as implemented in SPM8. We then modeled the three-second period during which participants were exposed to the peer feedback as a boxcar (duration = 3 sec). Specifically, we crossed participants’ responses to group feedback using three regressors: *not rated*, *same*, and *different* (*higher+lower*), with whether the participant changed their rating or not. For example, we used the shorthand “gDifferent” to indicate a block during which a participant receives *higher* or *lower* feedback during the group feedback trial. Conformity was defined as changing a rating in response to *different* peer group feedback. We modeled conformity by crossing the group feedback conditions noted above with outcomes pertaining to whether participants updated their initial rating or not following feedback about group ratings (*change* and *no change*). In other words, we had two regressors for each feedback condition noted above, depending on whether or not the participant changed their rating for that trial, resulting in six focal regressors crossing group feedback condition and whether the participant changed their final rating or not. Two of the possible combinations gNotRated_bChange and gSame_bChange did not have sufficient instances across participants to be modeled on their own and so the few instances where this occurred, therefore we grouped this data with trials where no response was recorded under an ‘Other’/nuisance regressor condition.

The six rigid-body translation and rotation parameters derived from spatial realignment were also included as nuisance regressors. Data was high-pass filtered with a cutoff of 128s. Volumes were weighted according to the inverse of their noise variance using the robust weighted least squares toolbox (Diedrichsen, Hashambhoy, Rane, & Shadmehr, 2005).

Whole brain analyses. Whole brain analyses were conducted in order to: 1) examine which brain networks most consistently respond to social norms that suggest a person is misaligned with the group (processing); 2) examine which brain networks most consistently respond to social norms that suggest a person is aligned with the group (processing); and 3) examine which brain networks are most central to conforming to social influence (conformity). The current analyses will make distinctions between operational definitions of conformity. Including contrasts that compare changing an initial opinion to adhere to a divergent group norm versus maintaining one's original position in the face of divergent peer norms (i.e., holding constant divergent peer feedback and examining the effect of change), and contrasts that compare changing an initial position to adhere to a group norm versus maintaining one's original position in the face of similar peer feedback (i.e., holding constant final agreement with the group and examining the effects of having to move to become aligned). To do this we examined neural activity during the contrasts (gDifferent > gNotRated, gSame > gNotRated, gDifferent > gSame, gSame > gDifferent, gDifferent_bChange > gDifferent_bNoChange, gDifferent_bChange > gSame_bNoChange, and gDifferent_bNoChange > gSame_bNoChange), controlling for study (contrast definitions are outlined below). Results from the first level models were combined at the group level using a random effects model implemented in SPM8. All whole brain analyses were corrected for multiple comparisons using the false discovery rate (FDR), $p<.05$, $k>20$. In addition, to balance concerns about type I and type II error, we also explored a less conservative uncorrected threshold to explore potential regions worth pursuing moving ahead for null FDR results ($p=.005$, $k>20$). All coordinates will be reported in MNI space.

Processing social feedback (gDifferent > gNotRated): This contrast will examine neural processes associated with receiving social feedback that the participant is misaligned with peers, controlling for processes associated with considering the games and the act of making ratings, without social feedback.

Processing social feedback (gSame > gNotRated): This contrast will examine neural processes associated with receiving social feedback that the participant is aligned with, controlling for processes associated with considering the games and the act of making ratings, without social feedback.

Processing social feedback (gDifferent > gSame): This contrast will examine neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers. Thus, comparing the difference between receiving divergent versus convergent social feedback.

Conformity (gDifferent_bChange > gDifferent_bNoChange): This contrast will examine neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial ratings when misaligned with peers. Thus, this contrast will examine neural processes associated with the decision to change versus not change one’s opinion when confronted with divergent social feedback, which holds the type of social feedback constant while examining differences in behavior.

Conformity (gDifferent_bChange > gSame_bNoChange): This contrast will examine neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial ratings when aligned with peers. Thus, this contrast will examine neural processes associated with conforming to divergent social feedback versus conforming to convergent social feedback. In other words, this contrast captures neural processes that contribute to adhering to peers depending on whether the participant previously agreed or disagreed with the social feedback, which holds agreeing with peer opinions constant while examining differences in having to change versus not change to adhere to peer opinions.

Unwilling to conform (gDifferent_bNoChange > gSame_bNoChange): This contrast will examine neural processes associated with maintaining initial ratings when misaligned with peers, compared to processes associated with maintaining initial ratings when aligned with peers. Thus, this contrast captures neural activity associated with maintaining one's initial opinion when confronted with convergent versus divergent social feedback.

Results

Whole brain analyses

First, in order to expand and clarify our understanding of social influence processing and conformity the current study included a series of whole brain analyses: 1) that examined which brain networks most consistently respond to social norms that suggest a person is misaligned with the group (processing); 2) examined which brain networks most consistently respond to social norms that suggest a person is aligned with the group (processing); and 3) examined which brain networks are most central to conforming to social influence (conformity). In addition, this set of analyses will be used in the construction of our functional ROIs in later dissertation chapters.

Processing social feedback

Whole brain$_{\text{(gDifferent > gNotRated)}}$. First, we examined which brain regions were associated with processing social norms that suggest a person is misaligned with the group. Neural activity in the SMA showed significantly greater activity when receiving social feedback that the participant is misaligned with peers compared to processes associated with considering the games and the act of making recommendations, without social feedback. In addition, neural activity in the superior temporal gyrus was less active when receiving social feedback that the participant is misaligned with peers compared to processes associated with considering the games and the act of making recommendations, without social feedback (table 2.1, figure 2.4).

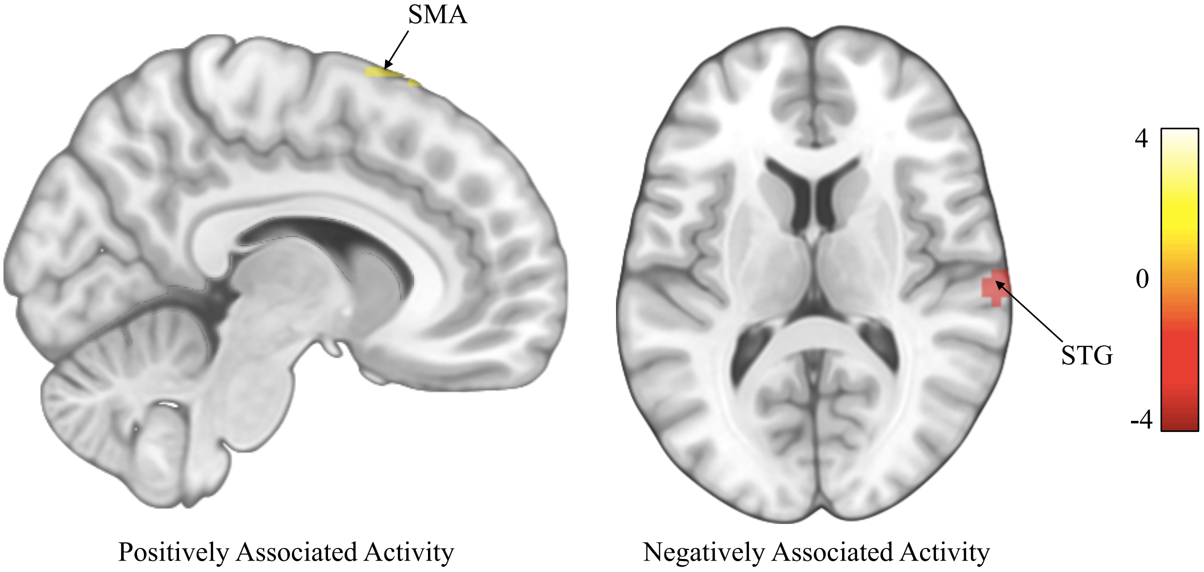
Table 2.1. gDifferent > gNotRated

Positively associated regions	hemisphere	x	y	z	k	t(247)
SMA	R/L	8	15	70	23	5.05

Negatively associated regions	hemisphere	x	y	z	k	t(247)
superior temporal gyrus	R	66	-19	10	20	-5.09

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Figure 2.4. gDifferent > gNotRated



Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Whole brain$_{(\text{gSame > gNotRated})}$. Second, we examined which brain regions were associated with processing social norms that suggest a person is aligned with the group compared to processes associated with considering the games and the act of making recommendations, without social feedback. Results did not reveal any significant differences between processing social norms that suggest a person is aligned with the group compared to no social feedback[3].

Whole brain$_{(\text{gDifferent > gSame})}$. Furthermore, we examined the difference in neural activity when processing social feedback that the participant was misaligned with the group compared to social feedback that the participant was aligned with the group. This contrast controls for receiving social feedback, and examines the effect of the feedback diverging from the participant's initial opinion. Results indicated that the SMA, DMPFC, dACC, middle frontal gyrus (MFG), and inferior frontal gyrus (IFG) were significantly more active when receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers. For a full list of regions see

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[3] Note: When examined at a reduced threshold (*p*=.005, *k*>20, uncorrected) significant activity in the superior temporal gyrus, paracentral lobule, and medial prefrontal cortex (MPFC) were associated with no social feedback compared to convergent social feedback (table A1).

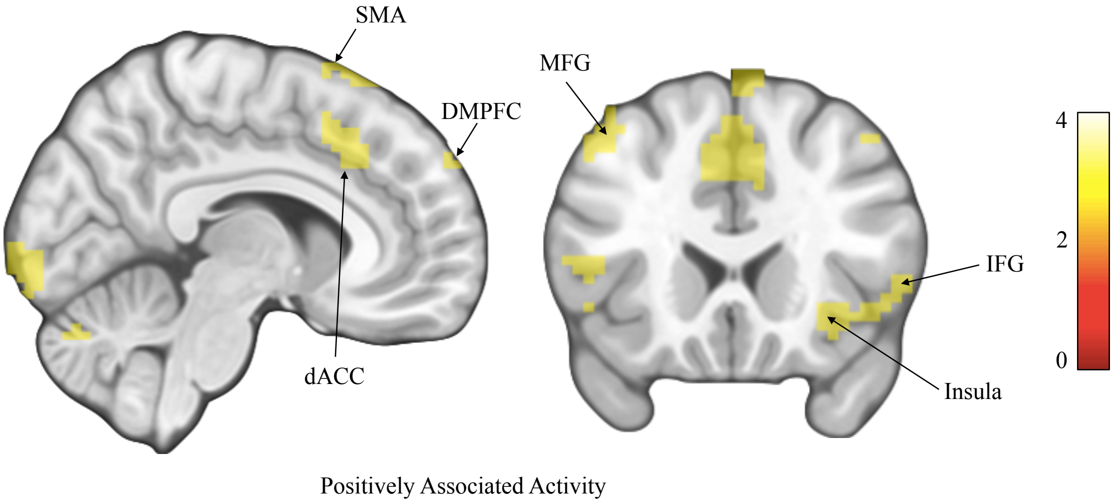
table 2.2, figure 2.5. There were no significant regions associated with social feedback that the participant is aligned compared to being misaligned with peers.

Table 2.2. gDifferent > gSame

Positively associated regions	Hemisphere	x	y	z	k	t(247)
SMA / DMPFC / dACC	R/L	1	22	46	254	5.17
occipital lobe / cerebellum / fusiform gyrus / inferior temporal gyrus	R/L	39	-91	1	1545	5.08
IFG	L	-37	63	-8	35	4.03
IFG	L	-47	19	7	42	3.74
IFG / insula	R	32	22	-8	35	3.38
MFG	R	32	60	22	93	4.04
MFG	R	42	5	61	58	3.71
MFG	L	-44	22	52	26	3.7
superior parietal lobule	L	-30	-67	64	28	3.98
superior parietal lobule / angular gyrus	R	29	-71	61	81	3.7
angular gyrus	R	35	-71	43	22	3.45

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Figure 2.5. gDifferent > gSame



Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Conformity

Whole brain$_{\text{(gDifferent\_bChange > gDifferent\_bNoChange)}}$. Next, we examined whether neural regions differed when participants received social feedback that they were misaligned with peers and participants conformed to that feedback compared to when participants maintain their initial recommendation. Results did not reveal any neural regions that were significantly more or less active when conforming to peer feedback when misaligned with peers compared to processes associated with maintaining initial recommendations when misaligned with peers[4].

Whole brain$_{\text{(gDifferent\_bChange > gSame\_bNoChange).}}$ Finally, we examined whether neural regions differed when participants received social feedback that they were misaligned with peers and participants conformed to that feedback compared to when received social feedback that they were aligned with peers and participants maintained their initial recommendation. In other words, this contrast holds constant being in line with peers while varying whether the participant had to change their rating or not to align with others. Results indicated that the SMA, DMPFC, dACC, MFG, IFG, and insula were significantly associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned. For a full list of activations see table 2.3, figure 2.6.

Table 2.3. gDifferent bChange > gSame bNoChange

Positively associated regions	hemisphere	x	y	z	k	t(247)
SMA / DMPFC / dACC	R/L	1	22	46	404	5.03
insula / IFG / MFG	R	46	19	49	430	4.10
IFG	L	-37	63	-8	127	4.43
IFG	L	-54	22	10	63	3.75
IFG	R	46	56	-2	136	3.70
MFG	L	-44	22	52	149	4.80
occipital lobe / cerebellum / superior parietal lobule / angular gyrus / precuneus	R/L	-33	-84	-20	2478	5.06
superior parietal lobule	L	-26	-67	64	134	4.60

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

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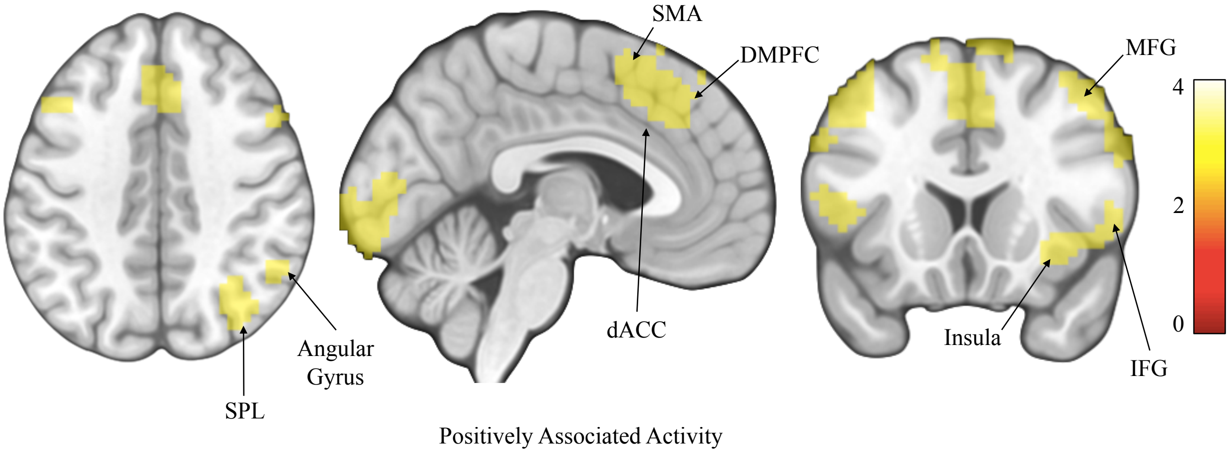
[4] Note: When examined at a reduced threshold (*p*=.005, *k*>20, uncorrected) results demonstrated that increased activity in the TPJ, IFG, and precuneus were associated with conforming to divergent social feedback compared to when participants maintain their initial recommendation (table A2).

Figure 2.6. gDifferent bChange > gSame bNoChange



Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Unwilling to conform

Whole brain$_{\text{(gDifferent\_bNoChange > gSame\_bNoChange).}}$ This contrast was conducted to address alternative explanations for our primary contrasts of interest. Specifically, we observed robust differences in the conformity contrast (gDifferent_bChange > gSame_bNoChange), which examines differences in changing versus not changing to adhere to peer opinions, while holding constant agreeing with peer opinions. However, although this contrast conceptually holds constant agreeing with peer opinions, it varies both the type of social feedback received (gDifferent vs. gSame) and in the action taken by the participant (bChange vs. bNoChange). Therefore, we also tested whether findings associated with conformity defined in this way could be explained merely by the presence of divergent peer feedback, even if the participant did not change their final rating. To do this, we examined neural processes associated with unwillingness to conform in the face of divergent peer feedback compared to maintaining the same rating following convergent peer feedback (gDifferent_bNoChange > gSame_NoChange). Results did not reveal any neural regions that were significantly more or less active when maintaining one's initial rating when misaligned with peers compared to processes associated with maintaining initial recommendations when aligned with peers, suggesting that the processes observed in the original conformity contrast (gDifferent_bChange > gSame_bNoChange) are not fully explained by the presence of divergent feedback. However, at reduced thresholds (*p*<.005, *k*>20) differences were witnessed in the SMA, SFG, and MFG, such that increased activity was associated with maintaining one's initial rating in the face of divergent compared convergent social feedback (table A3). Consistent with the direct comparison of gDifferent_bChange > gDifferent_bNoChange, this implies that divergent social feedback regardless of whether or not a person conforms may activate regions associated with conflict detection but to different extents depending on whether someone conforms.

Discussion

The current study aimed to expand and clarify our understanding of social influence processing and conformity by: 1) examining which brain networks most consistently respond to social norms that suggest a person is misaligned with the group (processing); 2) examining which brain networks most consistently respond to social norms that suggest a person is aligned with the group (processing); and 3) examining which brain networks are most central to conforming to social influence (conformity).

Neural responses to processing divergent social feedback

First, we examined which brain networks most consistently respond to social norms that suggest a person is misaligned with the group. Results suggest that receiving social feedback that the participant was misaligned with peers is associated with activity in brain regions implicated in conflict detection and adjustment, including the SMA (gDifferent > gNotRated and gDifferent > gSame), and dACC (gDifferent > gSame) (Botvinick et al., 2004; Garavan et al., 2002). In addition, being misaligned with peers activated DMPFC (gDifferent > gSame), which is often implicated in mentalizing (Saxe, 2010). Activity in these regions is consistent with the idea that being misaligned with others may elicit activity in brain regions, which help monitor behavior, and generate a neural signal when behavioral adjustments need to be made. This process is likely guided by inferences about the mental states of others.

Past studies examining the contrast (gDifferent > gSame) have reported similar activity in regions associated with prediction error (Klucharev et al., 2009) and mentalizing (Klucharev et al., 2009; Wei, Zhao, & Zheng, 2013) when confronted with divergent social feedback compared to convergent. However, this finding has not been witnessed in all studies that have examined this contrast (Cascio, O'Donnell, et al., 2015; Nook & Zaki, 2015). In addition, prior studies have also shown that divergent compared to convergent social feedback is associated with decreased activity in the VS (Klucharev et al., 2009; Nook & Zaki, 2015), a region involved in reward sensitivity (Bartra et al., 2013), which was not observed in the current study. Past research has argued that people find convergent social feedback more rewarding or valued compared to divergent social feedback (Nook & Zaki, 2015; Zaki et al., 2011). Although this finding in the reward system makes logical sense, it has not been consistently found in other studies that have examined this contrast (Cascio, O'Donnell, et al., 2015; Wei et al., 2013). One possibility is that the nature of the stimuli being evaluated might alter the robustness of involvement of the reward system. For example, the studies that found involvement of the reward system used attractive faces (Zaki et al., 2011) and foods (Nook & Zaki, 2015) as stimuli, which may have more inherent reward value than mobile game applications.

Furthermore, two studies have examined the contrast (gDifferent > gNotRated). Similar to the current findings Welborn et al., 2015 found increased activity in the SMA and decreased activity in the superior temporal gyrus. However, both studies also found increased activity in regions associated with mentalizing (Wei et al., 2013; Welborn et al., 2015), conflict detection (Wei et al., 2013), and reward sensitivity (Welborn et al., 2015), results not witnessed in the current study when using FDR correction. It should be noted, however, that when we used a more liberal statistical threshold, activations in parts of the mentalizing and reward systems were evident, leaving open the possibility that these processes may contribute, though less robustly. Methodologically, the current findings and findings from past literature highlight that although the contrast (gDifferent > gNotRated) produces similar neural activity compared to the contrast (gDifferent > gSame), the later contrast may be more robust. Results of the contrast (gDifferent >

gNotRated) examined at a reduced threshold in appendix A, which reveal activity in regions associated with reward sensitivity and mentalizing, suggest similarities across the two contrasts. It was not obvious that contrasting receipt of divergent social feedback with convergent social feedback would produce more robust results than contrasting with the “no social feedback” condition, given that receiving convergent social feedback might be thought to be more similar to receiving divergent feedback than receiving no social feedback. That said, it is possible that the absence of affirming social feedback could prompt further consideration of others’ mental states in the context of the rest of the social influence task. This explicit characterization of activations related to each contrast in the same sample, thus represents a useful empirical advance.

Neural responses to processing convergent social feedback

Second, we examined which brain networks most consistently respond to social norms that suggest a person is aligned with peer preferences. Our results did not find any neural regions that were significantly more active when receiving social feedback that the participant is aligned with peers compared to receiving no social feedback based on an FDR correction. However, when examined at a reduced threshold activity in the superior temporal gyrus, paracentral lobule, and MPFC were associated with no social feedback compared to convergent social feedback. Although these findings should be interpreted with caution given the more liberal threshold, one possibility is that the absence of social feedback involves greater self-processing (MPFC; (Murray, Schaer, & Debbané, 2012)) compared to exposure to convergent social feedback. Although these differences are not robust enough to survive FDR correction, it does help explain why the type of contrast used to examine processes associated with social feedback and conformity can be influenced by the control condition choice. Although this has not been a focus of past neuroimaging work on normative influence and results pertaining to this contrast have not reported in previous studies, the current findings suggest that the distinction may be important. From a theory perspective, these results are also revealing; it is possible that receiving feedback that others share your opinion is the default expectation. Indeed, a large number of studies suggest that people have a strong bias to believe that others share their own opinions (Marks &

Miller, 1987). By contrast, receiving divergent peer feedback triggers robust alarm system implicated in conflict detection and mental state inference, motivating the individual to act. The similarities between receiving divergent peer feedback and no feedback may also help explain the less robust activation observed in contrasting these two conditions. Although behavioral evidence has demonstrated congeniality and related biases (Marks & Miller, 1987), neural evidence bolsters the idea that a default expectation may be that others agree with our own position, or that congenial views require less cognitive processing.

Neural responses to conformity

In addition to examining which neural regions are associated with processing social feedback, the current study also examined which regions were associated with conforming to feedback that a person is misaligned with peers. Results did not reveal any differences in activity when participants conformed to social feedback that they were misaligned with the recommendation of others compared to when they maintained their initial recommendation (corrected with FDR). However, at a less conservative threshold we found significant activity in regions associated with mentalizing (TPJ; (Saxe, 2010)) and inhibitory control (right IFG; (Aron, Robbins, & Poldrack, 2004; Simmonds, Pekar, & Mostofsky, 2008)) were associated with conforming to divergent social feedback compared to maintaining one's initial preference. Several past studies have examined this contrast and have found greater neural activity in regions associated with reward sensitivity (Cascio, O'Donnell, et al., 2015; Nook & Zaki, 2015), conflict detection (Klucharev et al., 2009; Stallen, Smidts, & Sanfey, 2013; Wei et al., 2013), and mentalizing (Wei et al., 2013). In addition, Klucharev et al., 2009 found that activity in the VS, a region associated with reward sensitivity (Bartra et al., 2013), decreased during conformity to divergent social feedback, which is attributed to decreases in reward associated with prediction error. One potential reason the current study does not demonstrate robust differences in neural activity between changing one's rating versus maintaining one's initial rating in the face of divergent social feedback may be attributed to the time point in which we examine neural activity. The current study only examines neural activity at the point of exposure to social feedback (group feedback block), however, changes in neural activity that differentiate between maintaining one's initial preference compared to conforming to divergent social feedback may not manifest until a decision is actual made (final rating block). Thus, future work may need to examine changes in neural systems between exposure to social feedback and decision-making.

