



Neural correlates associated with conformity in adolescent and young adult men

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ARTICLE INFO

Keywords:

Social influence
Conformity
Development
Conflict monitoring
fMRI

ABSTRACT

Social influence affects us throughout our lives, shaping our attitudes, behaviors, and preferences. Thus, the current study aimed to examine whether key age groups (adolescence versus young adulthood) were associated with differences in neural correlates associated with processing social feedback and conformity (i.e., conflict detection, positive valuation, and mentalizing) among young men. We recruited 153 participants across 5 studies, who completed a social influence task during an fMRI scan. Overall, participants were more likely to conform by changing their ratings when misaligned with others, and adolescents were more likely to conform when misaligned (compared to aligned) with others compared to young adults. Further, we found that adolescents showed increased activity in mentalizing (TPJ, dmPFC) and positive valuation regions (VS, vmPFC), compared to young adults, in response to misalignment with others. In contrast, young adults showed increased activity in conflict detection regions (AI, dACC) when exposed to feedback that they were misaligned with others and when conforming to that feedback. Overall, our results offer initial evidence that adolescent and young adult men engage different neural processes when they find out they are misaligned with others and when conforming to the recommendations of others, and this difference appears to track with brain responses in conflict detection, mentalizing and value regions.

Data statement: Raw data and analysis codes are available upon request.

1. Introduction

Social influence affects us throughout our lives, shaping our attitudes, behaviors, and preferences (Cialdini and Goldstein, 2004; Steinberg and Monahan, 2007). Although adults' and adolescents' preferences and behaviors are shaped by social influence, adolescents are more likely than adults to conform (Ciranka and Van den Bos, 2019; Gardner and Steinberg, 2005). This tendency is attributed to an increased salience placed on peer relationships, as suggested by the social reorientation model (Nelson et al., 2005, 2016; Cosme et al., 2022), and developmental changes occurring in the brain (Steinberg, 2008). This susceptibility is often seen as a danger by parents, educators and other adults, who worry that "peer pressure" will drive adolescents to dangerous or delinquent behaviors. Indeed, research finds that peer

influence is a factor in many adolescent risk behaviors, including drug use (Andrews et al., 2002), alcohol use (Urberg et al., 1997), risky sexual behavior (Romer et al., 1994), and dangerous driving (Simons-Morton et al., 2005; Simons-Morton et al., 2011). Social influence among adolescents has also been associated with prosocial behavior (van Hoorn et al., 2016) and reduced risk-taking (Goddings et al., 2019). Thus, understanding the mechanisms behind conformity to peer influence is essential for understanding risk and promoting broader well-being.

There is already considerable research into the neural mechanisms associated with social influence, but most of this work has been conducted on independent adolescent (Berns et al., 2010; Cascio, O'Donnell et al., 2015; Welborn et al., 2016) or adult (Berns et al., 2005; Klucharev et al., 2009; Zaki et al., 2011) samples. A smaller number of studies have directly compared the ways adolescents and adults process peer

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<https://doi.org/10.1016/j.dcn.2023.101215>

Received 19 September 2022; Received in revised form 2 February 2023; Accepted 8 February 2023

Available online 15 February 2023

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influenced driving risk (Chein et al., 2011) and social influence among women (Knoll et al., 2020), but more research is needed that examines how age differences may influence social influence, particularly among young men. In this study, we investigated the neural mechanisms behind susceptibility to social influence by directly comparing the processing of social feedback and subsequent conformity by young adult (18–31 years old; post-high school early adults) and late adolescent (16–17 years old; underage high school students) men, groups particularly at risk for risk taking and susceptibility to peer influence (Cranka and Van den Bos, 2019; Gardner and Steinberg, 2005) and at different stages in their social growth with early adulthood serving as a major transition point where young adults are becoming more independent (Yelle et al., 2009).

A recent review suggests that adolescent men are more susceptible to social influences to engage in risk-taking behavior than adolescent women (McCoy et al., 2019), which may contribute to higher rates of accidental death (Goldstick et al., 2022). For example, teenage men driving with peers are more likely than women to be injured or killed in a car accident (Chen et al., 2000; McCartt et al., 2003). Male gender norms have also been attributed to adolescent men's (compared to women's) increased likelihood of school misconduct, including being disruptive and aggressive in class, lower achievement, disciplinary problems, and alcohol and smoking use (Aloe et al., 2014; Heyder et al., 2021). Further, adolescent men seem to be particularly sensitive to social rewards for cruel behavior (Altikulaç et al., 2019), which they exhibit more than adolescent women (Snyder et al., 2012). These differences may be explained by socialization to a risk-taking ideal (McCoy et al., 2019), but they may also be partly attributable to differences in brain development across the biological sexes (Lenroot and Giedd, 2010). Both social and biological explanations suggest the importance of understanding susceptibility to social influence in adolescent men.

1.1. The role of developmental differences

Differences in adults' and adolescents' susceptibilities to peer influence may be attributed to changes in salience placed on peer relationships, as suggested by the social reorientation model (Cosme et al., 2022; Nelson et al., 2005, 2016). This model suggests that social cues related to social acceptance are particularly salient during adolescence compared to adulthood (Nelson et al., 2016). Thus, socially oriented networks in the brain may be more responsive to social cues from peers in adolescents, compared to young adults, and differences in brain response may explain differences in susceptibility to peer influence. For example, during adolescence social influence is associated with increased activity in regions associated with considering the mental states of others, or mentalizing, (Cascio, O'Donnell et al., 2015; Welborn et al., 2016), which has not been observed as consistently in young adult samples of social influence (Berns et al., 2005; Klucharev et al., 2009; Zaki et al., 2011). Although, these two groups are close in age they are at different stages in their social growth with early adulthood serving as a major transition point where young adults may be beginning college, living on their own, and gaining more independence/separation from their parents (Yelle et al., 2009). In addition, the focus on men during social influence provides an important extension to the small number of studies have directly compared the ways adolescents versus adults process peer influenced driving risk (Chein et al., 2011) and social influence among women (Knoll et al., 2020).

Differences in young adults' and adolescents' susceptibilities to peer influence may also be explained in part by developmental changes in the brain during adolescence. Such changes are thought to partly explain the adolescent tendency toward increased risk-taking (Steinberg, 2008), particularly when the risky behavior is performed in the presence of a peer. Though both mature by adulthood, affective processing regions develop more quickly during adolescence than prefrontal cognitive control regions (Steinberg, 2008). This asymmetric development is thought to create a preference for "bottom up" over "top down" decision-making (Hare et al., 2008), which tends to produce more

risk-taking behavior during adolescence (Hare et al., 2008; Steinberg, 2010; Van Leijenhorst et al., 2010).

Importantly, this imbalance in the rate of development between subcortical and prefrontal regions does not imply that adolescents lack 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 more mature subcortical regions are compensating for the less developed prefrontal cognitive control regions.

At this point, however, it is not clear how differences in maturation may influence neural processes known to be involved in social influence. Past research implicates both affective processing regions within the limbic system (e.g., ventral striatum (VS)) and more cognitively oriented regions of prefrontal and temporal cortex (e.g., mentalizing) in social influence (Campbell-Meiklejohn et al., 2010; Cascio, O'Donnell et al., 2015; Chein et al., 2011; Nook and Zaki, 2015; Welborn et al., 2016; Zaki et al., 2011). Thus, given developmental changes in these regions, neural differences in regions most strongly implicated in social influence may change across development.

One study that directly examined social influence on risk decision making found that young adult women (aged 23–29) compared to adolescent girls (aged 12–14) displayed increased activity in the putamen, middle frontal gyrus, postcentral gyrus, and inferior parietal lobe during social agreement (i.e., participant opinions aligned with peers) (Knoll et al., 2020). However, null findings during social disagreement make it unclear whether neural regions associated with conforming to the opinions of others are the same versus different between adolescents and young adults when directly compared, and did not clarify whether the same would be true in young men. Another direct comparison of adolescents and adults on peer influenced risk-taking in the driving context found that during simulated driving, adolescents displayed increased activity in the VS and ventral medial prefrontal cortex (vmPFC) in the presence of a peer (compared to no peer presence) and this activity predicted increased risk taking on the driving task (Chein et al., 2011). Differing degrees of convergence and divergence in results reported in independent adolescent (Berns et al., 2010; Cascio, O'Donnell et al., 2015; Welborn et al., 2016) and adult studies (Berns et al., 2005; Klucharev et al., 2009; Zaki et al., 2011), however, suggest direct comparisons between the two age groups should be further examined.