Next, the current study examined which neural mechanisms were associated with conforming to feedback that a person is misaligned with peer recommendations compared to maintaining one's initial recommendation when receiving social feedback that a person is aligned with peers. This contrast holds agreeing with peer opinions constant while examining differences in having to change versus not change one's opinion to adhere to peers. Results demonstrated that overlapping regions with those that initially detect misalignment with peers, including those associated with conflict detection (SMA, dACC, and insula; (Botvinick et al., 2004; Garavan et al., 2002)), inhibitory control (IFG and MFG; (Aron et al., 2004; Simmonds et al., 2008)), and mentalizing (DMPFC, superior parietal lobule and TPJ/angular gyrus; (Saxe, 2010) were more active during conformity to misalignment compared to maintaining one's initial recommendation when aligned with peers. In addition, results from direct comparisons between decisions to conform and not conform in the face of divergent peer feedback, as well as results from our unwillingness to conform analysis tested whether findings associated with conformity were more genetally associated with viewing divergent social feedback, or were specific to conforming. Results indicated that divergent social feedback, regardless of whether or not a person conforms, may activate regions associated with conflict detection, however this may occur to different extents depending on whether or not someone conforms.

The current study also aimed to clarify differences in contrasts identified in the social influence neuroimaging literature. Our results suggest that comparisons between receiving divergent and convergent peer feedback are more robust than comparing to a "not rated" control condition. It is possible that the convergent control condition offers a cleaner control since both conditions then account for receiving some feedback. It is also possible that receiving divergent feedback and no feedback are closer to one another than receiving convergent feedback, since "no feedback" may indicate that others are less interested.

Consistent with the current findings, past studies of social influence have found activity in the TPJ/supramarginal gyrus/inferior parietal lobule, regions associated with mentalizing (Saxe, 2010), when conforming to higher social feedback compared to maintaining initial preferences when aligned with peers (Nook & Zaki, 2015). However, findings by Nook et al., 2015 also found increased activity in the thalamaus and regions associated with reward sensitivity (VMPFC; (Bartra et al., 2013)). One reason for these differences may be attributed to the specific stimuli used in the Nook et al., 2015 study. The current study examined game apps, whereas Nook et al., 2015 examined neural responses to food, thus different types of rewards (e.g., primary versus secondary) might evoke different neural responses during conformity. Future research comparing different types of rewards might help shed light on whether social influence related to different classes of ideas and objects are processed differently.

Strengths and limitations

The current study examined a large-scale fMRI study (*N*= 249) in order to determine which neural mechanisms underlie processing social norms and which neural mechanisms are associated with conformity. This is a substantial increase in power from previous studies, which had average sample sizes of 34 participants, ranging from 18-86, thus the results presented provide stronger evidence aimed at understanding the underlying mechanisms involved in social influence. The current study identified key brain regions involved in processing social feedback (DMPFC, implicated in mentalizing and the dACC and SMA, implicated in conflict detection) and regions associated with conforming to divergent social feedback (IFG and MFG, implicated in inhibitory control, DMPFC, implicated in mentalizing). In addition, functional meta-analytic regions of interest (ROIs) have become increasingly important in understanding the brain and results from the current study will be valuable to future studies, serving as functional masks to evaluate individual differences in activity in processing social feedback and conformity or seed regions for functional connectivity analyses.

However, the current study is also limited in a number of ways. The lack of robust results in the contrast (gDifferent_bChange > gDifferent_bNoChange) makes it difficult to know whether there are different neural processes involved in updating versus maintaining one's preferences in response to divergent social feedback. One possibility is that changes in neural activity that differentiate between maintaining one's initial preference compared to conforming to divergent social feedback, may not manifest until a decision is actual made. Future research specifically designed to examine neural processes as they change over time should examine this question. Alternatively, the direction of social feedback (higher versus lower), which was combined in the current study as different social feedback, may be masking significant neural activity if higher and lower social feedback is processed differently in the brain. Additional analyses that examine higher and lower feedback independently may shed light on whether differences exist.

Although we did not find robust differences in in the contrast (gDifferent_bChange > gDifferent_bNoChange), we did examine which regions were associated with conforming compared to maintaining one's initial rating in response to feedback that a person is misaligned with peers at reduced thresholds. We found significant activity in regions associated with mentalizing (TPJ; (Saxe, 2010)) and inhibitory control (right IFG; (Aron, Robbins, & Poldrack, 2004; Simmonds, Pekar, & Mostofsky, 2008)) were associated with conforming to divergent social feedback compared to maintaining one's initial preference.

Next, neural activity was not examined when initial preferences were given. Thus, the current study cannot speak to which processes contribute to formulating initial preferences or dislikes for an app. Future research may consider examining this data in order to compare how changing a preference in response to normative influence is similar or different compared to neural processes associated with the initial formulation of preferences (i.e., changing from not holding a preference to holding a preference). This may help researchers better understand how preferences are formed and maintained.

In addition, neural regions do not work in isolation and therefore future research should examine how these key regions found in the current study operate in a neural network (i.e., which neural regions are functionally activated in conjunction with the key regions found in our analyses). Multivariate analyses may reveal findings that are not apparent with the general liner model approach taken here in which we average across brain activity in space and time.

Furthermore, the current data are limited in diversity based on the primary focus of the individual studies. For example, the adolescent samples were recruited to examine driving behaviors in males and therefore the current dataset consists of primarily males (172 males and 77 females). In addition, the current dataset primarily consisted of Caucasian participants (157) compared to 55 people who identified as minorities and 37 who did not respond to our race question. Thus, future research should aim to better represent the racial diversity in the United States. Finally, the focus of the current study was restricted to adolescents and young adults (16 to 34 years old), therefore results can only speak to these age groups.

Finally, it should be noted that although the current study interprets the specific regions identified in the whole brain analyses, these are not the only interpretations. Forward inference identifies regions that are associated with the specific processes we manipulate (i.e., processing social feedback and conformity). Our speculations about the related cognitive functions of these regions (e.g., conflict detection, mentalizing) rely on *reverse inferences*. Reverse inferences are offered for the purpose of advancing theory, however, each brain regions supports multiple functions. Therefore caution should be taken when interpreting reverse inferences, and the psychological functions ascribed to each brain region (beyond what we directly manipulated) should be interpreted as one of several possible explanations (Poldrack, 2006). Specifically, in the current discussion we suggest activity in the dACC, SMA, and DMPFC is associated with conflict detection and mentalizing, respectively. However, these are not the only processes these regions are involved in. For example, activity in the SMA has also been associated speech and language processing (Hertrich, Dietrich, & Ackermann, 2016), and activity in the dACC has also been associated with value processing (Kolling et al., 2016), among other functions. Therefore, issues pertaining to reverse inference apply to all the results discussed in the current dissertation. Based on our prior theory, we will discuss regional activation in terms of specific neurocognitive functions in the remainder of the dissertation, but additional research is needed to test these explanations further.

Conclusion

Overall, the current study aimed to expand and clarify our understanding of social influence. We found that key regions involved in conflict detection (SMA and dACC; (Botvinick et al., 2004; Garavan et al., 2002)) and mentalizing (DMPFC; (Saxe, 2010)) were more active when processing social feedback that the individual was misaligned with peers than aligned with peers. In addition, responding to divergent peer feedback through conformity was associated with activity in regions associated with conflict detection (SMA and dACC; (Botvinick et al., 2004; Garavan et al., 2002)) and mentalizing (DMPFC; (Saxe, 2010)) when processing social feedback that a person is misaligned with peers, however conforming to those social norms also involves processes associated with inhibitory control (IFG and MFG; (Aron et al., 2004; Simmonds et al., 2008)). Taken together these findings suggest that processing divergent social feedback involves detecting conflict with others coupled with considering the mental states of others. Conforming to that social feedback involves processes associated with inhibitory control, potentially to inhibit or override one’s own preferences. The current findings provide a baseline in which the studies that follow can examine how these neural regions may differ depending socio-demographic characteristics, such as the different phases of development (e.g., teens versus adults; Chapter 3) or socioeconomic background (high versus low; Chapter 4).

CHAPTER 3. NEURAL CORRELATES OF SOCIAL INFLUENCE ACROSS SOCIOECONOMIC STATUS

Introduction

People routinely change their preferences and behaviors in response to social influence (Cialdini & Goldstein, 2004). Not all groups are equally susceptible to social influence, however, and may be influenced through different neurocognitive pathways. One potential moderator of social influence processing and conformity is socioeconomic status (SES). However, research has not yet examined whether SES affects neural processes associated with social influence. Therefore, the aim of the current study is to examine common and distinct neural mechanisms associated with social influence in individuals from higher and lower SES backgrounds. Understanding the relationship between social environments, brain, and behavior may begin to shed light on the underlying factors that contribute to behavioral disparities associated with socioeconomic status. In addition, optimal tailoring of persuasive communications and other intervention strategies aimed at social influence would benefit from a deeper understanding of the biological mechanisms associated with commonalities and differences across SES in social influence processing (i.e., understanding that others' views differ from one's own) and conformity (updating one's own behavior or preferences to align with the group).

SES and social influence

Although the relationship between SES and health, health behavior, and educational disparities has been well documented (Hanson & Chen, 2007; Hiscock et al., 2012; Patrick et al., 2012), limited research has examined whether differences in SES background relate to differences in conformity. For example, research has demonstrated that those from higher SES backgrounds tend to be more independent or have an individualistic orientation, whereas those from lower SES backgrounds tend to have more interdependent or external orientation to the environment (Kraus, Piff, Mendoza-Denton, Rheinschmidt, & Keltner, 2012). This cognitive orientation may suggest different mechanisms through which SES moderates social influence, such that lower SES individuals may be more sensitive to social cues in general, and may conform for social reasons, whereas higher SES individuals may conform for individualistic reasons. However, it is difficult overall based on the current literature to know whether those from different SES backgrounds are differently susceptible to conformity or use different mechanisms when conforming or processing social feedback or whether differential outcomes are a byproduct of differential exposure to social cues. It is also unclear whether it is only extreme deprivation that would alter these basic processes or whether differences would be apparent across a continuum of SES.

SES and the brain

Research examining the relationship between SES and the brain is relatively new, and the majority of research on this topic focuses on neural processes associated with executive function. Initial findings from behavioral and EEG/ERP studies support the idea that disparities across SES are relevant to neural processes underlying executive function, which develop differently depending on high and low SES environments (Czernochowski et al., 2008; D'Angiulli et al., 2008; Kishiyama et al., 2009; Stevens et al., 2009). For example, differences in regions associated with working memory have been related to slower rates of learning among low compared to high SES individuals (Sheridan et al., 2012). In addition, differences in regions associated with inhibitory control have been associated with less efficient inhibition among individuals from lower compared to higher SES backgrounds (Spielberg et al., 2015). Furthermore, differences in social and cultural backgrounds have been tied to differences in sensitivity to social cues (for reviews, see (Hong & Chiu, 2001; Kraus et al., 2012)), which may be related to different brain responses to social feedback (Kitayama & Park, 2010; Tompson, Lieberman, & Falk, 2015).

Although the relationship between SES and neural correlates of social influence processing and conformity have not directly been examined, research suggests that different backgrounds and environments may train different approaches to problem solving and more generally navigating the social world. Understanding whether those from different SES backgrounds use different neural processes when conforming to social feedback, even if they do not differ in their rates of conformity, can help clarify the underlying reasons for conformity between the two groups. Furthermore, gaining this knowledge may be useful when designing normative interventions aimed at changing behaviors.

The current study focuses on parental education as our main measure of SES, being the one of the three most common measures of objective SES (education, income, and occupation) (Ensminger et al., 2000). Parental education was selected in part because parental education is straightforward and accurate to collect in young adults and adolescents and has a long history of correlating well with educational and health outcomes (Ensminger et al., 2000). In addition, results pertaining the current study capture factors associated with human capital (i.e., intellectual environment; (Beaulieu, 1992)) components of SES rather than factors associated with financial capital (income and occupation). Human capital or the intellectual environment a person grew up in likely relates to how a person learns to make decisions in their social environment. For example, theories on human capital suggest that higher educational attainment is associated with greater personal control (Mirowsky & Ross, 1998). This may suggest that those who grew up in a highly-educated household conform when they feel it is personally beneficial, whereas those who grew up with less educated parents may conform because of the external situation, thus using different learned strategies for navigating social decision-making. This idea is consistent with research showing those from higher SES backgrounds tend to be more independent, whereas those from lower SES backgrounds tend to have external orientations to the environment (Kraus et al., 2012). In the brain, this might translate into differences in conflict detection or reward sensitivity, such that those from lower SES backgrounds may find divergent peer feedback, and/or find greater value in conforming to others compared those from higher SES backgrounds. Another possibility is that those from lower SES backgrounds might employ more mentalizing and less self-related processes compared to those from higher SES backgrounds in arriving at their final preference judgments (Tompson et al., 2015).

However, given that past studies have primarily found differences in cognitive control regions between those from different SES backgrounds (Hackman et al., 2010; Lawson et al., 2014), neural systems previously associated with social influence may not be influenced by one's SES background, including reward sensitivity (Campbell-Meiklejohn et al., 2010; Zaki et al., 2011), conflict monitoring (Berns et al., 2010; Klucharev et al., 2009), and mentalizing (Cascio, O'Donnell, et al., 2015; Welborn et al., 2015). For example, processing social feedback may be a more basic process that is similar across people, and those from different SES backgrounds may differ more strongly in other areas, such as processes directly related to cognitive control. In addition, it is possible that differences might only be observed in cases where one set of participants has been more severely deprived (e.g., during development). Thus, the extent of possible similarities and differences by level of SES remains an open question.

The current study

The current study aims to extend the current literature on social influence, SES and the brain by directly examining whether SES moderates neural mechanisms associated with social influence in a two-part study. First, the relationship between SES and social influence processing will be examined in a sample (low versus high SES) specifically recruited for this purpose. Second, we will determine if the findings from part one extend to a broader set of participants by examining the relationship between SES and social influence processing using a continuous measure of SES. One potential way in which those from higher versus lower SES backgrounds may be differentially influenced by the social environment may be attributed to differential responses in the way that the brain processes social feedback and makes social decisions. Past research has shown SES influences processes associated with including processes associated with working memory (Sheridan et al., 2012) and cognitive control (Spielberg et al., 2015), and may be associated with underlying mechanisms of social influence as well. However, neural processes related to social influence may be similar if SES related differences are limited to severely deprived conditions rather than along the spectrum of SES backgrounds, or in contexts that involve strong differences in behavior across groups.

Methods part 1

Part one of the study will examine the relationship between SES (high versus low) and neural mechanisms associated with social influence using a between subjects design and sample that was specifically recruited for this purpose.

Participants

Fifty-nine participants, aged 18-31 (mean=22.62 years old, standard deviation=3.17 years; 41 females) were recruited from the University of Pennsylvania and the local Philadelphia area. We initially screened a pool of 466 respondents, of which 150 participants were eligible (77 high SES, 73 low SES). Our sample consisted of 28 low SES (9 male, 19 female; mean age = 23.28 years old, standard deviation = 3.22 years) and 31 high SES (10 male, 21 female; mean age = 22.15 years old, standard deviation = 3.11 years) participants, run on a first come, first served basis. All participants were right-handed, did not suffer from claustrophobia, were not currently taking any psychoactive medications, had normal (or corrected to normal) vision, and did not have metal in their body that was contraindicated for fMRI.

Study design

Participants were recruited into between subject (high and low SES) groups based on parental education (combined mothers' and fathers' education) based on a pre-study questionnaire (details given below). After participants gave consent to participate in the study, they completed a number of self-report online survey measures and initial ratings of mobile game applications as part of a social influence task (described in detail below) prior to the fMRI scan. Next, they received experimentally manipulated group feedback during the second part of the social influence task in an fMRI scanner, and re-rated the mobile game applications. Finally, they completed additional post-scan online survey measures.

Socioeconomic status (SES)

The primary socioeconomic status measure used was parents' education, which was part of a pre-study questionnaire. Participants were asked what level of education their father and mother had completed on 7-point scales, where 1 = less than high school, 2 = high school, 3 =

trade school, 4 = associates degree, 5 = bachelor degree, 6 = graduate degree, and 7 = unknown. Parents with an unknown level of education (response = 7) were dropped and then a combined parents' education variable was created using the average score between the father and mother. Participants were eligible to participate in the study if they had an average parental education score equal to average parental education of an associate degree or lower (low SES) or average parental education of a graduate degree (high SES). Participants with an average parental education score of a bachelor degree (5) were not eligible to participate in order to clearly differentiate the two groups (we elected an extreme groups design to increase power to detect potential group differences, given funding restrictions on total sample size).

Social influence task

The fMRI social influence task is the same as described in chapter 2. However, participants in part 1 (sample 3) were asked to make recommendations for others on 60 (recommend rating condition) rather than 80 mobile game apps. In addition, participants were asked to make ratings on the same 60 (download rating condition) mobile game apps in regards to whether they would download the app for themselves, for a total of 120 rating trials. For part 1, all trials were used in the analyses, as there were no significant differences in neural activity between the download and recommendation conditions in our whole brain analyses, corrected for multiple comparisons using FDR, $p<.05$, $k>20$. In all other parts of the dissertation, we focus only on the recommend trials since these are identical to the other samples, but focus on combined trials here to maximize power.

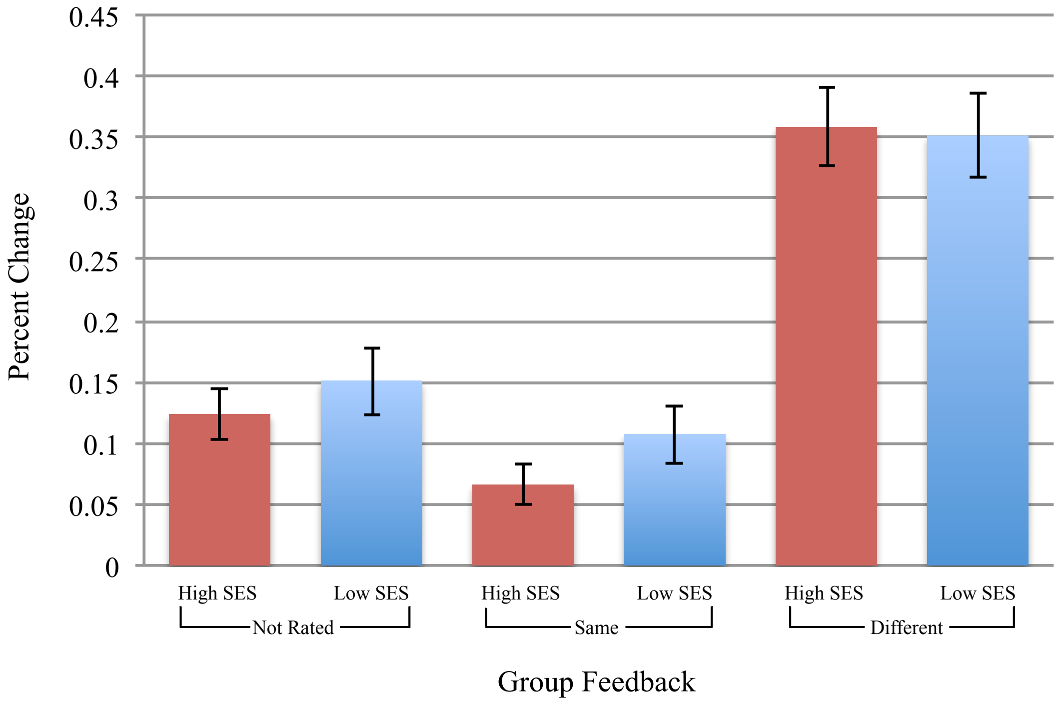
fMRI data acquisition

MRI data were acquired using a 3 Tesla GE Signa MRI scanner. Functional images were recorded using a reverse spiral sequence (TR = 2000 ms, TE = 30 ms, flip angle = 90°, 43 axial slices, FOV = 220 mm, slice thickness = 3mm; voxel size = 3.44 x 3.44 x 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = .86 x .86 x 3.0mm) and high-resolution T1-weighted images (MPRAGE; 124 slices; slice thickness = 1.02 x 1.02 x 1.2 mm) for use in coregistration and normalization.

Manipulation check

Differences in peer group feedback. A repeated measures analysis of variance (ANOVA) was run to examine whether there were significant differences in the proportion of time participants changed their rating in response to group feedback (*not rated*, *same*, and *different [combined higher and lower]*) and whether the proportion of time participants changed their rating differed by SES and rating condition (recommend versus download). Results indicated that the three feedback conditions were significantly different from one another (*F*(1,49)=66.07, *p*<.001), such that participants changed their recommendation most often when receiving *different* feedback (*M*=35.52%, *SD*=16.53%), compared to the *same* (*M*=8.45%, *SD*=9.97%; *F*(1, 50)=104.21, *p*<.001), or no social feedback (*M*=13.60%, *SD*=12.03%; *F*(1, 50)=68.56, *p*<.001) (figure 3.1). Rating condition (download versus recommend) was not significantly related to the proportion of time participants changed their ratings (*F*(1,49)=0.60, *p*=.443) and did not interact with social feedback conditions (*F*(1,49)=0.95, *p*=.335). Finally, SES (parents' education) was not significantly related to the proportion of time participants changed their ratings (*F*(1,49)=0.65, *p*=.423), and did not interact with social feedback condition (*not rated*, *same*, and *different*) (*F*(1,49)=0.40, *p*=.530), rating condition (download versus recommend) (*F*(1,49)=0.61, *p*=.440), or social feedback condition by rating condition (*F*(1,49)=0.20, *p*=.658).

Figure 3.1. Rating change across SES



Note: Proportion of time participants changed their rating in response to peer group feedback. Significant differences were found between feedback conditions (*not rated*, *same*, and *different*), however no significant differences were associated with SES. Error bars represent stand errors of the mean.

Data analysis

Quality checking. Quality checking of the brain data was done prior to the preprocessing step and after to ensure results are not driven by abnormalities related to data acquisition or preprocessing (e.g., scanner artifacts). All brain images were visually inspected for signal dropout or other abnormal data. In addition, motion parameters from SPM were examined and no runs displaying greater than 3mm (translation) or 2 degrees (rotation) of head movement during a task run were used.

Preprocessing. Functional data were pre-processed and analyzed using Statistical Parametric Mapping (SPM8, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). To allow for the stabilization of the BOLD signal, the first four volumes (eight seconds) of each run were discarded prior to analysis. Functional images were despiked using the 3dDespike program as implemented in the AFNI toolbox. Next, data were corrected for differences in the time of slice acquisition using sinc interpolation; the first slice served as the reference slice. Data was then spatially realigned to the first functional image. We then co-registered the functional and structural images using a two-stage procedure. First, in-plane T1 images were registered to the mean functional image. Next, high-resolution T1 images were registered to the in-plane image. After coregistration, high-resolution structural images were skull-stripped using the VBM8 toolbox for SPM8 (http://dbm.neuro.uni-jena.de/vbm), and then normalized to the skull-stripped MNI template provided by FSL ("MNI152_T1_1mm_brain.nii"). Finally, functional images were smoothed using a Gaussian kernel (8 mm FWHM).

Statistical Modeling. Data were modeled at the single subject level using the general linear model as implemented in SPM8. We then modeled the three-second period during which participants were exposed to the peer feedback as a boxcar (duration = 3 sec). Specifically, we crossed participants' responses to group feedback using three regressors: *not rated*, *same*, and *different* (*higher*+*lower*), with whether the participant changed their rating or not. For example, we used the shorthand "gDifferent" to indicate a block during which a participant receives *higher* or *lower* feedback during the group feedback trial. Conformity was defined as changing a rating in response to *different* peer group feedback. We modeled conformity by crossing the group feedback conditions noted above with outcomes pertaining to whether participants updated their initial rating or not following feedback about group ratings (*change* and *no change*). In other words, we had two regressors for each feedback condition noted above, depending on whether or not the participant changed their rating for that trial, resulting in six focal regressors crossing group feedback condition and whether the participant changed their final rating or not. Two of the possible combinations gNotRated_bChange and gSame_bChange did not have sufficient instances across participants to be modeled on their own and so the few instances where this occurred, therefore we grouped this data with trials where no response was recorded under an 'Other'/nuisance regressor condition.

The six rigid-body translation and rotation parameters derived from spatial realignment were included as nuisance regressors. Data was high-pass filtered with a cutoff of 128s. Volumes were weighted according to the inverse of their noise variance using the robust weighted least squares toolbox (Diedrichsen et al., 2005).

Participant matching and control variables. In an attempt to limit confounds between the primary focus of this paper (SES) and other known participant demographics (age, race, and gender), steps were taken in order to ensure demographic factors were similarly distributed across SES. First, males (low SES = 9, high SES = 10) and females (low SES = 19, high SES = 21) were evenly distributed across SES ($\chi^2(1, 59)=.00$, $p=.992$). Next, the average age was not significantly different across SES (low SES = 22.28, high SES = 22.15; $t(43)=1.14$, $p=.260$). Finally, race was similarly distributed across low (white = 18, minority = 10) and high (white = 21, minority = 8) SES ($\chi^2(1, 56)=.76$, $p=.383$). Therefore, because as planned in the study design, age, race, and gender do not differ between higher and lower SES individuals they were not used as control variables in order to conserve degrees of freedom.

Regions of interest (ROI). Regions of interest were constructed using regions most strongly associated with social influence based on the functional results in study 1 (chapter 2). Overall, only three of the five contrasts in chapter 2 revealed significant activity, therefore our ROI analyses only examined these contrasts as target regions of interest. MarsBar (Brett, Anton, Valabregue, & Poline, 2002) was used to convert these images to ROIs.

ROI analyses. Planned ROI analyses examined whether neural activity within each ROI contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) is differently activated by those from high and low SES backgrounds. The regression models and associated research questions that were analyzed are listed below. The following analyses were conducted in R (version 3.2.2).

$\text{ROI}_{(\text{gDifferent} > \text{gNotRated})} = \beta 1(\text{SES}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers is moderated by SES, controlling for processes associated with considering the games and the act of making ratings, without social feedback.

$\text{ROI}_{(\text{gDifferent > gSame})} = \beta 1(\text{SES}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers is moderated by SES. This regression captures whether those from different SES backgrounds differ in how different types of social feedback are processed.

$\text{ROI}_{(\text{gDifferent\_bChange > gSame\_bNoChange})} = \beta 1(\text{SES}) + \varepsilon$: We examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial ratings when aligned with peers is moderated by SES. This regression captures whether those from different SES backgrounds differ in processes that contribute to adhering to peers depending on whether the participant previously agreed or disagreed with the social feedback.

Whole brain analyses. Whole brain analyses examined neural activity during the contrasts (gDifferent > gNotRated; gSame > gNotRated; and gDifferent > gSame) and conforming to that feedback (gDifferent_bChange > gNotRated_bNoChange; gDifferent_bChange > gSame_bNoChange) for (low SES; high SES; and low SES – high SES). See methods section in chapter 2 for contrast definitions. Results from the first level models were combined at the group level using a random effects model implemented in SPM8. All whole brain analyses were corrected for multiple comparisons using FDR at $p<.05$, $k>20$. In addition, to balance concerns about type I and type II error, we also explored the difference models at a more liberal uncorrected threshold to explore potential regions worth pursuing moving ahead ($p=.005$, $k>20$). All coordinates are reported in MNI space.

Results part 1

ROI analyses

A series of ROI analyses examined whether processing of social feedback or conformity were moderated by SES.

Processing social feedback

$\text{ROI}_{(\text{gDifferent > gNotRated})} = \beta 1(\text{SES}) + \varepsilon$. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were moderated by SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, SES did not moderate neural activity in the functionally defined processing (gDifferent > gNotRated) ROI (β=-.11, *t*(45)=-0.73, *p*=.467, *CI*=[-.09, .04]).

$\text{ROI}_{(\text{gDifferent > gSame})} = \beta 1(\text{SES}) + \varepsilon$. Second, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by SES. Overall, SES did not significantly moderate neural activity in the functionally defined processing (gDifferent > gSame) ROI (β=.19, *t*(45)=1.29, *p*=.204, *CI*=[-.03, .12]).

Conformity

$\text{ROI}_{(\text{gDifferent\_bChange > gSame\_bNoChange})} = \beta 1(\text{SES}) + \varepsilon$. Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by SES. Overall, SES did not moderate neural activity in the functionally defined conformity (gDifferent_bChange > gSame_bNoChange) ROI (β=.13, *t*(45)=0.87, *p*=.391, *CI*=[-.02, .06]).

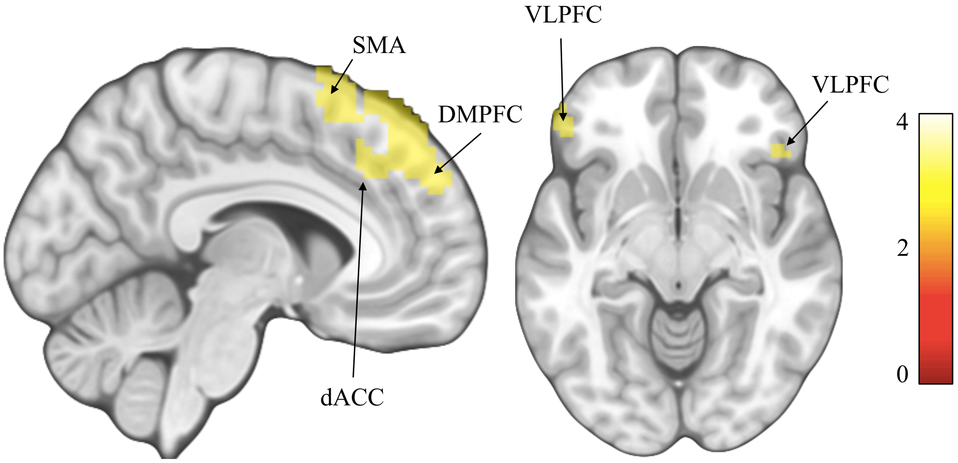
Whole brain analyses

A series of whole brain analyses examined whether processing of social feedback or conformity were moderated by SES (FDR, *p*<.05, *k*>20).

Processing social feedback

$\text{Whole brain}_{(\text{gDifferent > gNotRated})} = \beta 1(\text{SES}) + \varepsilon$. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were associated with SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, results of a conjunction analyses that examined common regions in both higher and lower SES individuals displayed activity in the SMA, DMPFC, dACC, left IFG, and right IFG (table 3.1; figure 3.2). In addition, those from lower SES backgrounds displayed less activity in the caudate and superior temporal gyrus, as well as increased activity in the inferior parietal lobule, superior parietal lobule, angular gyrus, MFG, middle temporal gyrus, and insula when misaligned with peers compared to no social feedback, activations not witnessed for those from higher SES backgrounds. See tables 3.2 (figure 3.3) and 3.3 (figure 3.4) for a full list of activations. When directly compared (low – high SES), however, no significant differences survived FDR correction between higher and lower SES individuals.

Figure 3.2. Conjunction analysis gDifferent > gNotRated (high & low SES)



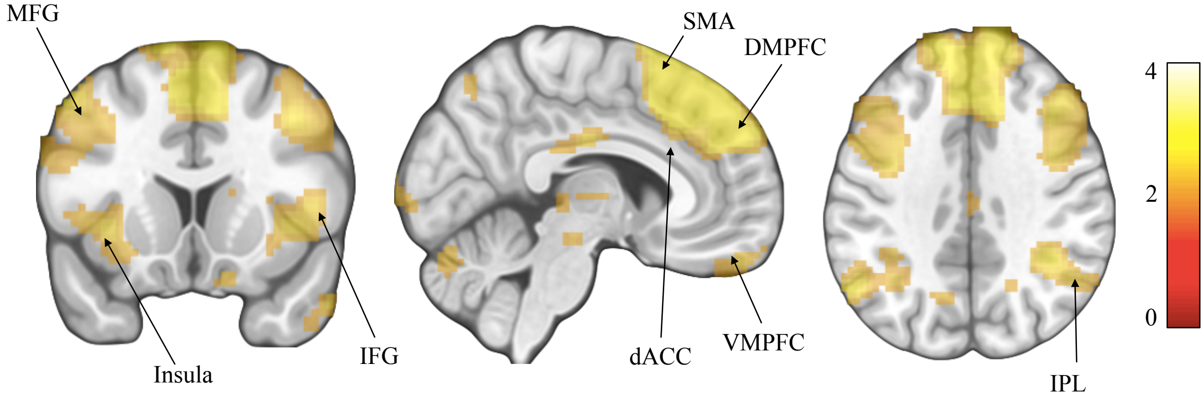
Note: Positive activations associated with gDifferent > gNotRated.

Table 3.1. gDifferent > gNotRated (conjunction high and low SES)

Positively associated regions	hemisphere	x	y	z	k
SMA / DMPFC / dACC	R/L	-24	56	28	622
DMPFC	R	12	50	40	63
IFG	R	42	23	-11	17
IFG	L	-54	38	-11	30
occipital lobe	R	36	-97	7	23

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Figure 3.3. gDifferent > gNotRated (low SES)



Note: Positive activations associated with gDifferent > gNotRated, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

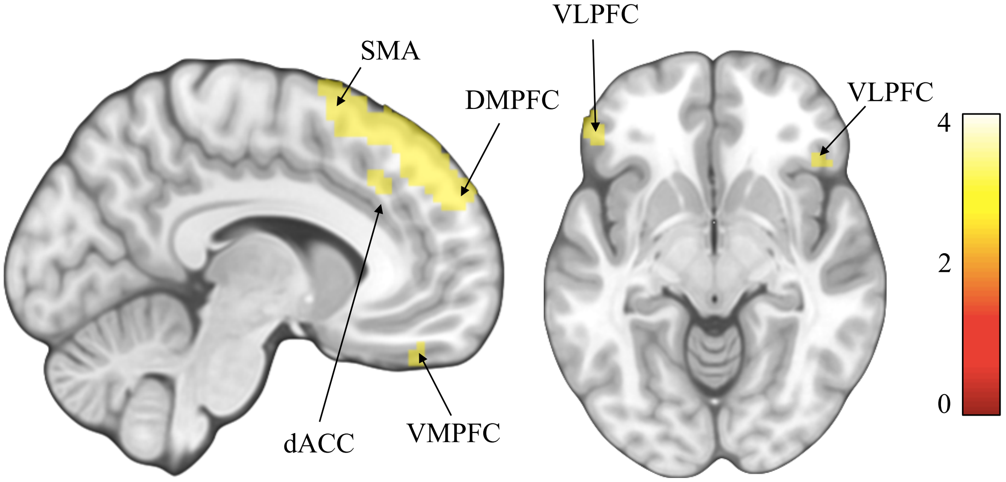
Table 3.2. gDifferent > gNotRated (low SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
inferior parietal lobule / superior parietal lobule / angular gyrus / precuneus	R	42	-46	52	1070	6.19
inferior parietal lobule / superior parietal lobule / angular gyrus / precuneus	L	-54	-64	46	965	5.50
SMA / DMPFC / dACC / insula / IFG / MFG / VMPFC	R/L	-9	35	61	4589	8.09
insula / IFG / MFG	L	-39	56	-5	1500	5.59
middle temporal gyrus	R	60	-34	-11	296	4.27
middle temporal gyrus	L	-51	-31	-5	379	3.95
cerebellum / fusiform / inferior occipital lobe	L	-30	-67	-29	2434	4.89
PCC	R/L	3	-16	31	119	3.79

Negatively associated regions	hemisphere	x	y	z	k	t(45)
superior temporal gyrus	L	-54	-31	22	37	-5.05
superior temporal gyrus	R	69	-25	13	34	-4.78
caudate	R	18	26	7	34	-4.89
PCC	L	-21	-34	43	37	-5.81

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Figure 3.4. gDifferent > gNotRated (high SES)



Note: Positive activations associated with gDifferent > gNotRated, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.3. gDifferent > gNotRated (high SES)

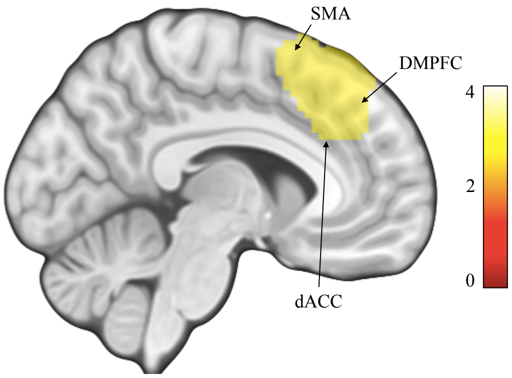
Positively associated regions	hemisphere	x	y	z	k	t(45)
SMA / DMPFC / dACC	R/L	-15	38	58	663	6.03
IFG	L	-51	41	-11	30	4.40
IFG	R	45	26	-11	20	4.45
VMPFC	R/L	-3	50	-26	32	4.45
superior frontal gyrus	R	18	53	37	65	4.44
occipital lobe	R	45	-91	7	37	4.60

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Whole brain$_{(\text{gSame > gNotRated})}$ = β1(SES) + ε. We examined whether neural processes associated with receiving social feedback that the participant is aligned with peers were associated with SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. No activity was associated with individuals from higher or lower SES backgrounds when examined independently. In addition, when directly compared (low – high SES) no significant differences were witnessed between individuals from higher and lower SES backgrounds.

Whole brain$_{(\text{gDifferent > gSame})}$ = β1(SES) + ε. We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were associated with SES. Although higher and lower SES participants demonstrated similar neural activity in the SMA, DMPFC, and dACC (see conjunction analysis, figure 3.5, table 3.4), we also observed additional widespread activation in lower SES participants that was not evident for higher SES participants. Specifically, when receiving feedback that group opinions differed from the participant's, lower SES participants showed significantly increased activity in the TPJ, MFG, insula, IFG, and VMPFC, among other regions, which was not witnessed in higher SES participants. For a full list of activations see tables 3.5 (figure 3.6) and 3.6 (figure 3.7). When directly compared (low – high SES), however, no significant differences in neural activity survived FDR correction.

Figure 3.5. Conjunction analysis gDifferent > gSame (low & high SES)



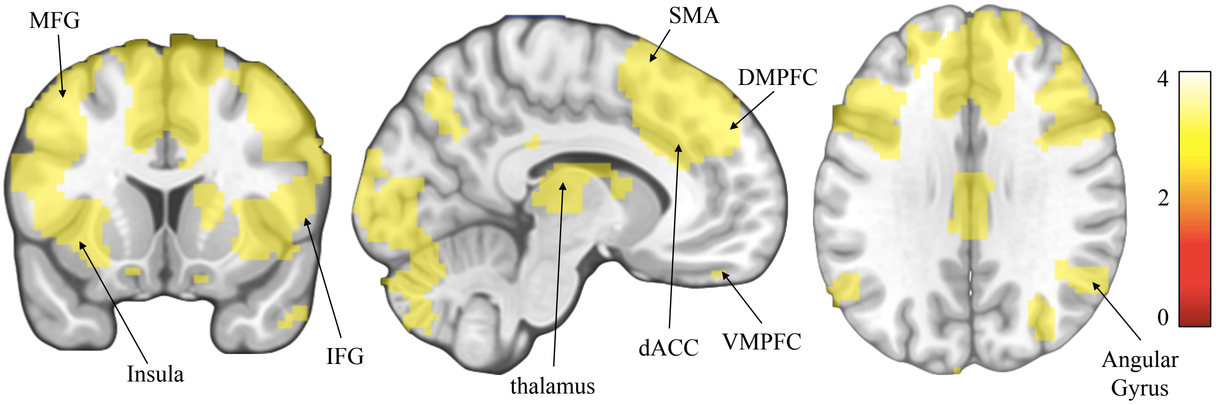
Note: Positive activations associated with gDifferent > gSame, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.4. Conjunction analysis gDifferent > gSame (low & high SES)

Positively associated regions	hemisphere	x	y	z	k
SMA / DMPFC / dACC	R/L	-15	14	64	485
Occipital lobe	R	36	-94	-5	36

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Figure 3.6. gDifferent > gSame (low SES)



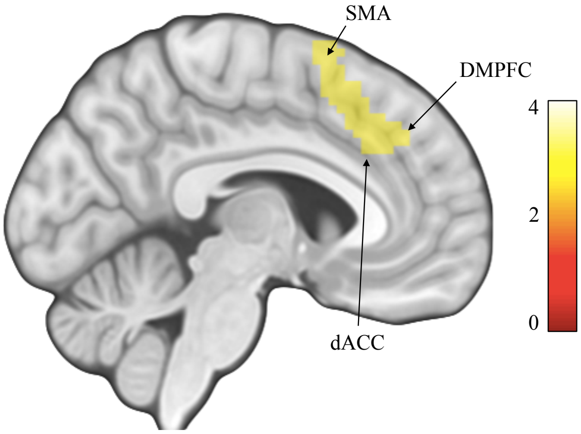
Note: Positive activations associated with gDifferent > gSame, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.5. gDifferent > gSame (low SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
inferior parietal lobule / superior parietal lobule / precuneus / angular gyrus/TPJ	R/L	39	-46	49	8328	6.35
SMA / DMPFC / dACC / MFG / IFG / insula / VMPFC / thalamus / basal ganglia	R/L	-6	17	49	10117	8.33
middle temporal gryus	L	-54	-37	-5	356	4.56
middle temporal gyrus	R	51	-1	-32	102	4.13
middle temporal gyrus	L	-51	5	-32	82	4.01
fusiform gyrus	L	-36	-16	-29	40	3.30
occipital lobe	R	18	-76	13	21	2.51

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Figure 3.7. gDifferent > gSame (high SES)



Note: Positive activations associated with gDifferent > gSame, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.6. gDifferent > gSame (high SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
SMA / DMPFC / dACC	R/L	0	29	40	491	5.64
inferior occipital lobe	R	42	-91	-5	40	4.31

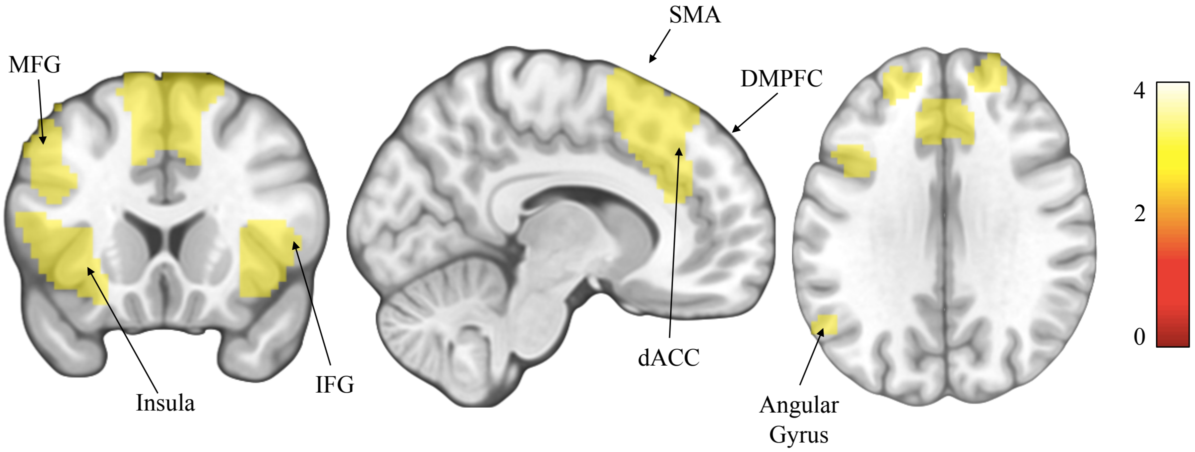
Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Conformity

Whole brain$_{(\text{gDifferent\_bChange > gDifferent\_bNoChange})}$ = β1(SES) + ε. Next, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when misaligned with peers were associated with SES. Overall, no significant activity was associated with those from higher and lower SES backgrounds when examined independently.

Whole brain$_{(\text{gDifferent\_bChange > gSame\_bNoChange})}$ = β1(SES) + ε. Next, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were associated with SES. Overall, higher and lower SES individuals showed overlapping activations in the SMA, DMPFC, dACC, IFG, MFG, and insula (figure 3.8; table 3.7). However, lower SES individuals showed increased activity in additional portions of IFG, VMPFC, thalamus, basal ganglia, precuneus, and TPJ/angular gyrus, regions that were not witnessed in those from higher SES backgrounds. In addition, higher SES individuals showed decreased activity in the parahippocampal gyrus, a region that was not significantly active among those from lower SES backgrounds. See tables 3.8 (figure 3.9) and 3.9 (figure 3.10) for a full list of activations. When directly compared (low – high SES), no significant differences in neural activity survived FDR correction.