1.2. Neural correlates of social influence during adolescence and adulthood

1.2.1. Positive valuation

Activity in the ventral striatum VS and vmPFC, regions associated with positive valuation (Bartra et al., 2013) and reward processing (McClure et al., 2004), has been associated with conformity in both adolescent and young adult samples (Campbell-Meiklejohn et al., 2010; Cascio, O'Donnell et al., 2015; Nook and Zaki, 2015). However, the VS has been associated with different types of social feedback. For example, increased activity in the VS, is more active during consensus with group norms compared to disagreeing with group norms in college-aged young adults (Nook and Zaki, 2015). Consistent with this finding, research on music preferences found that when preferences aligned with those of expert music reviewers, young adult participants displayed 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 suggest that in young adult samples, increased VS activity is associated with alignment with group norms, whereas adolescents display increased VS activity in response to learning new information (i.e., being misaligned with group norms). Thus, the two age groups may be sensitive to different social cues or may respond to the same cues differently.

Consistent with this view, research by [Chein et al. \(2011\)](#) found that adolescents show greater VS and vmPFC activity compared to adults when they believed they were being observed by others (compared to not being observed by others) ([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](#)). Research on risky decision-making among young adults has shown that increased connectivity between the VS and vmPFC was associated with increased risk-taking following the influence of parents' risky decisions compared to peer risk, suggesting parents and not peers may guide risky decisions associated with increased VS and vmPFC activity in young adults ([Kwon et al., 2021](#)).

1.2.2. Mentalizing

Another potential difference between adolescent and adult samples may be related to activity in the temporoparietal junction (TPJ) and dorsal medial prefrontal cortex (dmPFC), regions associated with mentalizing ([Kliemann and Adolphs, 2018](#)); activation of these brain regions has also been associated with social influence processing and conformity in prior research ([Cascio et al., 2015](#); [Welborn et al., 2016](#)).¹ Adult samples have not typically shown activity within mentalizing regions during divergent peer feedback or conformity ([Cascio et al., 2015](#)). Whereas, prior work on social influence in adolescent samples has highlighted brain regions involved in mentalizing ([Cascio et al., 2015](#); [Welborn et al., 2016](#)). Therefore, it may be that additional salience is placed on social relationships during adolescence ([Gardner and Steinberg, 2005](#)), and therefore adolescents are mentalizing more during social influence processing. However, with limited studies that have focused on mentalizing activity ([Cascio et al., 2015](#); [Welborn et al., 2016](#)) during social influence, and given that qualitatively similar processes have been implicated in single studies of adolescents and young adults, it is not clear whether differences exist.

1.2.3. Conflict monitoring

Conformity, or adjustment of attitudes or preferences to align with those of a group, has been associated with increased activity in the anterior insula (AI) and dorsal anterior cingulate (dACC) ([Berns et al., 2005, 2010](#); [Klucharev et al., 2009](#); [Tomlin et al., 2013](#)), regions implicated in conflict monitoring ([Botvinick et al., 2004](#)), social pain ([Eisenberger, 2012](#)), and negative valuation ([Bartra et al., 2013](#)) among adolescence ([Berns et al., 2010](#)) and adults ([Berns et al., 2005](#); [Klucharev et al., 2009](#); [Tomlin et al., 2013](#)). For example, work by [Klucharev et al. \(2011\)](#), 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 the dACC, a region within the conflict monitoring network ([Botvinick et al., 2004](#)), and conformity. In addition, research by [Tomlin et al. \(2013\)](#) found that increased activity in the anterior insula (AI), another region involved in conflict monitoring ([Botvinick et al., 2004](#)), was associated with realigning decisions with group members when receiving social feedback that the participant was misaligned with the group ([Tomlin et al., 2013](#)). Even exposure and conformity to implicit peer influence among young adults has been associated with increased activity in the dACC and dorsal striatum ([Venticinque et al., 2021](#)).