Figure 3.8. Conjunction analysis gDifferent_ bChange > gSame_bNoChange (low & high SES)



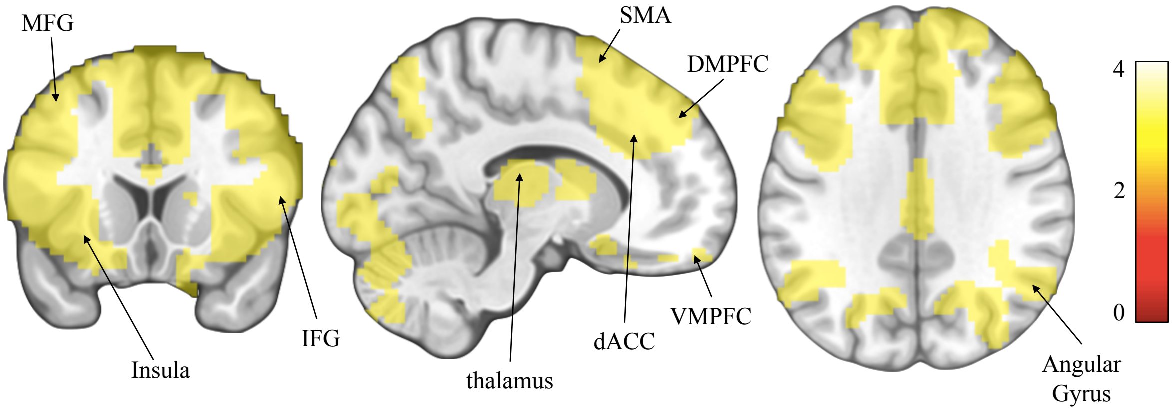
Note: Positive activations associated with gDifferent_bChange > gSame_bNoChange, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.7. Conjunction analysis gDifferent_bChange > gSame_bNoChange (low & high SES)

Positively associated regions	hemisphere	x	y	z	k
SMA / DMPFC / dACC	R/L	-27	47	28	1558
IFG / insula	R/L	-57	20	7	410
MFG	L	-54	14	46	128
precentral gyrus	L	-36	-1	61	33
angular gyrus	L	-57	-64	31	59
superior parietal lobule	L	-24	-76	55	31
superior frontal gyrus	R	12	50	40	83
middle temporal gyrus	L	-57	-1	-29	21
middle temporal gyrus	L	-66	-34	-14	54

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Figure 3.9. gDifferent_ bChange > gSame_bNoChange (low SES)



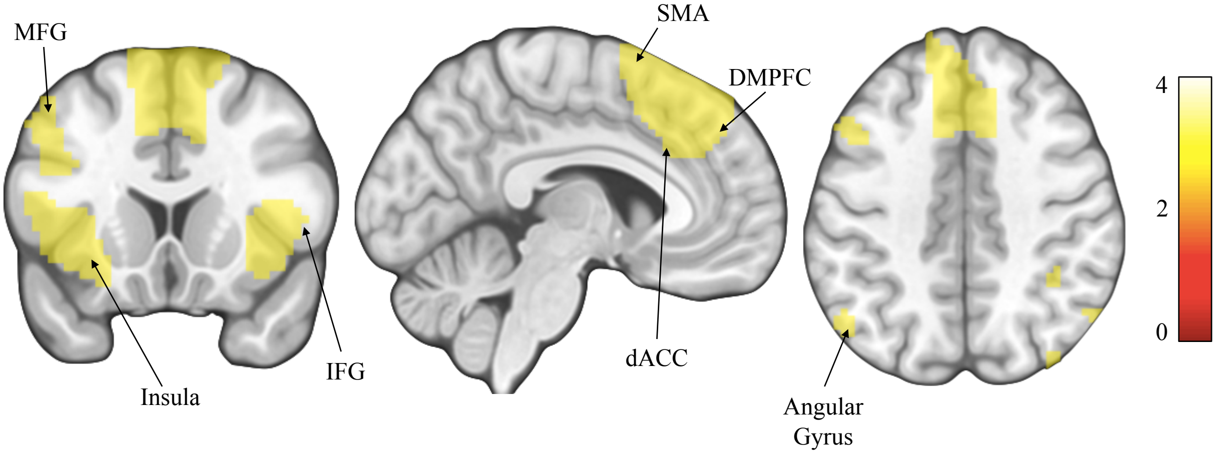
Note: Positive activations associated with gDifferent_bChange > gSame_bNoChange, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.8. gDifferent_bChange > gSame_bNoChange (low SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
inferior parietal lobule / superior parietal lobule / angular gyrus / precuneus / occipital lobe / cerebellum	R/L	39	-46	49	8539	7.13
SMA / DMPFC / dACC / MFG / IFG / insula / VMPFC / thalamus/ basal ganglia	R/L	-6	17	49	11002	8.61
middle temporal gyrus	L	-63	-31	-11	350	5.02
inferior temporal gyrus	R	48	-1	-35	114	4.11
inferior temporal gyrus	L	-54	-4	-29	100	4.03
fusiform gyrus	R	33	-19	-35	22	3.10
fusiform gyrus	L	-39	-16	-29	91	4.39

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Figure 3.10. gDifferent_ bChange > gSame_bNoChange (high SES)



Note: Positive activations associated with gDifferent_bChange > gSame_bNoChange, corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 3.9. gDifferent_bChange > gSame_bNoChange (high SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
SMA / DMPFC / dACC	R/L	0	29	40	1582	6.46
insula / IFG	R	36	17	7	257	5.18
insula / IFG	L	-45	23	-5	416	5.38
MFG	R	45	32	34	67	4.00
MFG	L	-48	17	43	129	4.42
superior frontal gyrus	R	21	56	31	91	4.98
inferior parietal lobule	R	39	-49	52	69	4.19
middle temporal gyrus	L	-60	-37	-11	55	4.19
middle occipital lobe	R	45	-91	13	148	6.29
occipital lobe	R	39	-85	40	28	4.28

Negatively associated regions	hemisphere	x	y	z	k	t(45)
parahippocampal gyrus	L	-33	-43	-2	22	-5.98

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20

Exploratory whole brain results

A series of exploratory whole brain analyses run at a less conservative threshold (*p*<.005, *k*>20, uncorrected) examined whether processing of social feedback or conformity were moderated by SES.

Processing social feedback

Whole brain$_{(gDifferent > gNotRated)}$ = β1(SES) + ε. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were associated with SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. When examining (low – high SES) at a reduced threshold (*k*>20, *p*=.005), no cortical activation survived; only increased activity in the cerebellum was associated with receiving feedback that group opinions differed from one's own for lower SES individuals compared to those from higher SES backgrounds (table 3.10).

Table 3.10. gDifferent > gNotRated (low - high SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
cerebellum	L	-6	-28	-41	44	3.51

Note: *k*=20, *p*=.005, uncorrected.

Whole brain$_{(gSame > gNotRated)}$ = β1(SES) + ε. Furthermore, we examined whether neural processes associated with receiving social feedback that the participant is aligned with peers were associated with SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. When examining (low – high SES) at a reduced threshold (*k*>20, *p*=.005) only increased activity in the cerebellum was associated with exposure to convergent social feedback compared to no social feedback for higher compared to lower SES individuals (table 3.11).

Table 3.11. gSame > gNotRated (low - high SES)

Negatively associated regions	hemisphere	x	y	z	k	t(45)
cerebellum	R	30	-85	-29	20	-3.31
cerebellum	L	-15	-82	-50	22	-4.18

Note: *k*=20, *p*=.005, uncorrected.

Whole brain$_{(gDifferent > gSame)}$ = β1(SES) + ε. We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were associated with SES. When examining (low – high SES) at a reduced threshold (*k*>20, *p*=.005) increased activity in the hippocampus and IFG was associated with divergent compared to convergent social feedback for lower SES individuals, relative to higher SES individuals (table 3.12).

Table 3.12. gDifferent > gSame (low – high SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
hippocampus	R	24	-34	4	32	3.41
IFG	L	-36	56	-5	54	3.28

Note: *k*=20, *p*=.005, uncorrected.

Conformity

Whole brain$_{\text{(gDifferent\_bChange > gDifferent\_bNoChange)}}$ = β1(SES) + ε. Next, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when misaligned with peers were associated with SES. When directly compared (low – high SES), no significant differences in neural activity were witnessed, even at a reduced threshold.

Whole brain$_{\text{(gDifferent\_bChange > gSame\_bNoChange)}}$ = β1(SES) + ε. Next, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were associated with SES. When examining (low – high SES) at a reduced threshold (*k*>20, *p*=.005) increased activity in the hippocampus, inferior temporal gyrus, and middle temporal gyrus were associated with conforming to divergent social feedback compared to maintaining one's initial preference for those from lower SES backgrounds relative to higher SES backgrounds (table 3.13).

Table 3.13. gDifferent_bChange > gSame_bNoChange (low – high SES)

Positively associated regions	hemisphere	x	y	z	k	t(45)
IFG	L	-33	56	-5	22	2.95
hippocampus / inferior temporal gyrus	R	27	-37	4	80	3.8
middle temporal gyrus	L	-39	-67	-2	85	3.31

Note: *k*=20, *p*=.005, uncorrected.

Discussion part 1

The current study examined whether SES moderates neural mechanisms associated with social influence. Specifically, the current study examined whether SES moderates neural mechanisms associated with processing social feedback and conformity in a group of young adults who were recruited based on having parents with high (graduate degree) versus low levels (less than high school, high school, associates, or trade school) of education.

Behavioral differences across SES

Overall, individual differences in conformity were not significantly moderated by SES. Therefore, any differences in neural activity witnessed between those from higher and lower SES backgrounds can be attributed to different cognitive approaches to processing social feedback and conformity.

SES commonalities in processing social feedback and conformity

First we examined whether SES moderated the neural mechanisms associated with processing social feedback (gDifferent > gNotRated and gDifferent > gSame). Results indicated that when processing social feedback that the participant was misaligned with peers those from both higher and lower SES backgrounds displayed increased activity in the SMA, DMPFC, and dACC. These findings are consistent with findings from our large-scale main effect meta-analytic analyses, demonstrating that a core set of neural regions, including the SMA, DMPFC, and dACC, was associated with processing social feedback. This finding is consistent with past research that suggests social influence is associated neural regions involved in prediction error (Klucharev et al., 2009), conflict detection (Berns et al., 2010; Klucharev et al., 2011; Tomlin et al., 2013) and mentalizing (Cascio, O'Donnell, et al., 2015; Welborn et al., 2015). In other words, regardless of SES, being misaligned with others may elicit activity in this set of regions, which help monitor behavior and generates a neural signal when behavioral adjustments need to be made, as well as trying to infer the mental states of others. In addition, when comparing social feedback that the participant was misaligned with peer preferences compared to no social feedback, those from higher and lower SES backgrounds displayed activation in the IFG, a region associated with emotion regulation (Ochsner et al., 2004) and inhibitory control (Aron et al., 2004; Simmonds et al., 2008).

Next, we examined whether SES moderated neural mechanisms associated with conforming to peer feedback that the participant was misaligned with peers compared to maintaining one's initial preference when aligned with peers. A conjunction analysis revealed that both higher and lower SES participants showed increased activity in a core set of regions including includes the SMA, DMPFC, dACC, anterior insula, IFG, and MFG when conforming to divergent peer feedback relative to maintaining initial ratings in line with the group. Thus, decisions to conform involved several of the core regions associated with processing divergent feedback more generally (SMA, DMPFC, and dACC; (Klucharev et al., 2009)), however, decisions to conform to divergent feedback also involved regions associated with inhibitory control (IFG and MFG; (Aron et al., 2004; Simmonds et al., 2008)) and emotional responses to being out of line with the group (anterior insula; (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003)). These results converge with recent findings suggesting that inhibitory control may aid people in overriding their existing attitudes or preferences to align with social feedback (Welborn et al., 2015).

Direct comparisons between those from higher and lower SES backgrounds

Overall, when we directly compared differences in neural processes associated with social influence processing and conformity between those from higher and lower SES backgrounds we did not find any significant results for our FDR corrected analyses. This supports the idea that there are robust commonalities in how social feedback is processed across those from different SES backgrounds. However for the purposes of aiding future research, we ran a series of analyses that examined those from higher and lower SES independently and ran a series of exploratory whole brain analyses that directly compared higher and lower SES participants at a less conservative threshold, which are discussed below. These results should be interpreted with caution given the exploratory nature of these analyses.

Independent examination of high and low SES in processing social feedback

First, we examined how social feedback is processed in those from different SES backgrounds independently; results indicated that those from lower SES backgrounds displayed additional activity in regions not witnessed in higher SES individuals. More specifically, those from lower SES backgrounds displayed increased activity in regions associated with inhibitory control (IFG and MFG; (Aron et al., 2004; Simmonds et al., 2008)), conflict detection (insula; (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003)), emotion regulation (IFG; (Ochsner et al., 2004)), positive valuation (VMPFC; (Bartra et al., 2013)), and mentalizing (TPJ; (Saxe, 2010)). These findings demonstrate that those from higher SES backgrounds recruit a more focal neural network compared to those from lower SES. Importantly, however, the current study did not find any differences in conformity in relation to SES. Thus, it is not clear whether those from higher SES backgrounds are recruiting a suboptimal or incomplete network or whether those from higher SES backgrounds are making more efficient use of the regions involved in social influence in comparison to those from lower SES backgrounds. It also may be the case that low and high SES individuals simply take different approaches to social feedback, suggesting that these functional differences are a result of a learned cognitive strategy or environmental factors altering neural functioning. These remain open questions and should be examined in future neuroimaging studies.

Exploratory SES differences in processing social feedback

Although no differences between higher and lower SES individuals survived FDR correction, results conducted at more liberal thresholds indicated that those from lower SES backgrounds compared to higher SES backgrounds displayed relatively higher activity in the hippocampus and IFG during social feedback (gDifferent > gSame), regions associated with memory (Shafer & Dolcos, 2012) and emotion regulation (Ochsner et al., 2004). Thus, when processing social feedback that suggests a person is misaligned with others, in addition to the core regions associated with conflict detection and mentalizing that are recruited by all participants, those from lower SES backgrounds also displayed significantly more activity than those from higher SES backgrounds in regions implicated in memory and emotion regulation.

One possibility is that lower SES participants recruit a more complex network when faced with social information that suggests a person is misaligned with others, and perhaps engage in more executive control to reconcile and integrate group opinions with their own. This may be related to research that suggests those from higher SES backgrounds tend to be more independent, whereas those from lower SES backgrounds tend to have external orientations to the environment (Kraus et al., 2012). This external orientation may then be related to the recruitment of a more complex neural network when evaluating social information.

Independent examination of high and low SES in conformity

Furthermore, when examining results associated with conformity for low and high SES participants separately, we observed somewhat different patterns of co-activations with the core set of regions that were common across both. Of particular note, those from higher SES backgrounds displayed decreased activity in the parahippocampal gyrus, which suggests that regions involved in memory retrieval (Rugg & Vilberg, 2013) may be more active when maintaining one's current preference when exposed to convergent social feedback compared to conforming to divergent social feedback. Alternatively, this may suggest that those from higher SES backgrounds rely less on prior information when conforming to divergent social feedback.

Those from lower SES backgrounds displayed greater activity in the TPJ, IFG and VMPFC, regions associated with mental state inference (Saxe, 2010), emotion regulation (Ochsner et al., 2004) and positive valuation (Bartra et al., 2013), respectively. Given that lower SES tends to be associated with more collectivistic orientations and stronger focus on social relations, those from lower SES backgrounds may preferentially recruit mentalizing resources and find positive value in the opinions of others and/or conformity (Campbell-Meiklejohn et al., 2010; Zaki et al., 2011). These findings complement past research demonstrating that when women move from lower to higher SES locations, they conform to the local norms (i.e., average heel size for their shoes), whereas women who relocate to lower SES locations tend to maintain their initial shoe preference (Galak, Gray, Elbert, & Strohminger, 2016). In other words, if those from higher SES backgrounds tend to be more independent or have an individualistic orientation, whereas those from lower SES backgrounds tend to have more interdependent or external orientation to the environment (Kraus et al., 2012), lower SES individuals may be more sensitive to social cues in general, and may conform for social reasons, whereas higher SES individuals may conform for individualistic reasons.

Exploratory SES differences in conformity

Although no differences between those from higher and lower SES backgrounds survived FDR correction, results conducted at more liberal thresholds also indicated that preceding decisions to conform with divergent peer feedback (gDifferent_bChange > gSame_bNoChange), those from lower SES backgrounds compared to higher SES backgrounds displayed relatively higher activity in the IFG, hippocampus, inferior temporal gyrus, and middle temporal gyrus, regions associated with memory (Shafer & Dolcos, 2012) and emotion regulation (Ochsner et al., 2004). One possibility is that lower SES participants may more actively override their own opinions when presented with divergent peer opinions. Our findings also complement past research demonstrating that SES and the situational social context also moderate the relationship between neural processing and important outcomes of interest, such as peer influenced risk-taking (Cascio et al., 2017) and physiological threat responses to ambiguous events (Chen, Langer, Raphaelson, & Matthews, 2004). Our results add to this literature by suggesting that lower SES participants may make differential use of executive processing regions in service of social goals such as conformity. In other words, although higher and lower SES participants conformed at similar rates, and showed largely similar underlying neural pathways to conformity, some preliminary evidence is suggestive that the processes leading to these decisions may not be identical.

Strengths and limitations

Overall, this is the first neuroimaging study to examine whether SES moderates neural mechanisms associated with social influence. The current study used a between subjects design, where participants were recruited based on having parents with high (graduate degree) versus low levels (less than high school, high school, associates, or trade school) of education. One strength of the current study design is that differences in SES can be attributed to one specific aspect of SES (parental education which is an index of human capital), rather than testing multiple aspects of SES at once (occupation and income which index financial capital). However, this is also a weakness in that the current study design may not capture all aspects of one's SES background. In addition, the current study primarily included college-aged students from local universities (University of Pennsylvania and Drexel) and did not directly recruit participants from extremely deprived circumstances. This factor may have contributed to the similar results observed between groups. It is possible that participants with more varied life circumstances would show stronger differences in behavior and neural mechanisms related to conformity. Thus, future research may aim to examine differences between more extreme SES environments in order to determine whether neural correlates of social influence between higher and lower SES individuals are further differentiated.

Finally, it should be noted that when directly comparing those from lower and higher SES backgrounds no results were witnessed in our FDR corrected analyses, neural differences were only witnessed at reduced thresholds. In addition, no behavioral differences were witnessed between those from higher and lower SES backgrounds, which made it less likely to find neural differences associated with SES. However, a lack of behavioral differences does not eliminate the idea that different underlying neural processes can drive behaviors that are similar on the surface. The lack of robust findings and lack of behavioral differences may suggest that education is not fully capturing factors associated with SES and may suggest that additional measures are needed to more clearly determine whether neural processes associated with conformity are moderated by SES. It is also possible, however, that processing social feedback may be a more basic process that is similar across people, including those from different SES backgrounds. In addition, it is possible that differences might only be observed in cases where one set of participants has been more severely deprived, thus differences along the spectrum of SES are not clearly observable.

Conclusion part 1

Overall, these results begin to shed light on the different processes that contribute to conformity among those from higher and lower SES backgrounds. Although those from higher and lower SES backgrounds recruit similar core regions during social feedback (SMA, DMPFC, and dACC) and conformity (SMA, DMPFC, dACC, IFG, MFG, and anterior insula), we also observed some suggestive differences in exploratory analyses at less conservative thresholds. These exploratory analyses suggest that those from lower SES backgrounds recruit regions associated with memory (Shafer & Dolcos, 2012) and emotion regulation (Ochsner et al., 2004) to a greater extent during conformity than those from higher SES. By contrast, higher SES individuals may engage these regions equally regardless of the type of social feedback (misaligned versus aligned). These results provide suggest potential importance of examining SES when examining psychological and neurological processes and offer targeted regions that may be of interest in future research on similarities and differences across SES groups.

Methods part 2

Part two of this study extended the above analyses to a larger set of studies that were not recruited specifically to study SES differences, but also examined neural mechanisms of social influence on the same task and measured SES (parental education). In the larger sample, SES was treated as continuous, using the same measure of parental education used to screen the groups in Part 1; the additional samples, however, were not recruited with specific SES inclusion or exclusion criteria, or to be specifically matched across SES on other demographics.

Participants

Participants were recruited across 3 additional (4 total) studies, including two adolescent samples (N_{smple1} = 78, $N_{sample2}$ = 104) and two young adult samples ($N_{sample3}$ = 59, $N_{sample4}$=43). Participants in samples 1 and 2 were 16-17 adolescent males recruited from the Michigan Driver License Records through the University of Michigan Transportation Research Institute as part of a series of larger studies examining adolescent driving behavior (Simons-Morton et al., 2014). Samples 3 and 4 included young adults recruited from the University of Pennsylvania and surrounding Philadelphia, PA community. Sample 5 did not collect SES information, and hence is not included in this chapter. Details regarding sample demographics for participants who were included in the current analyses (having both SES and fMRI data; *N*=196) can be found in tables 3.14-3.17. It should be noted that sample 3 is the same sample analyzed in part 1, however unlike part 1 where SES was dichotomized (given the extreme group design), SES will be treated as a continuous measure in part 2 to harmonize with the rest of the data in the other samples. All participants were right-handed, did not suffer from claustrophobia, were not currently taking any psychoactive medications, had normal (or corrected to normal) vision, and did not have metal in their body that was contraindicated for fMRI. In addition, participants that took part in our adolescent driving studies (samples 1 and 2) did not typically experience motion sickness, which could affect driving simulation testing.

Table 3.14. Sample demographics (SES)

Sample	N	Mean	Std Dev	Range	Low SES	Middle SES	High SES
Sample 1	44	4.82	1.12	2-6	14	9	25
Sample 2	64	4.84	1.12	2-6	21	18	21
Sample 3	49	4.51	1.82	1.5-6	21	0	28
Sample 4	39	4.23	1.35	1.5-6	21	8	10
Total	196	4.63	1.38	1.5-6	77	35	84
Adolescents	108	4.83	1.12	2-6	35	27	46
Young Adults	88	4.39	1.63	1.5-6	42	8	38

Note: Sample demographics across the 4 samples. SES scores ranged from 1 (no high school) to 6 (graduate degree). Low SES = no high school through associate degree, middle SES = bachelor degree, and high SES = graduate degree.

Table 3.15. Sample demographics (gender by SES)

	Males				Females			
Sample	Low SES	Middle SES	High SES	Total	Low SES	Middle SES	High SES	Total
Sample 1	14	9	21	44	0	0	0	0
Sample 2	21	18	25	64	0	0	0	0
Sample 3	8	0	9	17	13	0	19	32
Sample 4	10	1	1	23	11	7	9	27
Total	53	28	56	137	24	7	28	59
Adolescents	35	27	46	108	0	0	0	0
Young Adults	18	1	10	29	24	7	28	59

Table 3.16. Sample demographics (age (years) by SES)

Sample	Low SES	Middle SES	High SES	Total
Sample 1	16.99	16.70	16.92	16.90
Sample 2	16.52	16.15	16.41	16.36
Sample 3	23.28	n/a	22.18	22.65
Sample 4	20.81	19.75	20.60	20.54
Total	19.40	17.53	19.03	19.11
Adolescents	16.76	16.43	16.66	16.63
Young Adults	22.05	19.75	21.39	21.60

Table 3.17. Sample demographics (race by SES)

	White				Minority			
Sample	Low SES	Middle SES	High SES	Total	Low SES	Middle SES	High SES	Total
Sample 1	12	7	20	39	2	2	1	5
Sample 2	17	14	20	51	4	4	5	13
Sample 3	14	0	18	32	7	0	7	14
Sample 4	10	5	7	22	11	3	3	17
Total	53	26	65	144	24	9	16	49
Adolescents	29	21	40	90	6	6	6	18
Young Adults	24	5	25	54	18	3	10	31

Study design

After participants gave assent (for adolescents) or consent (for young adults) to participate in the study, they completed a number of self-report online survey measures, including measures of parental education (SES) and initial ratings on our social influence task prior to the fMRI scan. Next, they completed the social feedback version of the social influence task in an fMRI scanner. Finally, they completed additional post-scan online survey measures. Although the broader study designs and procedures differed across the individual studies, the target task and procedures (i.e., social influence task) were similar across all studies; details are given in the task section below.

Socioeconomic status (SES)

Fathers' and mothers' education served as our primary measure of SES. Participants were asked what level of education their father and mother had completed based on 7-point scale, where 1 = less than high school, 2 = high school, 3 = trade school, 4 = associates degree, 5 = bachelor degree, 6 = graduate degree, and 7 = unknown. Unknown levels of education (response = 7) were dropped from the analysis. Then a combined continuous parents' education variable was created using the average score between the father and mother. Details regarding the distribution of the three main measures of SES (parents' education) for each sample can be found in table 3.18.

Table 3.18. Socioeconomic status (Parents' Education)

Sample	Total Used	Some High School (1-1.5)	High School (2-2.5)	Trade School (3-3.5)	Associate Degree (4-4.5)	Bachelor Degree (5)	Graduate Degree (5.5-6)	Unknown (dropped)
Sample 1	44	0	4	3	7	9	21	29
Sample 2	64	0	5	7	9	18	25	3
Sample 3	49	2	11	4	4	0	28	1
Sample 4	39	1	6	7	7	8	10	2
Total	196	3	26	21	27	35	84	35
Adolescents	108	0	9	10	16	27	46	32
Adults	88	3	17	11	11	8	38	3

Note: Distribution of parents' education scores across samples. If parents' education level was unknown for mother or father, then the score was treated as a missing value. If neither parents' education levels were known or were not reported, then the average score was recorded as unknown (7).