Among adolescents, research examining music preferences found that activity in the AI and ACC when participants were misaligned with popularity ratings was positively associated with the tendency to conform by adjusting preferences ([Berns et al., 2010](#)). Similarly, activation in the AI and dACC in late-adolescent women was found when women received misaligned feedback about their attitudes toward female body types ([van der Meulen et al., 2017](#)). These results may suggest

that adolescents and young adults both use brain responses related to conflict monitoring 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.

1.3. The current study

The current study directly compared the processing of social influence in late adolescent (currently in high school) and young adult (post-high school early adults) male samples, groups particularly at risk for risk taking and susceptibility to peer influence ([Ciranka and Van den Bos, 2019](#); [Gardner and Steinberg, 2005](#)). Given the literature reviewed above, special attention was paid to regions associated with conflict detection, mentalizing, and positive valuation. We explicitly focus on brain activity first as participants were exposed to social feedback about their alignment with group norms, and then separately examine neural correlates of conformity. We operationalize these constructs using an ecologically valid social influence task that involves making recommendations of mobile puzzle game apps across five independent samples. The current study used stimuli (mobile puzzle game apps) that are known and relevant to both adolescents and young adults, two populations that grew up with mobile technologies.

Activity in the AI and dACC, VS and vmPFC, and dmPFC and TPJ are implicated in a variety of cognitive functions beyond the processes we highlight above. Given that we identified sub-regions of these areas for their roles in positive valuation, mentalizing, and conflict monitoring, respectively, we will refer to activity in these regions using these terms for simplicity in the methods and results sections. However, in the discussion we will expand on alternative explanations that may be tied to neural activity in these regions.

2. Methods

2.1. Participants

Eligible participants were recruited across 5 studies (total $N = 153$), including two late adolescent samples ($N_{=112}$) and three young adult samples ($N_{=41}$) that took part in a series of fMRI studies that all included a parallel neuroimaging social influence task ([Cascio et al., 2015](#)). Adolescent participants were 16–17 adolescent men ($M=16.90$ years old, $SD=0.37$) 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](#)). Young adult participants (18–31 years old; $M=22.43$ years old, $SD=3.54$) were men recruited from the University of Pennsylvania and surrounding Philadelphia, PA community and from the University of Michigan. It should be noted that age data was missing for one teen sample due to errors recording responses and in 9 of the young adult participants. Exploratory analyses including a continuous measure of age for participants with usable age data is reported in [supplemental materials](#). 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.

Participants in all but one young adult sample were asked about parents' education as a measure of socioeconomic status. Participants were asked what level of education their father(s) and/or mother(s) had completed based on 7-point scale, where 1 =less than high school, 2 =high school, 3 =trade school, 4 =associate 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(s) and/or mother(s). Late adolescent parents had a significantly higher average level of education ($t(127) = 3.31, p = .001, CI = [0.37, 1.46]$) equivalent to a bachelor degree ($M=4.78, SD=1.15, \min=2, \max=6$) compared to young adult parents that had an

¹ Note: It should be noted that the data from [Cascio et al. \(2015\)](#) are included in the current investigation, and thus these findings are not independent.

average level of education equivalent to an associate degree ($M=3.87$, $SD=1.66$, $min=2$, $max=6$). To address differences in parental education between the two groups the primary ROI analyses controlling for parental education are reported in [supplemental materials](#). All results are consistent across the two sets of analyses.

2.2. Study design

After participants gave assent (for late adolescent samples) or consent (for adult samples) to participate in the study, they completed self-report online survey measures and gave initial ratings of a series of mobile puzzle game apps, prior to the fMRI scan. Next, they completed a 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.

2.3. Social influence task

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 a series of mobile app puzzle games (similar to games like angry birds). During the initial rating session participants were asked to give their preliminary recommendations on 80² 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 1–5 Likert scale, where 1 represented “*wouldn't recommend*” and 5 represented “*would recommend*”. The 80 trials were randomly ordered within participants (Fig. 1).

Next, during the fMRI session participants completed a second round of the social influence task. Participants were told that they would be re-rating the same 80 mobile game apps, however, this time participants would be shown the title, logo, and a reminder of how they initially rated the game (2 s). Participants were instructed that they would then be shown information about whether others in the study were more/less likely (*misaligned*) or equally likely (*aligned*) to recommend the games to others. For some games, participants were told that information had not yet been collected so no peer recommendation information was available (*no social feedback*). Peer group recommendations were pseudo randomly computer generated in order to maintain 20 trials (3 s each) for each feedback type (15 trials for the sample that rated 60 apps). 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 (3 s; Fig. 2). Stimuli were presented over two runs (three runs for the sample with 60 apps).

2.4. fMRI data acquisition

Imaging data for samples conducted at the University of Michigan 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 = 3 mm; voxel size = 3.44 mm × 3.44 mm × 3.0 mm). We also acquired in-plane T1-weighted images (43 slices; slice thickness = 3 mm; voxel size = 0.86 mm × 0.86 mm × 3.0 mm) and high-resolution T1-weighted images (spoiled gradient echo; 124 slices; slice thickness = 1.02 mm × 1.02 mm × 1.2 mm) for use in coregistration and normalization. Imaging data for samples collected at the University of Pennsylvania were acquired using a 3 Tesla Siemens Trio scanner. Functional images were recorded using a reverse spiral sequence (TR = 1500 ms, TE

= 25 ms, flip angle = 70°, 54 axial slices, FOV = 200 mm, slice thickness = 3 mm; voxel size = 3.0 mm × 3.0 mm × 3.0 mm). We also acquired high-resolution T1-weighted images (MPRAGE; 160 slices; slice thickness = 0.9 × 0.9 × 1.0 mm) for use in coregistration and normalization.

Given data was collected at the University of Michigan and the University of Pennsylvania among the young adult sample we examined whether there were any significant differences within our ROIs between the two locations. Results indicated that there were no significant differences associated with scanner location within any of our ROIs. Full results are reported in [supplemental materials](#) (Table S1).

2.5. fMRI data analyses

2.5.1. Preprocessing

Functional data were pre-processed and analyzed using Statistical Parametric Mapping (SPM12, 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 were 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). Motion parameters from SPM were examined and no runs displaying greater than 3 mm (translation) or 2 degrees (rotation) of head movement during a task run were used.

2.5.2. Statistical modeling

Data were modeled at the single subject level using the general linear model as implemented in SPM12. We then modeled the three-second period during which participants were exposed to the peer feedback (*aligned*, *misaligned*, *no social feedback*) as a boxcar (duration = 3 s).

In a separate set of models, we combined information about peer feedback with 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*). Trials that had missing final ratings were excluded from analyses that included the contrast (*misaligned + change > misaligned + no change*). Two of the possible combinations, *no social feedback + change* and *aligned + change* 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. On average the combination of ‘*no social feedback + change*’ and ‘*aligned + change*’ occurred in 3.4 trials (out of 20) and 2 trials (out of 20), respectively. Further, 51 participants in the *no social feedback + change* condition and 73 in the *aligned + change* condition participants had 1 or 0 trials in which this occurred.

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

2.5.3. Region of interest analyses

Regions of interest (ROI) were constructed based on functional networks derived from the association test maps in the meta-analytical tool NeuroSynth (Yarkoni et al., 2011). NeuroSynth is a validated

² Note: One sample of young adults made ratings for 60 mobile phone apps, but other elements of the task were the same.