Social influence task

The fMRI social influence task is described in chapter 2. The task was similar across all samples with the exception of the number of trials. Participants in samples 1, 2, and 4 were asked to make recommendations on 80 mobile game apps, whereas participants in sample 3 (part 1) were asked to make recommendations on 60 mobile game apps. In addition, participants in sample 3 were asked to make similar ratings on the same 60 mobile game apps in regards to whether they would download the app for themselves, these trials were not included in the current analyses.

fMRI data acquisition

Imaging data for samples 1 and 2 were acquired using a 3 Tesla GE Signa MRI scanner. Functional images were recorded using a reverse spiral sequence (TR = 2,000 ms, TE = 30 ms, flip angle = 90°, 43 axial slices, FOV = 220 mm, slice thickness = 3 mm; voxel size = 3.44 mm x 3.44 mm x 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = .86 mm x .86 mm x 3.0 mm) and high-resolution T1-weighted images (spoiled gradient echo; 124 slices; slice thickness = 1.02 mm x 1.02 mm x 1.2 mm) for use in coregistration and normalization. Imaging data for samples 4 and 5 were acquired using a 3 Tesla

Siemens Trio scanner. Functional images were recorded using a reverse spiral sequence (TR = 1,500 ms, TE = 25 ms, flip angle = 70°, 54 axial slices, FOV = 200 mm, slice thickness = 3 mm; voxel size = 3.0 mm x 3.0 mm x 3.0 mm). We also acquired high-resolution T1-weighted images (MPRAGE; 160 slices; slice thickness = 0.9 x 0.9 x 1.0 mm) for use in coregistration and normalization.

Data analysis

Quality checking, fMRI data preprocessing, fMRI first level modeling, ROI construction, and the participant-level statistical contrasts are the same as part 1.

Participant matching and control variables. In an attempt to limit confounds between the primary focus of this paper (SES) and other known participant demographics (development, gender, and race), steps were taken in order to ensure demographic factors were similarly distributed across SES. First, we examined whether adolescent and young adult participants were similarly distributed across SES. Results indicated that the number of adolescents to adults across SES did significantly differ ($\chi^2(2, 196)=9.77$, $p=.008$), such that there were significantly more adolescents in the current sample compared to adults. Therefore, development was used as a control variable in analyses related to SES. In addition, we controlled for sample (which study the participant completed), which should also help control for the developmental state. Next, we examined whether gender differences were found across SES. Results indicated that there were no gender differences between SES ($\chi^2(2, 196)=2.16$, $p=.340$). Therefore, gender will not be used as a control variable in the analyses. Finally, we examined whether race differed across SES. We found that there were not significant differences between race across SES ($\chi^2(8, 196)=10.59$, $p=.226$). Thus, race will not be used as a control variable in the analyses.

Differences in peer group feedback. A repeated measures analysis of variance (ANOVA) was run to examine whether there were significant differences in the proportion of time participants changed their recommendations in response to group feedback (*not rated*, *same*, and *different*) and whether the proportion of time participants changed their recommendations differed by SES, controlling for gender and sample. Results indicated that the three feedback conditions were significantly different from one another (*F*(1,189)=597.87, *p*<.001), such that participants changed their recommendation most often when receiving *different* feedback (*M* = 40.95%, *SD* = 21.94%), compared to the *same* (*M* = 8.67%, *SD* = 11.52%; *F*(1,189)=386.38 *p*<.001) or no social feedback (*M* = 15.08%, *SD* = 15.15%; *F*(1,189)=233.48, *p*<.001). In addition, SES (parents' education) and the interaction between SES and social feedback were not significantly related to the proportion of time participants changed their recommendation (*F*(1,188)=0.04, *p*=.845; *F*(1,188)=1.24, *p*=.266, respectively).

ROI analyses. Next, planned ROI analyses examined whether neural activity within each separate functional ROI for each contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) is differently activated by those from high and low SES backgrounds. Overall, only three of the five contrasts in chapter 2 revealed significant activity, therefore our ROI analyses only examined these contrasts as target regions of interest. The regression models and research questions that were analyzed are listed below.

$\text{ROI}_{(\text{gDifferent > gNotRated})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers is moderated by SES, controlling for processes associated with considering the games and the act of making recommendations without social feedback, development, and sample.

$\text{ROI}_{(\text{gDifferent > gSame})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers is moderated by SES. This regression captures whether those from different SES backgrounds differ in how different types of social feedback are processed, controlling for development and sample.

$\text{ROI}_{(\text{gDifferent\_bChange > gSame\_bNoChange})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$: We examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers is moderated by SES. This regression captures whether those from different SES backgrounds differ in processes that contribute to adhering to peers depending on whether the participant previously agreed or disagreed with the social feedback, controlling for development and sample.

Whole brain analyses. In addition to examining our functional ROIs, we examined whether the relationship between feedback condition and activity in neural regions outside of our functional ROIs were moderated by SES in a series of exploratory whole brain analyses. To do this we regressed SES (parents' education) onto neural activity during the contrasts (gDifferent > gNotRated, gSame > gNotRated, gDifferent > gSame, gSame > gDifferent, gDifferent_bChange > gDifferent_bNoChange, and gDifferent_bChange > gSame_bNoChange), controlling for development and sample. See methods section in chapter 2 for contrast definitions. Results from the first level models were combined at the group level using a random effects model implemented in SPM8. All whole brain analyses were corrected for multiple comparisons using FDR, $p<.05$, $k>20$, implemented in SPM8. In addition, to balance concerns about type I and type II error, we also explored the difference models at a more liberal uncorrected threshold to explore potential regions worth pursuing moving ahead ($p=.005$, $k>20$). All coordinates were reported in MNI space.

Results part 2

ROI analyses

ROI analyses were conducted that examined whether neural activity within each functionally defined ROI for each contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) were differently activated by those from high and low SES backgrounds, controlling for sample and development.

Processing social feedback

$\text{ROI}_{(\text{gDifferent > gNotRated})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were moderated by SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, SES did not significantly moderate neural activity in the functionally defined processing (gDifferent > gNotRated) ROI (β=-.05, *t*(192)=-0.66, *p*=.512, *CI*=[-.05, .03]).

$ROI_{(gDifferent > gSame)}$ = β1(SES) + β2(sample) + β3(development) + ε. Second, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by SES. Overall, SES did not significantly moderate neural activity in the functionally defined processing (gDifferent > gSame) ROI (β=.07, *t*(192)=0.92, *p*=.357, *CI*=[-.02, .05]).

Conformity

$ROI_{(gDifferent\_bChange > gSame\_bNoChange)}$ = β1(SES) + β2(sample) + β3(development) + ε. Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by SES. Overall, SES did not significantly moderate neural activity in the functionally defined conformity (gDifferent_bChange > gSame_bNoChange) ROI (β=.04, *t*(192)=0.51, *p*=.613, *CI*=[-.02, .04]).

Whole brain analyses

In addition to examining our functional and hypothesized ROIs, we examined whether the relationship between feedback condition and activity in neural regions outside of our hypothesized ROIs were moderated by SES in a series of whole brain analyses that mirror the contrasts examined in our ROI analyses (FDR, *p*<.05, *k*>20).

Processing social feedback

Whole $brain_{(gDifferent > gNotRated)}$ = β1(SES) + β2(sample) + β3(development) + ε. First, neural activity was not significantly associated with SES when receiving social feedback that the participant is misaligned with peers, controlling for processes associated with considering the games and the act of making recommendations, without social feedback.

Whole $\text{brain}_{(\text{gSame} > \text{gNotRated})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$. Second, neural activity was not significantly associated with SES when receiving social feedback that the participant is aligned with peers were moderated by SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback.

Whole $\text{brain}_{(\text{gDifferent} > \text{gSame})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$. In addition, neural activity was not significantly associated with SES when receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers.

Conformity

Whole $\text{brain}_{(\text{gDifferent\_bChange} > \text{gDifferent\_bNoChange})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$. Next, neural activity was not significantly associated with SES when conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when misaligned with peers.

Whole $\text{brain}_{(\text{gDifferent\_bChange} > \text{gSame\_bNoChange})} = \beta1(\text{SES}) + \beta2(\text{sample}) + \beta3(\text{development}) + \varepsilon$. Finally, neural activity was not significantly associated with SES when conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned.

Exploratory whole brain analyses

Given the difference in findings between part 1 and part 2 of the current study we reran whole brain analyses that mirrored the recruitment processes used in part 1 (lower versus higher SES only). These follow up analyses were run for the contrasts that were most robustly activated in part 1 (gDifferent > gSame and gDifferent_bChange > gSame_bChange) at a reduced threshold[5] (p=.005, k>20, uncorrected) in order to determine whether the null results found in the full sample are due to a lack of differences between those from high and low SES backgrounds or whether we did not witness effects because of a conservative threshold.

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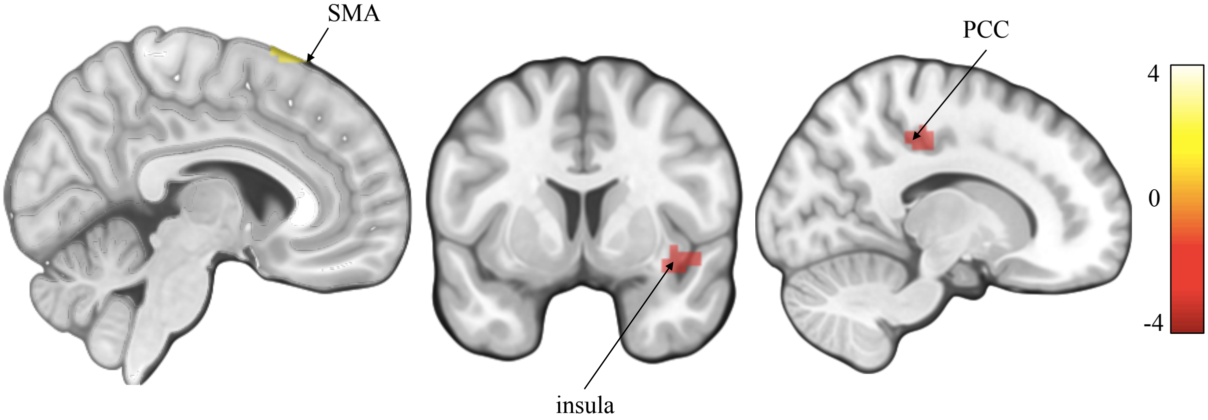
[5] Note: No significant activity was found when examining those from higher and lower SES backgrounds only using FDR, p<.05, k>20.

Whole brain$_{(gDifferent > gSame)}$ = β1(SES) + β2(sample) + β3(development) + ε. Overall, both high and low SES participants displayed increased activity in the SMA when receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers. In addition, when examined independently, those from lower SES backgrounds uniquely displayed decreased activity in the posterior cingulate (PCC) and insula (table 3.19; figure 3.11). Those from higher SES backgrounds uniquely displayed increased activity in a more robust network, including increased activity in separate parts of the dACC, DMPFC, and MFG not observed in lower SES participants, and decreased activity in the MPFC and rostral cingulate (table 3.20; figure 3.12). Finally, when directly compared those from higher SES backgrounds displayed greater activity in the cerebellum compared to those from lower SES backgrounds (table 3.21).

Figure 3.11. gDifferent > gSame (low SES)



Note: Note: *p*<.005, *k*>20, uncorrected.

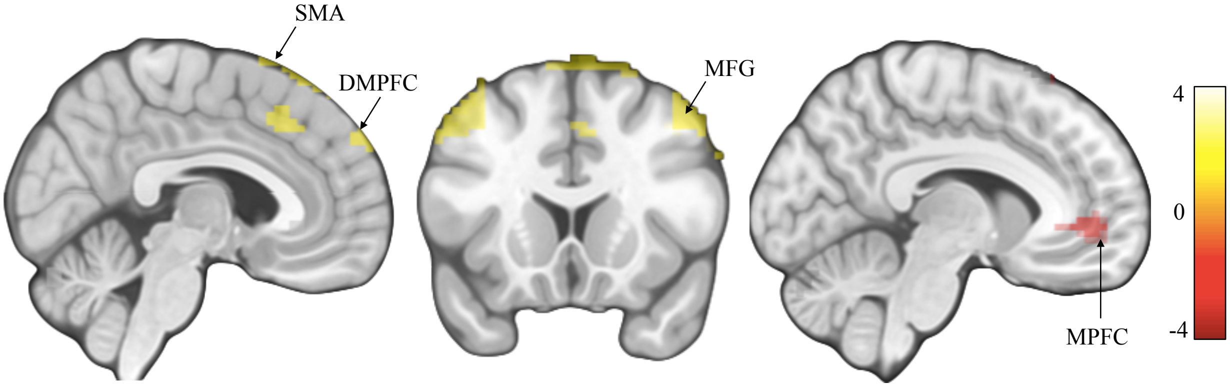
Table 3.19. gDifferent > gSame (low SES)

Positively associated regions	hemisphere	x	y	z	k	t(74)
SMA	R/L	5	19	73	53	4.21
Occipital lobe	L	-26	-98	13	48	4.24

Negatively associated regions	hemisphere	x	y	z	k	t(74)
PCC	R	18	-33	43	43	-3.51
PCC	L	-26	-33	40	38	-3.16
Insula	R	42	8	-11	28	-3.37

Note: *p*<.005, *k*>20, uncorrected.

Figure 3.12. gDifferent > gSame (high SES)



Note: Note: *p*<.005, *k*>20, uncorrected.

Table 3.20. gDifferent > gSame (high SES)

Positively associated regions	hemisphere	x	y	z	k	t(81)
Superior parietal lobule	L	-30	-67	64	37	3.78
SMA / DMPFC	R/L	11	26	70	138	4.97
dACC	R/L	5	26	43	39	3.53
MFG	L	-40	22	52	62	3.32
MFG	R	46	15	55	117	4.38
DMPFC	R	8	63	37	242	5.39
Occipital lobe	R	39	-98	-8	91	3.58
Occipital lobe	L	-26	-101	1	302	3.94
Cerebellum	L	-40	-74	-44	24	3.52

Negatively associated regions	hemisphere	x	y	z	k	t(81)
MPFC / rostral cingulate	L	-13	50	-5	57	-3.44
Occipital lobe	L	-40	-85	37	23	-3.30

Note: *p*<.005, *k*>20, uncorrected.

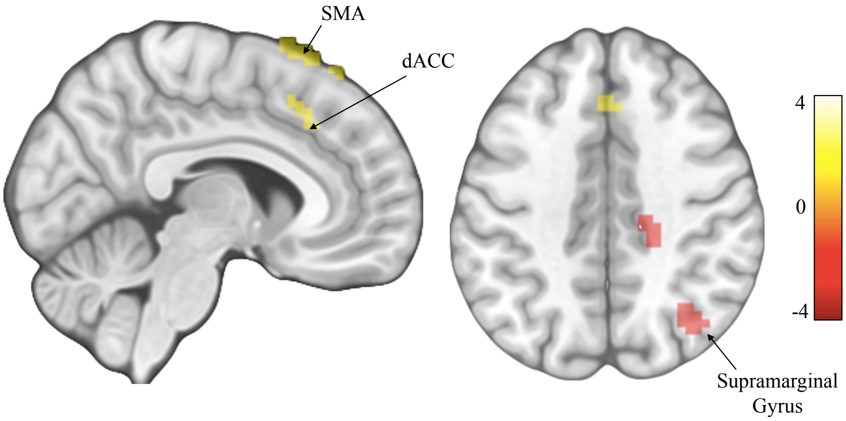
Table 3.21. gDifferent > gSame (low – high SES)

Positively associated regions	hemisphere	x	y	z	k	t(157)
Cerebellum	R	42	-64	-26	32	-3.10

Note: *p*<.005, *k*>20, uncorrected.

Whole brain$_{\text{(gDifferent\_bChange > gSame\_bNoChange)}}$ = β1(SES) + β2(sample) + β3(development) + ε. Overall, both high and low SES displayed increased activity in the SMA, dACC, and DMPFC when conforming to social feedback that the participant is misaligned with peers, compared to processes associated with maintaining one’s initial recommendation when receiving social feedback that the participant is aligned with peers. In addition, when examined independently, those from lower SES backgrounds uniquely displayed decreased activity in the MPFC, caudate, TPJ, and superior temporal gyrus, and increased activity in the IFG (table 3.22; figure 3.13). Those from higher SES backgrounds uniquely displayed increased activity in a more robust network, including increased activity in the inferior parietal lobule and MFG (table 3.23; figure 3.14). Finally, when directly compared those from higher SES backgrounds displayed greater activity in the PCC compared to those from lower SES backgrounds (table 3.24).

Figure 3.13. gDifferent_bChange > gSame_bNoChange (low SES)



Note: *p*<.005, *k*>20, uncorrected.

Table 3.22. gDifferent_bChange > gSame_bNoChange (low SES)

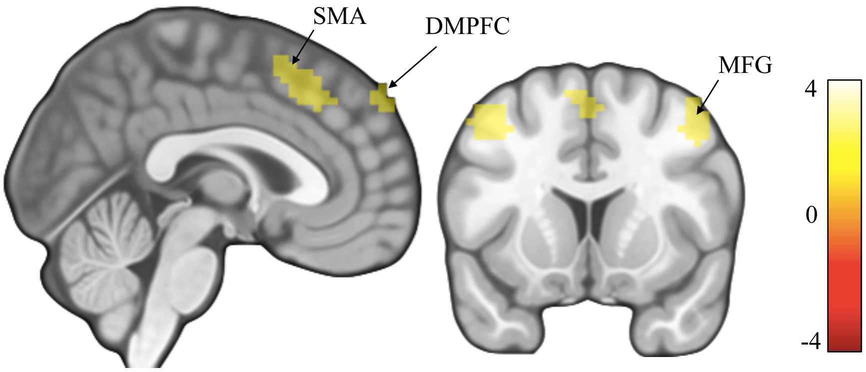
Positively associated regions	hemisphere	x	y	z	k	t(74)
SMA	R/L	5	19	73	65	4.02
Superior parietal lobule	R	25	-78	55	23	3.12
dACC / DMPFC	R/L	-6	26	40	89	4.43
IFG	R	53	29	-11	35	3.85

Negatively associated regions	hemisphere	x	y	z	k	t(74)
Superior temporal gyrus	L	-57	-33	19	48	-4.03
Supramarginal gyrus	R	53	-26	28	93	-3.97
caudate	R	22	26	13	83	-3.96
caudate	R	1	15	-5	188	-4.13
Superior temporal gyrus	R	63	8	4	50	-3.54

MPFC	R	11	50	-5	28	-3.03
cuneus	R	1	-88	31	47	-3.29
calcarine	R	5	-71	16	145	-3.50
calcarine	L	-23	-60	7	37	-3.44

Note: *p*<.005, *k*>20, uncorrected.

Figure 3.14. gDifferent_bChange > gSame_bNoChange (high SES)



Note: *p*<.005, *k*>20, uncorrected.

Table 3.23. gDifferent_bChange > gSame_bNoChange (high SES)

Positively associated regions	hemisphere	x	y	z	k	t(81)
SMA	R/L	18	26	67	56	3.69
Superior parietal lobule	L	-30	-64	64	66	3.65
Inferior parietal lobule	R	35	-50	46	57	3.20
dACC / DMPFC	R/L	1	26	43	111	3.72
DMPFC	R/L	11	63	37	277	4.56
MFG	L	-40	22	49	183	3.86
MFG	R	46	15	55	82	3.64
MFG	R	49	36	25	113	3.97
Fusiform gyrus	R	29	-78	-11	89	3.51
Occipital lobe	L	-6	-101	-5	423	4.00

Note: *p*<.005, *k*>20, uncorrected.

Table 3.24. gDifferent_bChange > gSame_bNoChange (low – high SES)

Positively associated regions	hemisphere	x	y	z	k	t(157)
PCC	R	22	-33	43	22	-3.11

Note: *p*<.005, *k*>20, uncorrected.

Discussion part 2

Overall, as in part 1, the current results did not find that SES moderated neural processes associated with processing social feedback or conformity, either in our ROI analyses or in our whole brain analyses when using FDR correction. However, we also found somewhat different patterns at more liberal thresholds, which stand in contrast to part 1. There are several key differences between the analyses in part 1 and part 2, which may have contributed to the different pattern of results in the larger sample (part 2). First, participants in part 1 were specifically recruited to examine whether SES moderated neural processes associated with social influence, excluding participants who had a parent with bachelor's degree and focusing on participants who had parents towards the more extreme ends of education. Therefore, as an attempt to determine whether differences between those from high and low SES backgrounds is driven by those towards more extreme scores we ran a second set of analyses that focused on only those from higher and lower SES backgrounds in the larger sample at a reduced threshold. Our set of alternative analyses confirmed that once we focused on more extreme group SES backgrounds, differences began to emerge between those from higher and lower SES backgrounds. The similarities and differences between our alternative exploratory analyses from part 2 and our results from part 1 are discussed below.

Similarities in exploratory results in part 2 compared to results in part 1

First, when examining divergent compared to convergent social feedback both high and low SES displayed increased activity in the SMA, a region associated with conflict detection (Botvinick et al., 2004; Garavan et al., 2002) and one of the core regions identified in our main effect analysis in chapter 2 and a region more activated by those from both higher and lower SES backgrounds in part 1. In addition, those from higher SES backgrounds also displayed activity in the dACC and DMPFC, regions associated with conflict detection (Botvinick et al., 2004; Garavan et al., 2002) and mentalizing (Saxe, 2010), respectively, when processing divergent compared to convergent social feedback. These results are consistent with findings from both groups in part 1, but diverge in that low SES participants in part 1 also showed activity in these regions.

Next, we examined neural activity when conforming to divergent social feedback compared to maintaining one's initial preference when exposed to convergent social feedback. Results indicated both high and low SES displayed increased activity in conflict detection (dACC and SMA; (Botvinick et al., 2004; Garavan et al., 2002)) and mentalizing (DMPFC; (Saxe, 2010)) regions when conforming to social feedback that the participant is misaligned with peers, compared to processes associated with maintaining one's initial recommendation when receiving social feedback that the participant is aligned with peers. These findings are consistent with regions identified in the large-scale meta-analytic main effect results from chapter 2 and common regions activated in those from higher and lower SES backgrounds in part 1. Taken together, these results reinforce the idea that a core set of brain regions are significantly active and support processing divergent peer feedback and subsequent conformity for both high and low SES participants.

Differences in exploratory part 2 results compared to results in part 1

In addition to the similarities witnessed in comparison to part 1, results from the analyses in part 2 also suggested some potential differences, when examining exploratory results at reduced thresholds. First, when examining divergent compared to convergent social feedback those from lower SES backgrounds did not display as robust of activity in the core regions associated with conflict detection (dACC; (Botvinick et al., 2004; Garavan et al., 2002)) and mentalizing (DMPFC; (Saxe, 2010)). This may be because the current analysis includes both adolescents and young adults, unlike part 1, which only included young adults. In addition, using controls for both development and race, which were balanced across SES in part 1 and therefore not used as control variables, may have some overlap with variance associated with SES. In addition, the current analysis revealed decreased activity in the PCC for those from lower SES backgrounds and decreased activity in the MPFC for those from higher SES backgrounds. Although, both the PCC and MPFC have been implicated in studies of self-processing (Murray et al., 2012), they are implicated in different dimensions of self-related processing. For example, MPFC has been more strongly implicated in signaling self-relevance (Moran, Macrae, Heatherton, Wyland, & Kelley, 2006), whereas PCC has been more strongly implicated in autobiographical memory (Rameson, Satpute, & Lieberman, 2010).These findings suggest that receiving divergent peer feedback may decrease different forms of self-processing for those from higher and lower SES backgrounds, or that these forms of self-related processing are more strongly activated when processing convergent social feedback in these groups.