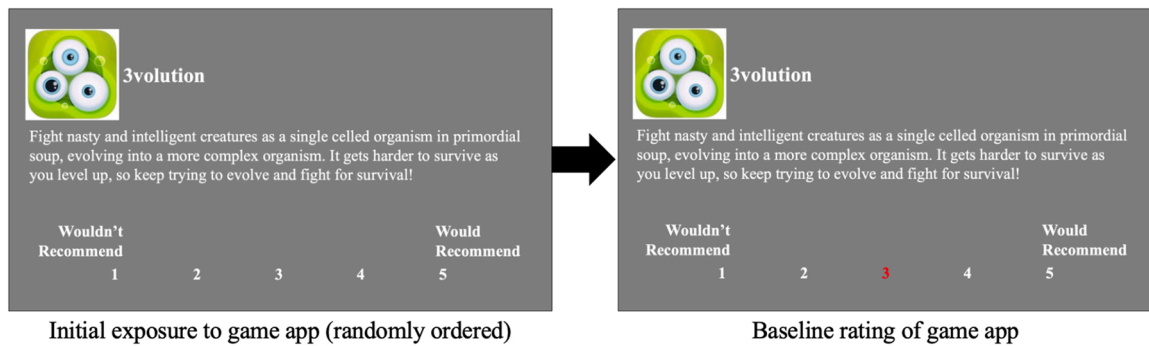


Fig. 1. Initial game app ratings, Note: Initial ratings of the game apps were collected before the scanning session. Rating were based on a 5 point scale from 1 = "wouldn't recommend" to 5 = "would recommend". Ratings were based on exposure to the game logo, title, and a brief description of the game.

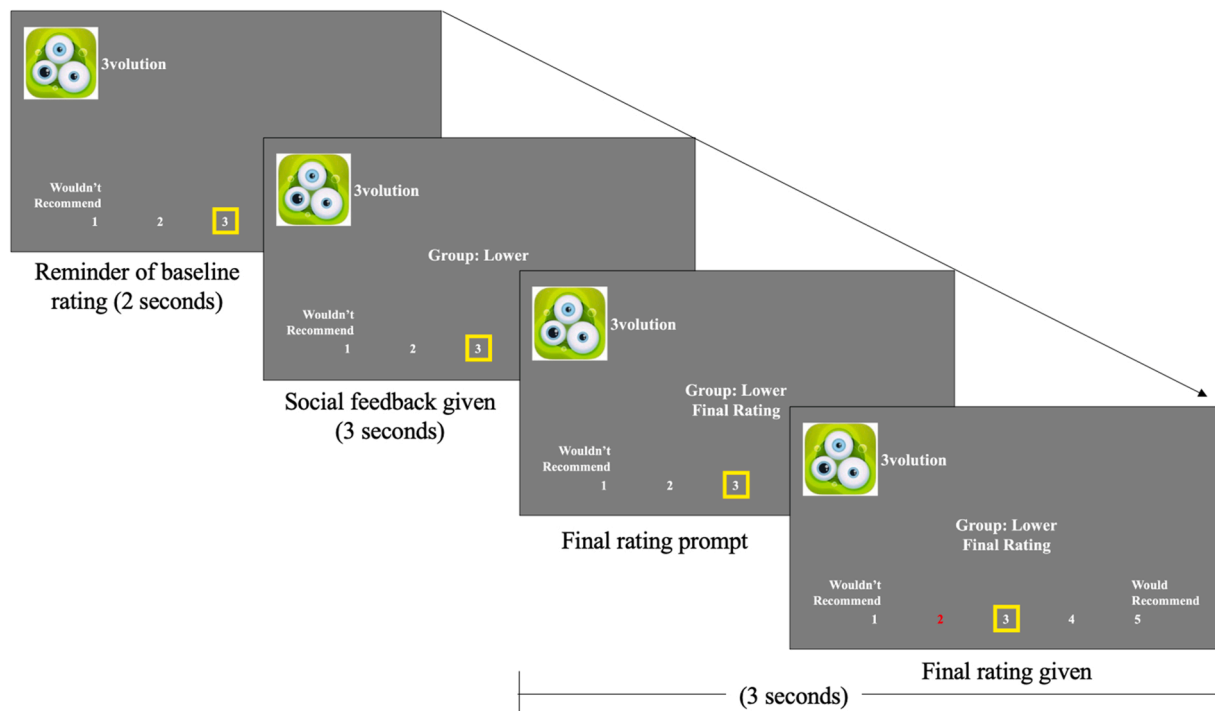


Fig. 2. fMRI social feedback ratings, Note: The social feedback (*higher, lower, same, or not rated*) version of the task was given during the scanning session. Rating were based on a 5 point scale from 1 = "wouldn't recommend" to 5 = "would recommend". Ratings were based on exposure to the game logo, title, and a reminder of the participant's initial rating.

meta-analytic approach that allows researchers to functionally map neural activity associated with cognitive functions of interest (Yarkoni et al., 2011). The advantage of the association test maps is that they provide activation in regions that are more consistently activated in studies that report the cognitive function of interest compared to studies that do not report the cognitive function, which adjusts for the base rate of activation in a given region (Yarkoni et al., 2011). For these reasons the current study constructed ROIs by identifying functional association test maps associated with the search terms "conflict", "mentalizing", and "value" using NeuroSynth (Fig. 3). In all cases, we found that the resulting ROIs included regions associated with the processes highlighted in our literature review: dACC and AI for conflict, vmPFC and VS for value, and dm PFC and TPJ for mentalizing, among other regions. Given our theoretical interest in the psychological processes outlined, we treated the association test maps as single regions of interest, averaging across activity in the regions surfaced by the NeuroSynth analysis. Regression analyses (outlined below) were conducted in R (version 4.1.2).

There is the potential that the activation differences witnessed

between late adolescents and young adults is attributed to increased activity across the brain and may not be specific to the ROI being tested. To address this concern, we ran an additional set of ROI analyses using the search term "attention", given this is a cognitive process that is likely involved in completing the task but does not have much overlap with the primary regions of interest and is a cognitive process we would not expect it to differ between late adolescents and young adults.

$ROI_{(misaligned > aligned)} = \beta_1(\text{age groups}) + \epsilon$: We examined whether neural processes associated with receiving social feedback that the participant is misaligned with others, compared to processes associated with receiving social feedback that the participant is aligned with others is associated with cross sectional comparisons between late adolescent and young adult men. These regressions captured whether the two age groups differ in how different types of social feedback are processed.

$ROI_{(misaligned + behavior change > misaligned + no behavior change)} = \beta_1(\text{age groups}) + \epsilon$: We examined whether neural processes associated with conforming to peer feedback when misaligned with others, compared to processes associated with maintaining initial ratings when misaligned with others is associated with cross sectional

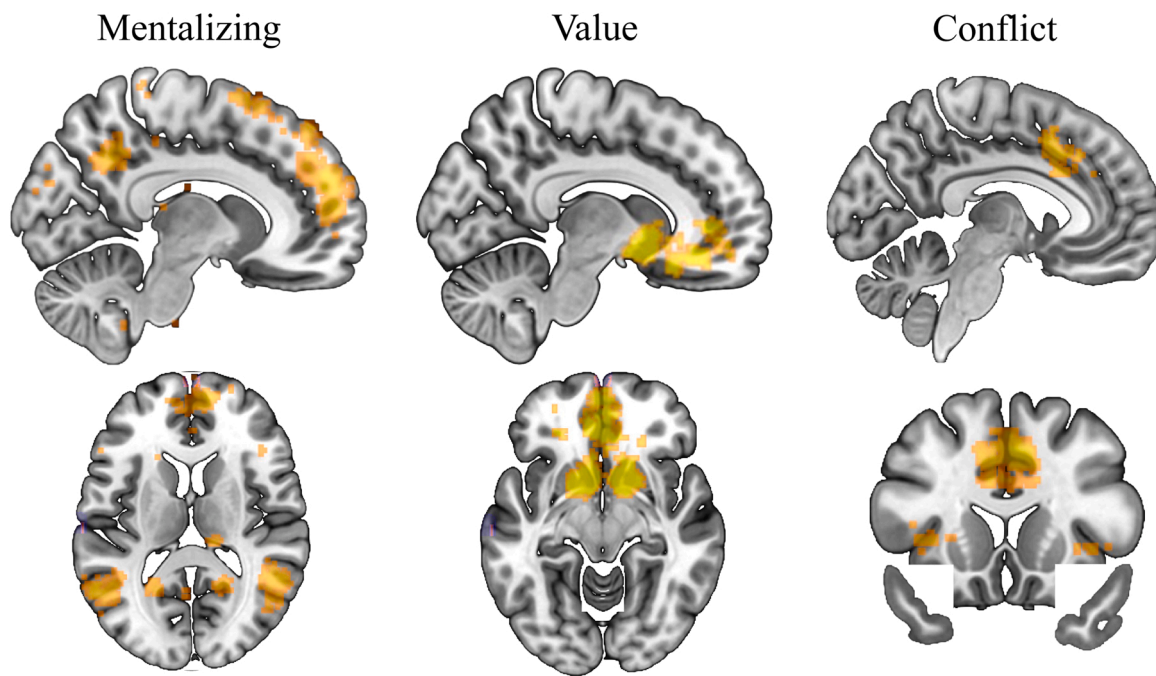


Fig. 3. Regions of interest, Note: Meta-analytically defined ROIs created using the association test maps in Neurosynth for the search terms “mentalizing”, “value”, and “conflict”.