Next, we examined neural activity when conforming to divergent social feedback compared to maintaining one's initial preference when exposed to convergent social feedback. The current study differed in findings associated with those from lower SES backgrounds; we found decreased activity in regions associated with self-processing (MPFC; (Murray et al., 2012)), results not witnessed in part 1. In addition, when directly compared those from higher compared to lower SES backgrounds displayed increased activity in the PCC, results not witnessed in part 1. In part 1 of our analysis we also found when directly comparing those from higher and lower SES backgrounds those from lower SES backgrounds displayed greater activity in regions associated with memory (Shafer & Dolcos, 2012) and emotion regulation (Ochsner et al., 2004), however, these findings were not witnessed in part 2 of the analysis.

Strengths and limitations

Overall, findings from the current analysis provide evidence that differences between those from higher and lower SES backgrounds in processing social feedback and conformity are more prominent when examining individuals on more extreme ends of the spectrum. This is a fruitful area of research that needs further exploration. The lack of robust results associated with our continuous measure of SES may also suggest that additional aspects of SES need to be examined. Parental education is only one of many factors associated with SES and, therefore, only captures one aspect of socioeconomic background, specifically human capital or the intellectual environment (Mirowsky & Ross, 1998). It may be that a composite variable composed of human capital (education), social capital (social environment), and a measure of financial capital (occupation and income) may be more sensitive in revealing differences in how those from different SES backgrounds process social feedback (Mirowsky & Ross, 1998) or that differences are only apparent with more extreme groups. In addition, it may be that objective SES interacts with subjective views of social status. Future research should take these factors into consideration when examining those from different SES backgrounds.

Conclusion part 2

Overall, the current analyses did not find evidence that SES moderated neural processes associated with social influence, however exploratory results from the current analysis suggest that SES may moderate neural mechanisms associated with processing social feedback and conformity. First, results suggest that in addition to core regions implicated in conflict detection (Botvinick et al., 2004; Garavan et al., 2002) those from higher and lower SES backgrounds may use regions associated with self-processing (Murray et al., 2012) in different ways in the social influence process. More specifically, exploratory findings at reduced thresholds suggest that when those from lower SES backgrounds reduce focus on the self, they later conform, whereas those from higher SES backgrounds may reduce focus on the self when evaluating social feedback, but do not necessarily incorporate it into their final opinions. In addition, different parts of the brain implicated in self-related processes may be differentially involved in processing feedback that peers agree with the participant, according to SES. Overall, these findings bolster the idea that activity in self-processing regions may help guide socially relevant decisions, and add nuance to our understanding of when and how this might unfold. In addition, although these results do not completely replicate the findings in part 1, they do reinforce the core commonalities across SES groups, and the importance of examining differences in SES when examining neural processes associated with social influence.

CHAPTER 4. NEURAL CORRELATES OF SOCIAL INFLUENCE ACROSS DEVELOPMENT

Introduction

Social influence is present throughout life and can influence our preferences and behaviors (Cialdini & Goldstein, 2004). Despite the fact that both adolescents and adults are susceptible to social influence, adolescents tend to conform at higher rates than adults (Gardner & Steinberg, 2005). In addition, there are some distinct maturational differences in the brain between the two populations that may alter the underlying neural processes associated with conformity. In addition to physical brain differences, differences exist in sensitivity to social cues between adolescents and adults, which also plays a role in conformity (Chein et al., 2011; O'Brien, Albert, Chein, & Steinberg, 2011; Pfeifer et al., 2011). For example, adolescents show an increased importance placed on social relationships (Gardner & Steinberg, 2005) and increase in peer-influenced risk taking (Steinberg, 2008). Thus, neural differences in social influence processing and conformity may be related to differences in salience placed on social feedback. However, it is currently unknown whether neural processes associated with social influence differ between adolescents and adults performing comparable tasks. Therefore, the aim of the current study is to examine whether development moderates neural correlates associated with social influence.

Developmental differences in the brain

There is an imbalance between rapidly developing subcortical affective processing regions and slower developing prefrontal cognitive control regions during adolescence, which are both mature by adulthood (Steinberg, 2008). This asymmetric brain development has been associated with increased risk taking, particularly in the presence of a peer (Steinberg, 2008). It is believed that having faster developing affective processing systems and slower developing prefrontal cognitive control systems may lead to bottom-up rather than top-down decision making (Hare et al., 2008), which has been associated with susceptibility to risk taking during adolescence (Hare et al., 2008; Steinberg, 2010; Van Leijenhorst et al., 2010).

However, this imbalance in the rate of development between subcortical and prefrontal regions does not imply that adolescents do not have the ability to regulate their behavior. In fact, adolescent research finds that more mature subcortical structures, including the ventral and dorsal striatum, can help facilitate emotion regulation (Masten et al., 2009; Pfeifer et al., 2011) and reduce increases in risk taking associated with peer influence under certain circumstances (Pfeifer et al., 2011; Telzer, 2016). This may suggest that matured subcortical regions are compensating for the less developed prefrontal cognitive control regions. Thus, it is not clear how differences in maturation may influence neural processes known to be involved in social influence, which includes both affective processing regions within the limbic system (e.g., reward processing) and more cognitively oriented regions of prefrontal and temporal cortex (e.g., mentalizing), or whether marked differences would be observed between adolescents and young adults.

Neural correlates of social influence during adolescence and adulthood

Adolescents. Prior work examining neural processes associated with social influence within adolescent samples have shown that activity in conflict detection (Berns et al., 2010), reward sensitivity (Beard et al., under review; Cascio, O'Donnell, et al., 2015; Welborn et al., 2015), mentalizing (Beard et al., under review; Cascio, O'Donnell, et al., 2015; Welborn et al., 2015), and emotion regulation (Welborn et al., 2015) regions during social feedback that a person is misaligned with peers is associated with conformity. Consistent with the idea that conflict detection and mentalizing may drive behavior change in response to social influence during adolescence, past research has examined the relationship between these networks in response to social exclusion and peer influence. Specifically, research by Falk and colleagues (2014) found that increased activity in conflict detection and mentalizing networks during social exclusion in teens was associated with increased risk taking on a driving task one week later while in the presence of a peer (Falk et al., 2014). Furthermore, evidence for heightened affective processing during adolescence has been found simply from the mere presence of a peer. For example, research found that adolescents compared to adults show heightened activity in reward sensitivity regions during a driving task when adolescents believe they are being observed by a peer, activity in these regions also went on to predict increases in risk taking (Chein et al., 2011). Overall, these studies find evidence that conforming to social influence during adolescence may be associated with affective processing systems (social pain, reward sensitivity) coupled with considering the mental state of others (i.e., mentalizing).

Young adults. Similar to adolescents, studies of young adults' responses to social influence have also found that increased activity in affective processing regions, including reward sensitivity (Campbell-Meiklejohn et al., 2010; Nook & Zaki, 2015), as well regions associated with as conflict detection (Berns et al., 2005; Klucharev et al., 2009) are associated with conformity. For example, work by Klucharev and colleagues (2011), demonstrated that experimentally down regulating an area of the brain that overlaps with the dACC, using transcranial magnetic stimulation (TMS) decreased susceptibility to social influence (Klucharev et al., 2011). This research provides a causal link between a region within the conflict detection network and conformity. In addition, research by Tomlin and colleagues (2013) found that increased activity in the AI, a region involved in social pain and conflict, was associated with realigning decisions with group members when receiving social feedback that the participant was misaligned with the group (Tomlin et al., 2013). These results may suggest that adolescents and adults both use brain responses related to social pain and conflict detection during social influence as a cue to alter preferences or behavior and may not show marked differences; however, it is unclear whether the association is stronger for one group or the other.

In addition, activity in reward sensitivity regions has been shown to be associated with conformity in both adolescent and young adult samples (Campbell-Meiklejohn et al., 2010; Cascio, O'Donnell, et al., 2015; Nook & Zaki, 2015). However, reward sensitivity has been associated with different types of social feedback. For example, increased activity in the VS, a region associated with reward sensitivity, has been shown to be more active during consensus with group norms compared to disagreeing with group norms in college-aged young adults (Nook & Zaki, 2015). Consistent with this finding research on music preferences found that when preferences aligned with expert music reviewers, participants display greater activity in the VS (Campbell-Meiklejohn et al., 2010). Although it is difficult to draw conclusions based on a limited number of small studies, results from the young adult and adolescent literature begin to suggest that in young adult samples increased reward sensitivity activity is associated with alignment with group norms, whereas adolescents display increased reward sensitivity activity in response to learning new information (i.e., being misaligned with group norms). Thus, the two populations may be sensitive to different social cues or may respond to the same cues differently. Consistent with this view, research by Chein and colleagues (2011) found that adolescents show exaggerated VS and VMPFC activity compared to adults when they believed they were being observed by peers (compared to not being observed by peers) (Chein et al., 2011). Increased activity in the VS and VMPFC in this study was also associated with greater risk taking in adolescents compared to adults (Chein et al., 2011).

Another potential difference between adolescent and adult samples may be related to mentalizing activity associated with social influence processing and conformity (Cascio, Scholz, et al., 2015; Welborn et al., 2015). Adult samples have not typically shown activity within this network during divergent peer feedback or conformity (Cascio, Scholz, et al., 2015). Therefore, it may be that additional salience is placed on social relationships during adolescence (Gardner & Steinberg, 2005), and therefore adolescents are mentalizing more during social influence processing. However, with limited studies that have focused on mentalizing activity (Cascio, Scholz, et al., 2015; Welborn et al., 2015) during social influence, and given that qualitatively similar processes have been implicated in single studies of adolescents and adults, it is not clear whether differences exist.

The current study

The current study examined whether key periods of development (adolescents versus young adults) moderate neural correlates associated with social influence processing and conformity. Social influence processing and conformity was measured using a social influence task that involves making recommendations of mobile game apps. The current study used stimuli (mobile game apps) that are known and relevant to both adolescents and young adults, two populations that grew up with mobile technologies. The current study examined neural data using our social influence task across five independent samples.

Methods

Participants

Eligible participants were recruited across 5 studies, including two adolescent samples (N_{smple1} = 78, $N_{sample2}$ = 104) and three young adult samples ($N_{sample3}$ = 59, $N_{sample4}$=43, $N_{sample5}$ = 34), as described in Chapter 3. Participants in samples 1 and 2 were 16-17 adolescent males recruited from the Michigan Driver License Records through the University of Michigan Transportation Research Institute as part of a series of larger studies examining adolescent driving behavior (Simons-Morton et al., 2014). Samples 3 and 4 included young adults recruited from the University of Pennsylvania and surrounding Philadelphia, PA community. Sample 5 included young adults recruited from the University of Michigan. In order to compare developmental differences the following set of analyses were restricted to males only because no females were recruited in our adolescent samples. Details regarding the final sample demographics can be found in tables 4.1 and 4.2. All participants were right-handed, did not suffer from claustrophobia, were not currently taking any psychoactive medications, had normal (or corrected to normal) vision, and did not have metal in their body that was contraindicated for fMRI.

Table 4.1. Sample demographics (age and race by development)

		Age			Race		
Sample	Total Used	Mean	Std Dev	Range	White	Minority	Unknown
Sample 1	65	16.9	0.32	16-17	40	5	20
Sample 2	66	16.36	0.46	16-17	53	13	0
Sample 3	16	24.4	3.85	18-31	11	4	1
Sample 4	12	20.92	2.31	18-24	6	6	0
Sample 5	10	20.25	0.96	19-21	3	2	5

Total	169	19.77	1.58	16-31	113	30	26
Adolescents	131	16.63	0.39	16-17	93	18	20
Young Adults	38	22.66	3.08	18-31	20	12	6

Table 4.2. Sample demographics for (SES by development)

		SES				
Sample	Total Used	Mean	Low	Middle	High	Unknown
Sample 1	65	4.82	14	9	21	21
Sample 2	66	4.84	21	18	25	2
Sample 3	16	4.51	7	0	9	0
Sample 4	12	4.23	10	1	1	0
Sample 5	10	n/a	n/a	n/a	n/a	10
Total	169	4.6	52	28	56	23
Adolescents	131	4.83	35	27	46	23
Young Adults	38	4.37	17	1	10	10

Note: Sample demographics across the 5 samples. Sample 5 did not include SES data.

Study design

After participants gave assent or consent to participate in the study, they completed a number of self-report online survey measures and initial ratings on our social influence task prior to the fMRI scan. Next, they completed the group feedback version of the social influence task in an fMRI scanner. Finally, they completed additional post-scan online survey measures. As described in the previous chapter, although the broader study designs and procedures differed across the individual studies, the target task and procedures (i.e., social influence task) were similar across all studies.

Social influence task

The fMRI social influence task is described in chapter 2. The task was similar across all samples with the exception of the number of trials. Participants in samples 1, 2, 4, and 5 were asked to make recommendations on 80 mobile game apps, whereas participants in sample 3 were asked to make recommendations on 60 mobile game apps. In addition, participants in sample 3 were asked to make similar ratings on the same 60 mobile game apps in regards to whether they would download the app for themselves, these trials were not included in the following analyses.

fMRI data acquisition

Imaging data for samples 1, 2, and 5 were acquired using a 3 Tesla GE Signa MRI scanner. Functional images were recorded using a reverse spiral sequence (TR = 2,000 ms, TE = 30 ms, flip angle = 90°, 43 axial slices, FOV = 220 mm, slice thickness = 3 mm; voxel size = 3.44 mm x 3.44 mm x 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = .86 mm x .86 mm x 3.0 mm) and high-resolution T1-weighted images (spoiled gradient echo; 124 slices; slice thickness = 1.02 mm x 1.02 mm x 1.2 mm) for use in coregistration and normalization. Imaging data for samples 3 and 4 were acquired using a 3 Tesla Siemens Trio scanner. Functional images were recorded using a reverse spiral sequence (TR = 1,500 ms, TE = 25 ms, flip angle = 70°, 54 axial slices, FOV = 200 mm, slice thickness = 3 mm; voxel size = 3.0 mm x 3.0 mm x 3.0 mm). We also acquired high-resolution T1-weighted images (MPRAGE; 160 slices; slice thickness = 0.9 x 0.9 x 1.0 mm) for use in coregistration and normalization.

Data analysis

Quality checking, fMRI data preprocessing, fMRI first level modeling, ROI construction, and the participant-level statistical contrasts are described in chapter 3, part 1.

Participant matching and control variables. In an attempt to limit confounds with other demographic characteristics, measures were taken in order to ensure that demographics are similarly distributed across adolescent and young adult samples or were controlled in statistical models[6]. First, we examined whether parents' education scores differed between adolescents and adults. Results indicated that there were significant differences in parents' education, such that our sample of adolescents (*M*=4.83) were on average from more highly educated families than our sample of young adults (*M*=4.37; *F*(1, 134)=9.31, *p*=.003), therefore parental education will be used as a control variable in all analyses. In addition, we examined whether race differed

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[6] Note: Sample is not being controlled for in analyses that focus on development as it is highly confounded with development (*r*=.87, *p*<.001).

across samples, such that the proportion of minorities in the young adult sample (46.15%) was significantly higher than in our adolescent sample (15.93%; χ^2(1, 169)=4.48, *p*=.034), thus race will be used as a control variable.

Differences in peer group feedback. A repeated measures analysis of variance (ANOVA) was run to examine whether there were significant differences in the proportion of time participants changed their recommendations in response to group feedback (*not rated*, *same*, and *different*) and whether the proportion of time participants changed their recommendations differed by development, controlling for race and parental education. Results indicated that the three feedback conditions were significantly different from one another (*F*(1,162)=12.27, *p*=.001), such that participants changed their recommendation most often when receiving *different* feedback (*M* = 42.22%, *SD* = 23.25%), compared to the *same* (*M* = 9.61%, *SD* = 11.72%; *F*(1,162)=18.94, *p*<.001) or no social feedback (*M* = 16.31%, *SD* = 17.20%; *F*(1,162)=12.27, *p*=.001). In addition, the proportion of time people changed their recommendations significantly differed by feedback condition and development (*F*(1,162)=7.40, *p*=.007), such that adolescents (*M* = 44.46%, *SD* = 23.95%) conformed significantly more often than young adults (*M* = 34.44%, *SD* = 18.93%) when exposed to feedback that diverged from their initial recommendation (*F*(1,163)=5.36, *p*=.022). However, adolescents and adults did not significantly differ in the proportion of time they changed their behavior when exposed to the *same* feedback (*F*(1,162)=1.16, *p*=.284) or no social feedback (*F*(1,162)=0.04, *p*=.849).

ROI analyses. Next, planned ROI analyses examined whether neural activity within each functional ROI for each contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) moderated by development (adolescents versus young adults). Overall, only three of the five contrasts in chapter 2 revealed significant activity, therefore our ROI analyses only examined these contrasts as target regions of interest. The regression models and research questions that were analyzed are listed below.

$\text{ROI}_{(\text{gDifferent} > \text{gNotRated})} = \beta1(\text{development}) + \beta2(\text{SES}) + \beta3(\text{race}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers is moderated by development, controlling for processes associated with considering the games and the act of making recommendations without social feedback, SES, and race.

$\text{ROI}_{(\text{gDifferent} > \text{gSame})} = \beta1(\text{development}) + \beta2(\text{SES}) + \beta3(\text{race}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers is moderated by development. This regression captures whether those from different SES backgrounds differ in how different types of social feedback are processed, controlling for SES and race.

$\text{ROI}_{(\text{gDifferent\_bChange} > \text{gSame\_bNoChange})} = \beta1(\text{development}) + \beta2(\text{SES}) + \beta3(\text{race}) + \varepsilon$: We examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers is moderated by development. This regression captures whether those from different SES backgrounds differ in processes that contribute to adhering to peers depending on whether the participant previously agreed or disagreed with the social feedback, controlling for SES and race.

Whole brain analyses. In addition to examining our functional ROIs, we examined whether the relationship between feedback condition and activity in neural regions outside of our functional ROIs were moderated by development in a series of exploratory whole brain analyses. To do this we will examine the contrasts (gDifferent > gNotRated, gSame > gNotRated, gDifferent > gSame, gSame > gDifferent, gDifferent_bChange > gDifferent_bNoChange, and gDifferent_bChange > gSame_bNoChange) for (adolescents – young adults), controlling for SES and race. See methods section in chapter 2 for contrast definitions. Results from the first level models were combined at the group level using a random effects model implemented in SPM8. All whole brain analyses were corrected for multiple comparisons using FDR, $p<.05$, $k>20$, implemented in SPM8. In addition, to balance concerns about type I and type II error, we also explored the difference models at a more liberal uncorrected threshold to explore potential regions worth pursuing moving ahead (*p*=.005, *k*>20). All coordinates were reported in MNI space.

Results

ROI analyses

First, we examined whether neural activity within each functional ROI for each contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) were differently activated by development (adolescents versus young adults) among male participants.

Processing social feedback

$\text{ROI}_{(\text{gDifferent > gNotRated})} = \beta 1(\text{development}) + \beta 2(\text{SES}) + \beta 3(\text{race}) + \varepsilon$. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were moderated by development, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, development did not moderate neural activity in the functionally defined ROI (β=-.02, *t*(165)=-0.19, *p*=.851, *CI*=[-.09, .07]).

$\text{ROI}_{(\text{gDifferent > gSame})} = \beta 1(\text{development}) + \beta 2(\text{SES}) + \beta 3(\text{race}) + \varepsilon$. Second, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by development. Overall, development did not significantly moderate neural activity in the functionally defined ROI (β=.05, *t*(165)=0.62, *p*=.535, *CI*=[-.03, .03]).

Conformity

$\text{ROI}_{(\text{gDifferent\_bChange > gSame\_bNoChange})} = \beta 1(\text{development}) + \beta 2(\text{SES}) + \beta 3(\text{race}) + \varepsilon$. Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by development. Overall, did not significantly moderate activity in the functionally defined ROI (β=.00, *t*(165)=0.04, *p*=.969, *CI*=[-

.06, .06]).

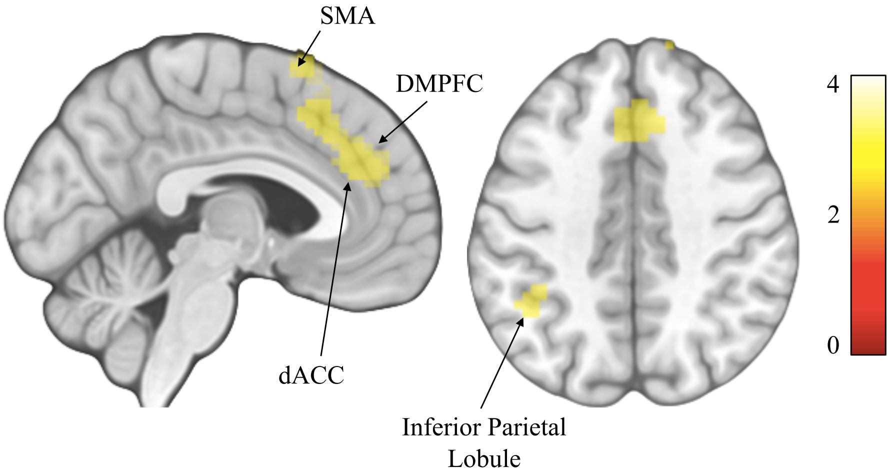
Whole brain analyses

In addition to examining our functional and hypothesized ROIs, we examined whether the relationship between feedback condition and activity in neural regions outside of our functional ROIs were moderated by development in a series of whole brain analyses that mirror the contrasts examined in our ROI analyses (FDR, *p*<.05, *k*>20).

Processing social feedback

Whole $\text{brain}_{(\text{gDifferent > gNotRated})}$ = β1(development) + β2(SES) + β3(race) + ε. First, we examined neural processes associated with receiving social feedback that the participant is misaligned with peers were significantly moderated by development, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Results indicate that young adults display greater activity in the SMA, DMPFC, dACC, inferior parietal lobule, and precentral gyrus when receiving social feedback that the participant is misaligned with peers, results not witnessed in teens (table 4.3; figure 4.1). Teens, however, did not show any significant differences when examined independently. When directly compared (adults – teens), no significant differences in neural activity survived FDR correction.

Figure 4.1. gDifferent > gNotRated (adults)



Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 4.3. gDifferent > gNotRated (adults)

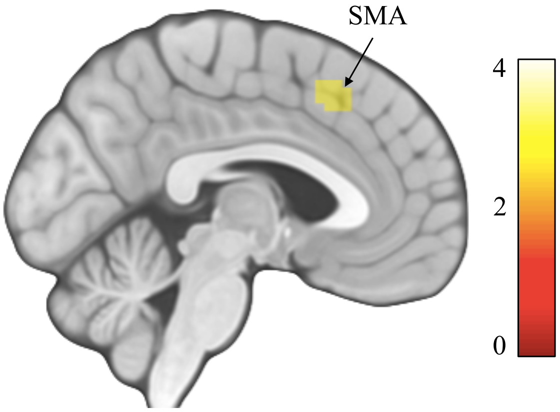
regions	hemisphere	x	y	z	k	t(36)
SMA / dACC	R/L	-6	19	49	374	5.74
dACC / DMPFC	R	22	56	31	42	5.07
inferior parietal lobule	L	-44	-54	46	30	4.56
precentral gyrus	R	42	5	31	26	4.13

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Whole $\text{brain}_{(\text{gSame} > \text{gNotRated})}$ = β1(development) + β2(SES) + β3(race) + ε. In addition, we examined whether neural processes associated with receiving social feedback that the participant is aligned with peers were moderated by development, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, adolescents and adults did not show any significant differences when examined independently. In addition, neural activity was not significantly moderated by development.

Whole $\text{brain}_{(\text{gDifferent} > \text{gSame})}$ = β1(development) + β2(SES) + β3(race) + ε. Next, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by development. Results indicate that young adults display greater activity in the SMA when receiving social feedback that the participant is misaligned with peers compared to aligned with peers, results not witnessed in teens (table 4.5; figure 4.3). Teens, however, did not show any significant differences when examined independently. When directly compared (adults – teens), no significant differences in neural activity survived FDR correction.

Figure 4.3. gDifferent > gSame (adults)



Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 4.5. gDifferent > gSame (adults)

regions	hemisphere	x	y	z	k	t(36)
SMA	R/L	-2	19	46	51	5
cerebellum	R	35	-60	-38	25	5.06

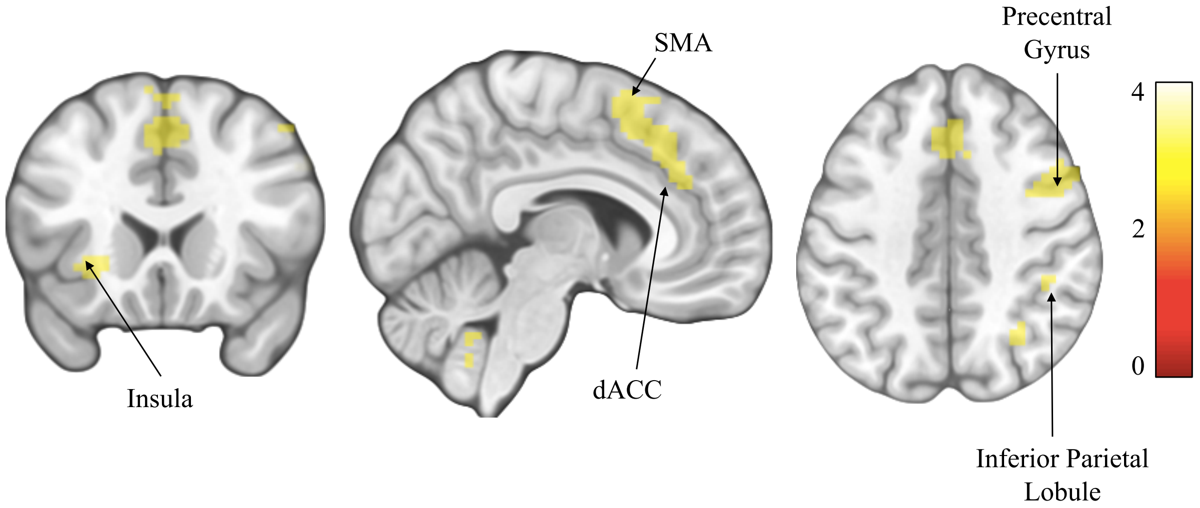
Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Conformity

Whole brain$_{(\text{gDifferent\_bChange > gDifferent\_bNoChange})}$ = β1(development) + β2(SES) + β3(race) + ε. Furthermore, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when misaligned with peers were moderated by development. Overall, no significant activity was found when examining teens and adults independently. In addition, when directly compared (adults – teens), no significant differences in neural activity survived FDR correction.

Whole brain$_{(\text{gDifferent\_bChange > gSame\_bNoChange})}$ = β1(development) + β2(SES) + β3(race) + ε. Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by development. Results indicated that activity in the SMA, dACC, precuneus, superior and inferior parietal lobules, and insula were significantly more active during conformity to divergent vs. convergent peer feedback for young adults, results not witnessed in teens (table 4.8; figure 4.6). In addition, no significant activity was witnessed when examining teens independently. Furthermore, when directly compared (adults – teens), no significant differences in neural activity survived FDR correction.

Figure 4.6. gDifferent_bChange > gSame_bNoChange (adults)



Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

Table 4.8. gDifferent_bChange > gSame_bNoChange (adults)

regions	hemisphere	x	y	z	k	t(36)
precentral gyrus	R	53	8	40	138	5.11
SMA / dACC	R/L	4	12	58	185	4.87
precuneus	R	11	-67	61	34	4.81
superior parietal lobule	L	-37	-54	58	34	4.36
inferior parietal lobule	R	32	-50	52	100	4.36
insula	L	-26	22	-5	22	3.72
cerebellum	L	-6	-57	-47	25	4.8

Note: Corrected for multiple comparisons using FDR, *p*<.05, *k*>20.

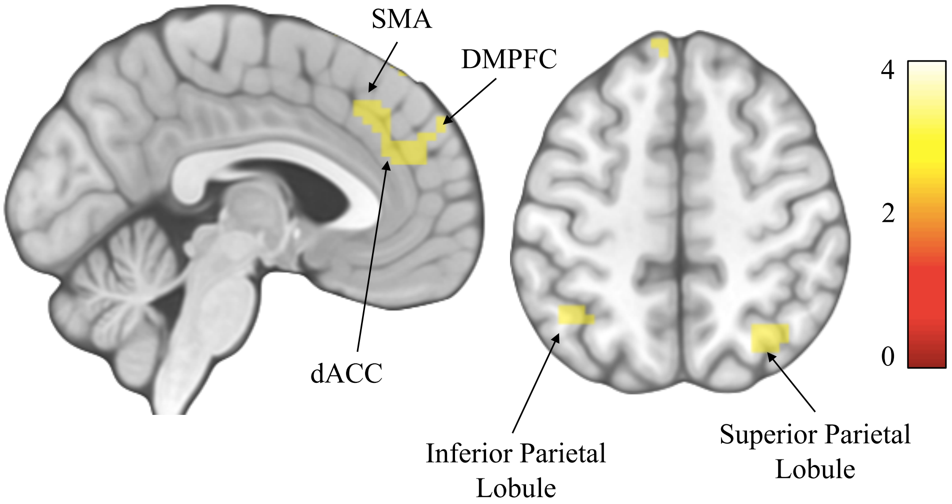
Exploratory whole brain analyses

A series of exploratory whole brain analyses run at a less conservative threshold (*p*<.005, *k*>20, uncorrected) examined potential additional regions in which processing of social feedback or conformity may be moderated by development.

Processing social feedback

Whole $\text{brain}_{(\text{gDifferent > gNotRated})}$ = β1(development) + β2(SES) + β3(race) + ε. First, we examined neural processes associated with receiving social feedback that the participant is misaligned with peers were significantly moderated by development, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. When examining (adults – teens) at a reduced threshold (*k*>20, *p*=.005) increased activity in the SMA, DMPFC, dACC, and inferior parietal lobule when receiving social feedback that the participant is misaligned with peers was found for young adults compared to teens (table 4.4; figure 4.2).

Figure 4.2. gDifferent > gNotRated (adults – teens)



Note: *k*>20, *p*=.005, uncorrected

Table 4.4. gDifferent > gNotRated (adults – teens)

regions	hemisphere	x	y	z	k	t(168)
SMA / DMPFC	R/L	-6	39	64	125	5.09
DMPFC / dACC	R/L	-2	29	40	61	2.99

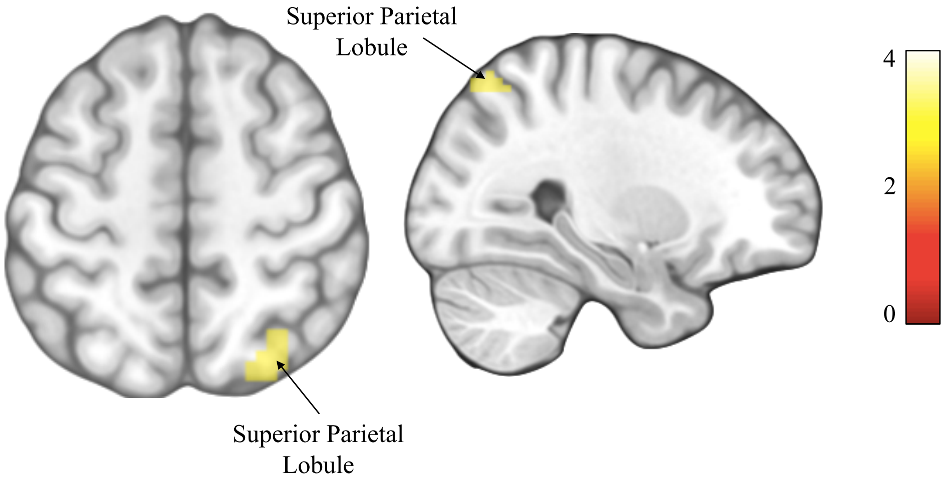
superior parietal lobule	R	32	-64	58	64	3.4
inferior parietal lobule	L	-44	-54	49	32	3.06
superior frontal gyrus	R	18	53	37	23	3.22

Note: *k*>20, *p*=.005, uncorrected

Whole brain$_{(\text{gSame > gNotRated})}$ = β1(development) + β2(SES) + β3(race) + ε. In addition, we examined whether neural processes associated with receiving social feedback that the participant is aligned with peers were moderated by development, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, neural activity was not significantly moderated by development, even at a less conservative threshold.

Whole brain$_{(\text{gDifferent > gSame})}$ = β1(development) + β2(SES) + β3(race) + ε. Next, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by development. When examining (adults – teens) at a reduced threshold (*k*>20, *p*=.005) increased activity in the superior parietal lobule when receiving social feedback that the participant is misaligned with peers was found for young adults compared to teens (table 4.6; figure 4.4).

Figure 4.4. gDifferent > gSame (adults – teens)



Note: *k*>20, *p*=.005, uncorrected

Table 4.6. gDifferent > gSame (adults – teens)

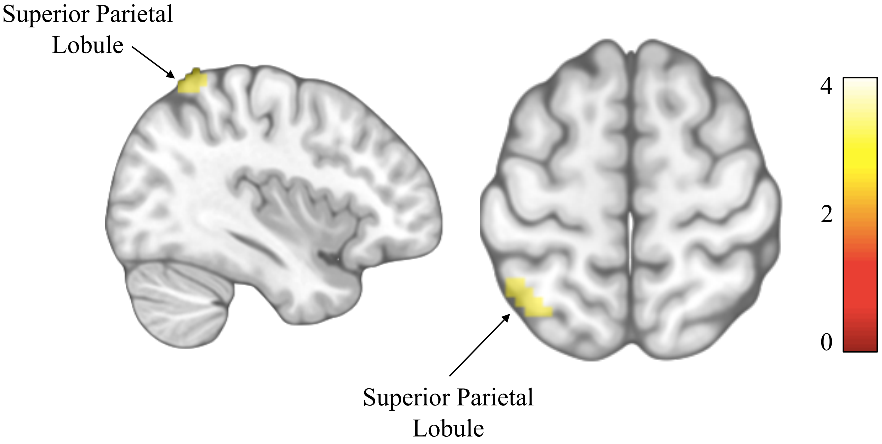
regions	hemisphere	x	y	z	k	t(168)
superior parietal lobule	R	25	-71	58	48	3.16

Note: *k*>20, *p*=.005, uncorrected

Conformity

Whole brain$_{(gDifferent\_bChange > gDifferent\_bNoChange)}$ = β1(development) + β2(SES) + β3(race) + ε. Furthermore, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when misaligned with peers were moderated by development. When examining (adults – teens) at a reduced threshold (*k*>20, *p*=.005) increased activity in the superior and inferior parietal lobules when conforming to social feedback that the participant is misaligned with peers compared to maintaining one's initial recommendation was found for young adults compared to teens (table 4.7; figure 4.5).

Figure 4.5. gDifferent_bChange > gDifferent_bNoChange (adults – teens)



Note: *k*>20, *p*=.005, uncorrected

Table 4.7. gDifferent_bChange > gDifferent_bNoChange (adults – teens)

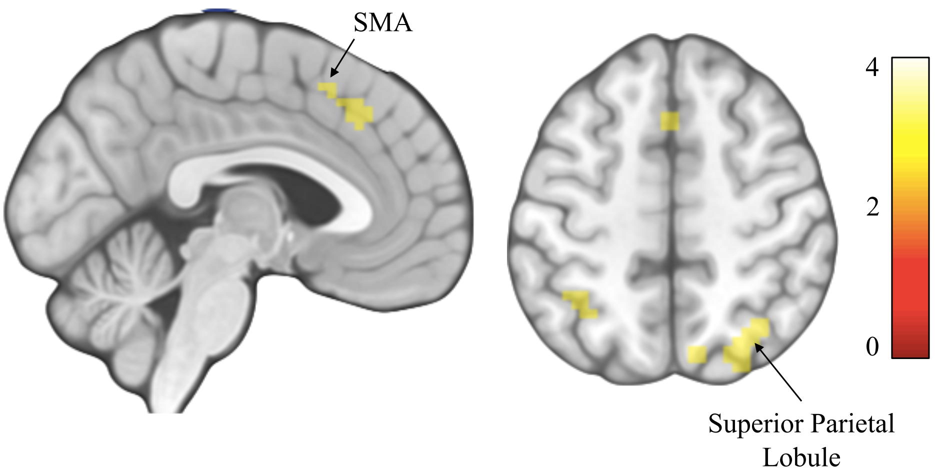
regions	hemisphere	x	y	z	k	t(168)
superior parietal lobule / inferior parietal lobule	L	-37	-54	67	40	3.37

Note: *k*>20, *p*=.005, uncorrected

$$\text{Whole brain}_{(\text{gDifferent\_bChange} > \text{gSame\_bNoChange})} = \beta1(\text{development}) + \beta2(\text{SES}) + \beta3(\text{race}) + \varepsilon.$$

Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by development. When examining (adults – teens), no significant differences in neural activity survived FDR correction. However, when examining (adults – teens) at a reduced threshold (*k*>20, *p*=.005) increased activity in the SMA, MFG, and superior and inferior parietal lobules when conforming to social feedback that the participant is misaligned with peers compared to maintaining one's initial recommendation were found for young adults compared to teens (table 4.9; figure 4.7).

Figure 4.7. gDifferent_bChange > gSame_bNoChange (adults – teens)



Note: *k*>20, *p*=.005, uncorrected

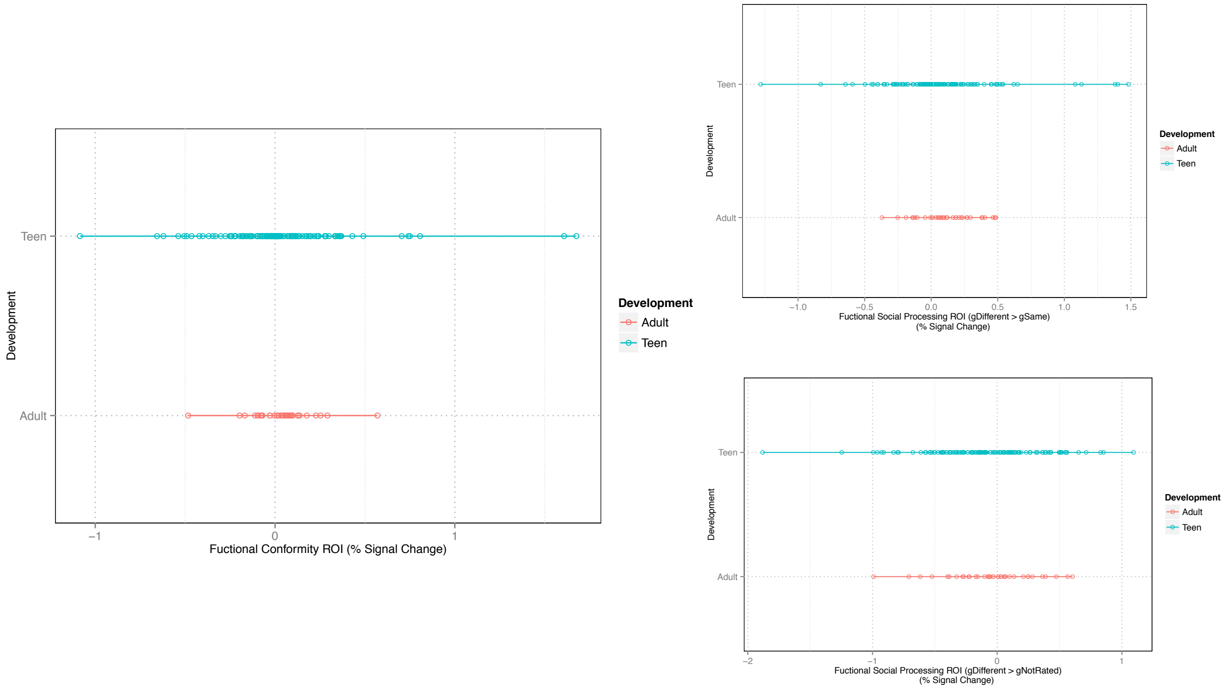
Table 4.9. gDifferent_bChange > gSame_bNoChange (adults – teens)

regions	hemisphere	x	y	z	k	t(168)
inferior parietal lobule / superior parietal lobule	L	-37	-54	55	42	3.16
superior parietal lobule	R	29	-64	61	184	3.92
SMA	R/L	5	36	64	46	3.32
SMA	R/L	-2	29	43	29	3.11
MFG	L	-33	59	16	33	3.19

Note: *k*>20, *p*=.005, uncorrected

Finally, because no significant results were witnessed when we examined teens independently (even at reduced thresholds of *p*=.005, *k*>20, uncorrected) we hypothesized that this may be attributed to a wider range of variance on the task. Therefore, we examined individual differences in percent signal change scores in our functional ROIs in order to determine whether teens show greater variance among adolescents compared to young adults (figure 4.8), making it more difficult to find effects that are common across teens. Results from a test of variance (*F*-test) demonstrated that adolescents displayed significantly greater variance in our conformity ROI (*F*(37)=4.27, *p*<.001) and social feedback ROI (gDifferent > gSame; *F*(37)=3.10, *p*<.001), and was marginally greater variance in our (gDifferent > gNotRated) ROI (*F*(37)=1.66, *p*=.075), compared to adults. These results suggest that increased variability may be driving the null results witnessed in our teen sample.

Figure 4.8. Scatterplot of individual differences in processing social feedback and conformity.



Note: Percent signal change scores for the functional ROIs (gDifferent_bChange > gSame_bNoChange; gDifferent > gNotRated; and gDifferent > gSame).

Discussion

The current study aimed to examine whether key periods of development (adolescents versus young adults) moderate neural correlates associated with social influence processing and conformity. Overall, we observed greater levels of conformity in teens compared to young adults. Functional ROI analyses did not reveal any significant differences between adolescents and young adults in neural regions associated with processing social feedback and conformity, suggesting that there are not robust differences in these core regions across teens and young adults. This suggests that although similar processes underlie processing social feedback and conformity the two groups differ in their willingness to conform. This is consistent with prior evidence demonstrating that adolescents show an increased importance placed on social relationships (Gardner & Steinberg, 2005).

However, a series of exploratory whole brain analyses did find neural differences between adolescents and young adults at more liberal thresholds that are suggestive of some changes in the way that social influence is processed. We also observed significant differences in the variance of brain activity associated with social influence, such that teens showed significantly more variability than young adults. These results are discussed below, however given the exploratory nature of the analyses these results should be interpreted with caution.

Behavioral differences between adolescents and young adults

Significant differences in conformity were witnessed between adolescents and young adults, such that teens conformed to divergent social feedback significantly more often compared to young adults. This is consistent with the literature on adolescents, suggesting teens are more susceptible to peer influence compared to adults (Gardner & Steinberg, 2005; Steinberg, 2008).

Developmental differences in processing social feedback

First, when examining processes associated with exposure to divergent social feedback compared to no social feedback at exploratory thresholds, adults compared to adolescents showed greater activity in the SMA, DMPFC, dACC, inferior parietal lobule, and superior parietal lobule. In addition, when examining processes associated with exposure to divergent social feedback compared to convergent social feedback, adults compared to adolescents showed greater activity in the superior parietal lobule, as well as greater activity in the SMA when adults were examined independently. These findings in young adults are consistent with the overall findings from our large-scale main effect meta-analytic analyses, demonstrating that the SMA, DMPFC, and dACC cluster was a core set of neural regions associated with processing social feedback, and may suggest that the older participants in the main analysis drove the effects. The finding in young adults is consistent with past research that suggests social influence is associated neural regions involved in prediction error (Klucharev et al., 2009) and conflict detection (Berns et al., 2010; Klucharev et al., 2011; Tomlin et al., 2013). In addition, young adults showed greater activity in the inferior and superior parietal lobules, regions that have been found to be active during episodic memory retrieval (Wagner, Shannon, Kahn, & Buckner, 2005). This may suggest that when confronted with social feedback that suggests one is misaligned with peers, in addition to using regions associated with conflict detection and mentalizing, adults also attempt to retrieve the memory of their initial preference or other relevant information.

By contrast, adolescents did not show any significant differences between divergent social feedback and no social feedback even when examined independently. Results from exploratory follow-up analyses (see scatterplots in Figure 4.8) suggest that this may be related to higher variance between teens in how they process social feedback. Indeed, a growing body of studies suggest that teens show more diffuse patterns of brain activity than adults (Blakemore, 2008). This may suggest that teens are still learning how to process social feedback and have not yet developed a consistent, strategic way of dealing with divergent social feedback, or that there is greater heterogeneity among developing teens than young adults. In addition, anatomical and functional shifts occur over the course of adolescence (Crone & Dahl, 2012). Coupled with the current findings that suggest high levels of variability in strategies adopted and brain regions recruited in teens, this may help explain the null findings observed in the current investigation.

Developmental differences in conformity

Next, we examined whether development moderated neural activity associated with conformity. First, we examined activity associated with conforming compared to maintaining one's initial recommendation when exposed to divergent social feedback. At exploratory thresholds, adults compared to adolescents showed greater activity in the inferior and superior parietal lobules. These findings may suggest that the retrieval of details associated with the initial preference help guide adults as to whether or not they are willing to conform to divergent social feedback. No activity was associated with conformity in the adolescent sample. As outlined above this may be attributed to heterogeneity in how adolescents process social feedback and changes in brain structure and function that render activation patterns more variable and diffuse during adolescence.

Finally, we examined activity associated with conforming to divergent social feedback compared to maintaining one's initial recommendation when confronted with convergent social feedback. Results at exploratory thresholds indicated that activity in the SMA, DMPFC, dACC, superior and inferior parietal lobules were significantly more active for adults compared to adolescents. In addition, when examined independently, adults also showed increased activity in regions associated with emotional responses to being out of line with the group (insula; (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003)). However, no regions were more active for adolescents when examining neural activity associated with conformity, again potentially attributable to heterogeneity in how adolescent brains process social feedback. Overall, consistent with processing social feedback these findings suggest that neural systems conflict detection (Berns et al., 2010; Klucharev et al., 2009, 2011; Tomlin et al., 2013) and memory retrieval (Wagner et al., 2005) are involved in conformity among young adults, and a less consistent pattern may be associated with conformity in teens.

Comparisons to previous literature

The current study is one of the first studies to directly compare teens to young adults on processes associated with social influence. Prior work has primarily focused on one developmental group or the other, and although there are some consistencies there are notable differences with past literature. First, in our teen sample, the current study did not find any significant differences in how social feedback was processed when peers agreed and disagreed with the participant. Prior work examining teens has found that activity in regions associated with conflict detection (Berns et al., 2010), mentalizing (Welborn et al., 2015), and emotion regulation (Welborn et al., 2015) during social feedback that a person is misaligned with peers is associated with conformity. These differences between our study and the prior literature may be attributed, in part, to the populations studied. For example, Welborn et al. (2015) examined conformity in a group of Mexican-Americans who mainly came from households with parents with less than a high school diploma and were currently receiving subsidized lunches. Therefore, in addition to being teens, the majority of the sample was also from a lower SES background and a different cultural background than the participants in our study; coupled with results from Chapter 3, it may be important to account not only for differences in development, but also for differences in a range of socio-demographic factors such as different dimensions of SES. In addition, Berns et al., (2010) found that regions associated with conflict detection were associated with conformity among adolescents, however, this sample examined teens aged 12 to 17. This large age range, particularly when the brain is still developing, may be one reason we find different results.

Findings from our young adult sample suggest that neural systems associated with conflict detection (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003), mentalizing (Saxe, 2010), and memory retrieval (Wagner et al., 2005) are involved in processing social feedback and conformity. Past research examining young adults also finds that neural regions associated with conflict detection (Berns et al., 2005; Klucharev et al., 2009, 2011; Tomlin et al., 2013) are associated with conformity. In addition, memory retrieval is a process that has not previously been associated with conformity within adult populations.

Strengths and limitations

Overall, this is one of the first studies to directly compare differences in neural mechanisms associated with processing social feedback and conformity in young adults and adolescents. Although the current study finds evidence for processes underlying the adult brain, null results in our adolescent sample make it difficult to infer which neural systems underlie social influence in this population. The increased variance witnessed in our functional ROIs among teens compared to adults may suggest that teens are still learning how to deal with social feedback more broadly, and do not process and evaluate convergent and divergent social feedback in a consistent way. Another possibility is that anatomical shifts associated with development render the processes associated with influence more diffuse in this period. In order to better understand which processes are involved in social influence future research may focus on the examination of functional networks by determining which regions communicate with core regions identified in our large-scale meta-analytic main effects analysis. Another limitation of this study is the lack of female participants, thus generalizations can only be extended to males and results are limited to the age ranges included in the current study. Indeed, our young adults are still quite young, and stronger differences might be observed across studies that track a wider span of development. Future research should extend the current findings to include female participants and a wider range of ages. In addition, as fleshed out in more detail in earlier chapters, it should be noted that neural regions do not map onto a single process and we are inferring cognitive processes that are taking place when processing social feedback and conformity (i.e., reverse inference; (Poldrack, 2006)). Therefore, additional interpretations of the findings as discussed in previous chapters are plausible.

Conclusion

Overall, the current study aimed to examine whether key periods of development (adolescents versus young adults) moderate neural correlates associated with social influence processing and conformity. Although differences between teens and young adults were not witnessed in our FDR corrected analyses, findings from our exploratory whole brain analyses conducted at more liberal thresholds suggest that neural systems associated with conflict detection (Botvinick et al., 2004; Garavan et al., 2002), mentalizing (Saxe, 2010), and memory retrieval (Wagner et al., 2005) are involved in processing social feedback and conformity among young adults compared to adolescents. The current findings are consistent with past studies of social influence in adults, which have found that increased activity in conflict detection regions are associated with conformity (Berns et al., 2005; Klucharev et al., 2009, 2011; Tomlin et al., 2013). Given the findings in the current study were associated with young adults compared to adolescents, this may suggest that adults more strongly use brain responses related to conflict detection and mentalizing during social influence as cues to alter preferences, or that they do so in a more consistent and focal manner.

CHAPTER 5. INTERACTION BETWEEN SES AND DEVELOPMENT ON THE NEURAL CORRELATES OF SOCIAL INFLUENCE

Introduction

People encounter social influence on a regular basis, which has the power to influence our preferences and behaviors (Cialdini & Goldstein, 2004). In the two previous studies we examined whether SES (study 2) and development (study 3) independently moderated the neural mechanisms associated with processing and conforming to social feedback that a person is misaligned with peer norms. However, research has not yet addressed whether development (adolescence versus adulthood) and SES (low versus high) interact to influence neural processes associated with social influence processing and conformity. Although we did not find robust differences when considering either SES or development on their own, we have not yet examined whether differences in social influence functioning associated with SES are consistent or different across development and into adulthood.

The current study

Study 4 brings together studies 2 and 3, by examining whether SES (parents' education) and development (adolescents versus young adults) moderate neural processes associated with social influence and conformity.

Methods

Participants

Participants were recruited across 4 studies, including two adolescent samples (N_{smple1} = 78, $N_{sample2}$ = 104) and two young adult samples ($N_{sample3}$ = 59, $N_{sample4}$=43). Participants in samples 1 and 2 were 16-17 year old adolescent males recruited from the Michigan Driver License Records through the University of Michigan Transportation Research Institute as part of a series of larger studies examining adolescent driving behavior (Falk et al., 2014; Simons-Morton et al., 2014). Samples 3 and 4 included young adults recruited from the University of

Pennsylvania and surrounding Philadelphia, PA community. Details regarding sample demographics can be found in table 22. All participants were right-handed, did not suffer from claustrophobia, were not currently taking any psychoactive medications, had normal (or corrected to normal) vision, and did not have metal in their body that was contraindicated for fMRI. In addition, participants that took part in our adolescent driving studies (samples 1 and 2) did not typically experience motion sickness, which could affect driving simulation testing.

Study design

After participants gave assent to participate in the study, they completed a number of self-report online survey measures, including measures of parental education (SES) and initial ratings on our social influence task prior to the fMRI scan. Next, they completed the group feedback version of the social influence task in an fMRI scanner. Finally, they completed additional post-scan online survey measures. Although the broader study designs and procedures differed across the individual studies, the target task and procedures (i.e., social influence task) were similar across all studies.

Socioeconomic status (SES)

Fathers' and mothers' education served as our primary measure of SES. Participants were asked what level of education their father and mother had completed based on 7-point scale, where 1 = less than high school, 2 = high school, 3 = trade school, 4 = associates degree, 5 = bachelor degree, 6 = graduate degree, and 7 = unknown. Unknown levels of education (response = 7) were dropped from the analysis. Then a combined continuous parents' education variable was created using the average score between the father and mother.

Social influence task

The fMRI social influence task is described in chapter 2. The task was similar across all samples with the exception of the number of trials. Participants in samples 1, 2, and 4 were asked to make recommendations on 80 mobile game apps, whereas participants in sample 3 were asked to make recommendations on 60 mobile game apps. In addition, participants in sample 3 were asked to make similar ratings on the same 60 mobile game apps in regards to whether they would download the app for themselves, these trials were not included in the following analyses.

fMRI data acquisition

Imaging data for samples 1 and 2 were acquired using a 3 Tesla GE Signa MRI scanner. Functional images were recorded using a reverse spiral sequence (TR = 2,000 ms, TE = 30 ms, flip angle = 90°, 43 axial slices, FOV = 220 mm, slice thickness = 3 mm; voxel size = 3.44 mm x 3.44 mm x 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = .86 mm x .86 mm x 3.0 mm) and high-resolution T1-weighted images (spoiled gradient echo; 124 slices; slice thickness = 1.02 mm x 1.02 mm x 1.2 mm) for use in coregistration and normalization. Imaging data for samples 3 and 4 were acquired using a 3 Tesla Siemens Trio scanner. Functional images were recorded using a reverse spiral sequence (TR = 1,500 ms, TE = 25 ms, flip angle = 70°, 54 axial slices, FOV = 200 mm, slice thickness = 3 mm; voxel size = 3.0 mm x 3.0 mm x 3.0 mm). We also acquired high-resolution T1-weighted images (MPRAGE; 160 slices; slice thickness = 0.9 x 0.9 x 1.0 mm) for use in coregistration and normalization.

Data analysis

Quality checking, fMRI data preprocessing, fMRI first level modeling, ROI construction, and the participant-level statistical contrasts are described in chapter 3, part 1.

Participant matching and control variables. Based on the previous analyses conducted in studies 2 and 3 we took the following steps to limit confounds with SES and development. First, we controlled for the main effects of SES and development. Next, race was shown to be significantly different between adolescents and young adults, therefore, race was also used as a control variable. Finally, we limited the sample to males, given the confound with development.

Differences in peer group feedback. The proportion of time participants changed their recommendations in response to group feedback (*not rated*, *same*, and *different*) was reported above. As reported in chapter 3, results indicated that the three feedback conditions were significantly different from one another. In addition, we examined whether the interaction between SES and development moderated the effect of feedback condition on conformity. Results indicated that the interaction between SES and development did not significantly moderate the effect of feedback condition on conformity (*F*(3, 157)=0.66, *p*=.578).

ROI analyses. Next, planned ROI analyses will examine whether neural activity within each functional ROI for each contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) is differently activated by the interaction of development (adolescents versus young adults) and SES (parents' education). The regression models and research questions that will be analyzed are listed below.

$\text{ROI}_{(\text{gDifferent} > \text{gNotRated})} = \beta 1(\text{development}) + \beta 2(\text{SES}) + \beta 3(\text{development} * \text{SES}) + \beta 4(\text{race}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers is moderated by the interaction of development and SES, controlling for processes associated with considering the games and the act of making recommendations without social feedback and race.

$\text{ROI}_{(\text{gDifferent} > \text{gSame})} = \beta 1(\text{development}) + \beta 2(\text{SES}) + \beta 3(\text{development} * \text{SES}) + \beta 4(\text{race}) + \varepsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers is moderated by the interaction of development and SES. This regression captures whether those from different SES backgrounds differ in how different types of social feedback are processed, controlling for race.

$\text{ROI}_{(\text{gDifferent\_bChange} > \text{gSame\_bNoChange})} = \beta 1(\text{development}) + \beta 2(\text{SES}) + \beta 3(\text{development} * \text{SES}) + \beta 4(\text{race}) + \varepsilon$: We examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers is moderated by the interaction of development and SES. This regression captures whether those from different SES backgrounds differ in processes that contribute to adhering to peers depending on whether the participant previously agreed or disagreed with the social feedback, controlling for race.

Whole brain analyses. In addition to examining our functional ROIs, we examined whether the relationship between feedback condition and activity in neural regions outside of our functional ROIs are moderated by development and SES in a series of exploratory whole brain analyses. To do this we will regress SES (parents' education) onto the contrasts (gDifferent > gNotRated, gSame > gNotRated, gDifferent > gSame, gSame > gDifferent, gDifferent_bChange > gDifferent_bNoChange, and gDifferent_bChange > gSame_bNoChange) for (adolescents – young adults), controlling for race. See methods section in chapter 2 for contrast definitions. Results from the first level models will be combined at the group level using a random effects model implemented in SPM8. All whole brain analyses were corrected for multiple comparisons using FDR, $p<.05$, $k>20$, implemented in SPM8. In addition, to balance concerns about type I and type II error, we also explored the difference models at a more liberal uncorrected threshold to explore potential regions worth pursuing moving ahead ($p=.005$, $k>20$). All coordinates were reported in MNI space.

Results

ROI analyses

First, we examined whether neural activity within each functionally defined ROI for each contrast (gDifferent > gNotRated, gDifferent > gSame, and gDifferent_bChange > gSame_bNoChange) were differently activated by SES and development (adolescents versus young adults) among male participants.

Different feedback

$\mathrm{ROI}_{(\mathrm{gDifferent} > \mathrm{gNotRated})} = \beta1(\mathrm{development}) + \beta2(\mathrm{SES}) + \beta3(\mathrm{development} * \mathrm{SES}) + \beta4(\mathrm{race}) + \varepsilon$. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were moderated by the interaction of development and SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Overall, the interaction of development and SES did not significantly moderate neural activity in the functionally defined conformity ROI ($\beta=.05$, $t(131)=0.52$, $p=.604$, $CI=[-.05, .08]$).

$\mathrm{ROI}_{(\mathrm{gDifferent} > \mathrm{gSame})} = \beta1(\mathrm{development}) + \beta2(\mathrm{SES}) + \beta3(\mathrm{development} * \mathrm{SES}) + \beta4(\mathrm{race}) + \varepsilon$. Second, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by the interaction of development and SES. Overall, the interaction of development and SES did not significantly moderate neural activity in the functionally defined conformity ROI (β=-.01, *t*(131)=0.11, *p*=.916, *CI*=[-.06, .05]).

Conformity

$\text{ROI}_{(\text{gDifferent\_bChange} > \text{gSame\_bNoChange})}$ = β1(development) + β2(SES) + β3(development * SES) + β4(race) + ε. Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by the interaction of development and SES. Overall, the interaction of development and SES did not significantly moderate neural activity in the functionally defined conformity ROI (β=.01, *t*(131)=0.05, *p*=.959, *CI*=[-.05, .05]).

Whole brain analyses

In addition to examining our functional ROIs, we examined whether the relationship between feedback condition and activity in neural regions outside of our hypothesized ROIs were moderated by the interaction of development and SES in a series of whole brain analyses that mirror the contrasts examined in our ROI analyses (FDR, *p*<.05, *k*>20)..

Processing social feedback

Whole $\text{brain}_{(\text{gDifferent} > \text{gNotRated})}$ = β1(development) + β2(SES) + β3(development * SES) + β4(race) + ε. First, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers were moderated by the interaction of development and SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Neural activity was not significantly moderated by the interaction of development and SES.

Whole $\text{brain}_{(\text{gSame} > \text{gNotRated})}$ = β1(development) + β2(SES) + β3(development * SES) + β4(race) + ε. Furthermore, we examined whether neural processes associated with receiving social feedback that the participant is aligned with peers were moderated by the interaction of development and SES, controlling for processes associated with considering the games and the act of making recommendations, without social feedback. Neural activity was not significantly moderated by the interaction of development and SES.

Whole $\text{brain}_{(\text{gDifferent} > \text{gSame})}$ = β1(development) + β2(SES) + β3(development * SES) + β4(race) + ε. Second, we examined whether neural processes associated with receiving social feedback that the participant is misaligned with peers, compared to processes associated with receiving social feedback that the participant is aligned with peers were moderated by the interaction of development and SES. Neural activity was not significantly moderated by development and the interaction of development and SES.

Conformity

Whole $\text{brain}_{(\text{gDifferent\_bChange} > \text{gDifferent\_bNoChange})}$ = β1(development) + β2(SES) + β3(development * SES) + β4(race) + ε. Next, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when misaligned with peers were moderated by the interaction of development and SES. Neural activity was not significantly moderated by the interaction of development and SES.

Whole $\text{brain}_{(\text{gDifferent\_bChange} > \text{gSame\_bNoChange})}$ = β1(development) + β2(SES) + β3(development * SES) + β4(race) + ε. Finally, we examined whether neural processes associated with conforming to peer feedback when misaligned with peers, compared to processes associated with maintaining initial recommendations when aligned with peers were moderated by the interaction of development and SES. Neural activity was not significantly moderated by the interaction of development and SES.

Discussion

Overall, the current study did not find any evidence that the interaction between SES and development moderated neural mechanisms associated with processing social feedback or conformity. Given the robust similarities observed across high and low SES participants in our sample, it is possible that there is less of an interaction between SES and development in moderating the neural processes implicated in social influence than we originally hypothesized. There are, however, also a number of limitations that may have led to the null findings. First, participants were not specifically recruited for the purposes of exploring the interaction between SES and development. Therefore, the loss of data due to the lack of SES responses, as well as examining a male only sample may have reduced the sample size to the point that the study was underpowered to detect a multi-way interaction effect. In addition, we found in chapter 3 that effects associated with SES were more strongly related to participants with more divergent SES scores, in a similar way the age range between our young adult (22.66 years old) and teen (16.63 years old) samples is restricted, therefore there may not have been enough of a discrepancy between the groups to detect an interaction. Overall, these limitations may suggest that in order to answer the question of whether the interaction between SES and development moderate neural processes associated with social influence processing new data may need to be collected or combined with existing data that can clearly discriminate between groups that vary more across SES and development.

Future work may also want to focus on a multivariate approach to answering this question. For example, multi-voxel pattern analysis (MVPA) may be more sensitive to classifying patterns of neural activity across the brain during conformity and when processing social feedback that are unique to SES (high versus low) and development (adolescents versus young adults).

In addition, as mentioned in part 2 of chapter 3, the current study only captured one aspect of SES, parental education, which is a proxy for human capital, among other things (Mirowsky & Ross, 1998). Measuring additional aspects of SES, including financial and social capital, may help clarify whether neural mechanisms associated with social influence differ between adolescents and young adults along other dimensions or whether social influence is processed in the same way for each group.

CHAPTER 6. CONCLUSIONS

Overall, gaining a better understanding of the underlying mechanisms that drive social influence is of great interest across many fields, and the current set of studies aimed to advance that understanding. The current dissertation aimed to examine two important aspects of social influence by focusing on the neural mechanisms associated with viewing or processing social feedback, as well as the neural mechanisms associated with conforming to social feedback. In order to explore these questions the current dissertation answered 4 questions.

First, we examined which neural mechanisms underlie processing social feedback and conformity across 249 people, making it the largest study of social influence in the brain to date. Key findings from the first study indicated that neural regions involved in conflict detection (Botvinick et al., 2004; Garavan et al., 2002) and mentalizing (Saxe, 2010) were more active when processing social feedback that the individual was misaligned with peers. In addition, conformity to social feedback that the individual was misaligned with peers was associated with neural activity in regions associated with conflict detection (Eisenberger & Lieberman, 2004; Eisenberger et al., 2003), inhibitory control (Aron et al., 2004; Simmonds et al., 2008), and mentalizing (Saxe, 2010). These findings are consistent with past research that suggests social influence is associated neural regions involved in prediction error (Klucharev et al., 2009), conflict detection (Berns et al., 2010; Klucharev et al., 2011; Tomlin et al., 2013), and mentalizing (Cascio, O’Donnell, et al., 2015; Welborn et al., 2015). Importantly, the results from this large-scale study of social influence provide a baseline mapping of neural mechanisms involved in processing social feedback and conformity, which can serve as a comparison group for other studies or can be used to create functional ROIs for use in future analyses.

Second, we examined whether SES (high versus low) moderates neural mechanisms associated with social influence processing and conformity in a 2-part study. We first examined the relationship between SES and social influence processing in a study specifically recruited for this purpose. Findings demonstrated that high and low SES recruit similar core regions when processing social feedback (SMA, DMPFC, and dACC) and conformity (SMA, DMPFC, dACC, IFG, MFG, and anterior insula), however, exploratory analyses conducted at more liberal thresholds provide some suggestive evidence that participants from high and low SES backgrounds may differ in the degree to which they employ certain regions previously associated with conformity. Specifically, when directly compared the current study suggests that those from lower SES backgrounds recruit regions associated with memory (Shafer & Dolcos, 2012) and emotion regulation (Ochsner et al., 2004) to a greater extent during conformity than those from higher SES. However, these findings were only revealed at less conservative thresholds and therefore should be interpreted with caution. Overall, these findings suggest that along with core commonalities, SES may moderate neural processes associated with social influence in somewhat subtle ways and suggest promise in examining SES when examining psychological and neurological processes.

In addition, when examining whether SES (high versus low) moderates neural mechanisms associated with social influence processing and conformity in the larger dataset in part 2 of the study we found evidence that SES moderated neural processes associated with social influence, but only when we examined extreme groups and (i.e., removing participants who had parents with an average of a bachelors degree) and used a more liberal threshold.

Next, we examined whether development (adolescents versus adults) moderates neural mechanisms associated with social influence. First, at our FDR corrected threshold no significant differences were witnessed between teens and young adults. However, when examined independently, results demonstrated that neural systems associated with conflict detection (Botvinick et al., 2004; Garavan et al., 2002), mentalizing (Saxe, 2010), and memory retrieval (Wagner et al., 2005) are involved in processing social feedback and conformity among adults, results not witnessed in our adolescent samples. The current findings are consistent with past studies of social influence in adults, which have found that increased activity in conflict detection regions are associated with conformity (Berns et al., 2005; Klucharev et al., 2009, 2011; Tomlin et al., 2013). However, results from our development study did not reveal which neural processes were associated with processing social feedback or conformity among adolescents. The null findings may be attributed to the increased variance in neural activity associated with teens versus adults, suggesting that teens vary in the strategies they use to process social feedback or that functional differences in the development of neuroanatomy make it difficult to find consistent effects. In addition, given the findings in our developmental study were associated with adults rather than adolescents, this may suggest that young adults more consistently use brain responses related to conflict detection and mentalizing during social influence as cues to alter preferences, or that they do so in a more focal manner.

Finally, we examined whether the relationship between SES and social influence processing and conformity is different depending on developmental trajectories. Our analyses did not find any evidence that the interaction between SES and development moderated neural mechanisms associated with processing social feedback or conformity. These null results may suggest that no differences in neural activity exist between SES (high and low) and development (adolescents compared to young adults). However, the current analyses may not have been sensitive enough to capture whether SES and development moderated neural mechanisms associated with social influence.

Taken together, the current dissertation provides robust evidence for a core set of brain systems implicated in social influence. We address previous limitations in the control conditions used across different past studies of influence and begin to explore ways that socio-demographic factors may moderate the neural bases of social influence. Moving forward, research that also examines the connections between different brain regions in response to peer feedback, and that support conformity will further illuminate commonalities and differences across groups.

APPENDIX

Table A1. gDifferent > gNotRated (chapter 2 alternative analysis)

positively	hemisphere	x	y	z	k	t(248)
middle frontal gyrus	R	42	22	49	20	3.24
supplementary motor area / dorsal medial prefrontal cortex	R/L	8	15	70	421	5.02
inferior frontal gyrus	R	53	29	1	23	3.81
inferior frontal gyrus	L	-51	29	-2	60	3.46
ventral medial prefrontal cortex	R	11	56	-26	24	3.72
cerebellum	R	35	-85	-35	39	3.71

region	hemisphere	x	y	z	k	t(248)
posterior cingulate	R	11	-30	49	79	3.67
occipital lobe	R	15	-88	34	41	3.5
middel temporal gyrus	R	63	-57	16	29	3.15
temporoparietal junction	L	-44	-33	13	196	3.35
temporoparietal junction	R	66	-19	10	396	5.03

Note: *p*=.005, *k*>20, uncorrected.

Table A2. gDifferent_bChange > gDifferent_bNoChange (chapter 2 alternative analysis)

region	hemisphere	x	y	z	k	t(247)
inferior parietal lobule / precuneus	L	-20	-60	37	96	3.76
temporoparietal junction	R	46	-50	28	44	3.25
inferior frontal gyrus	R	53	22	16	146	4.3
inferior occipital lobe	L	-37	-67	10	77	3.52

Note: *p*=.005, *k*>20, uncorrected.

Table A3. gDifferent_bNoChange > gSame_bNoChange (chapter 2 alternative analysis)

region	hemisphere	x	y	z	k	t(247)
SMA	R/L	1	22	49	30	2.99
SFG / MFG	R	35	56	25	67	3.47
Occipital lobe	L	-16	-105	4	95	3.93
Occipital lobe	R	22	-102	10	224	4.48
Occipital lobe	R/L	-2	-91	-11	220	4.09
Cerebellum	R/L	1	-78	-26	31	3.25

Note: *p*=.005, *k*>20, uncorrected.

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