differences between late adolescent and young adult men. These regressions examined 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. Participants who presented missing data in either condition (i.e., participants who never entered a second rating in that condition) were excluded from this analysis.

2.5.4. Whole brain analyses

Exploratory whole brain analyses were conducted to examine whether neural processes associated with social influence within and beyond our hypothesized ROIs were associated with cross sectional differences between late adolescent and young adult men. Whole brain analyses paralleled our ROI analyses for the contrasts (misalignment > alignment and misaligned + behavior change > misaligned + no behavior change) and fit a regression model predicting whole brain activity (WBA) between late adolescents and young adults ($WBA = \beta_1(\text{age groups}) + \epsilon$). All whole brain analyses were reported using the false discovery rate (FDR), $p < .05$, $k > 5$. Independent results for young adults and adolescents are reported in [supplemental materials](#).

3. Results

3.1. Conformity behavior

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 (*no social feedback*, *alignment*, and *misalignment*) and whether the proportion of time participants changed their recommendations differed by age groups. Results indicated that the four feedback conditions were significantly different from one another ($F(2147) = 91.56$, $p < .001$), such that participants changed their recommendation most often when receiving *misaligned* feedback compared to the *same* ($t(148) = 15.96$, $p < .001$, $\beta = 0.31$, $CI = [0.27, 0.35]$) and compared to no social feedback ($t(148) = 11.88$, $p < .001$, $\beta = 0.24$, $CI = [0.20, 0.28]$). In addition, participants changed their recommendation significantly more often when receiving *no social feedback* compared to being

aligned with others ($t(148) = -6.34$, $p < .001$, $\beta = -0.07$, $CI = [-0.09, -0.05]$). Means and standard deviations are reported in [Table 1](#).

Further, the proportion of time participants changed their recommendations significantly differed for late adolescents and young adults, as indicated by the interaction between feedback condition and age group ($F(2147) = 4.36$, $p = .038$); adolescents conformed significantly more often than young adults when exposed to *misaligned* feedback ($t(148) = -2.23$, $p = .027$, $\beta = -0.18$, $CI = [-0.09, -0.01]$). However, adolescents and young adults did not significantly differ in the proportion of time they changed their behavior when exposed to the *aligned* feedback ($t(147) = 0.59$, $p = .559$, $\beta = 0.05$, $CI = [-0.02, 0.03]$) or no social feedback ($t(147) = 0.10$, $p = .918$, $\beta = 0.01$, $CI = [-0.03, 0.03]$). Means and standard deviations are reported in [Table 1](#).

3.2. Region of interest analyses

3.2.1. Neural correlates associated with social feedback and development

First, we examined whether neural activity in regions associated with mentalizing, positive valuation, conflict monitoring when exposed to social feedback (*misaligned* versus *aligned*) were associated with differences across age groups (late adolescents versus young adults). When presented with *misaligned* peer feedback (compared to *aligned*), late adolescents (compared to young adults) showed significant increased activation in regions associated with positive valuation ($t(151) = -2.05$, $p = .042$, $\beta = -0.16$, $CI = [-0.18, -0.00]$). Late adolescents also showed increased activation in regions associated with mentalizing, but

Table 1
Conformity by social feedback condition and age groups.

Social feedback condition	Overall		Adolescents		Young adults	
	Mean	Std dev	Mean	Std dev	Mean	Std dev
misaligned	41.62%	23.38%	44.11%	24.48%	34.53%	18.41%
aligned	10.12%	12.17%	9.77%	12.39%	11.10%	11.63%
no social feedback	17.02%	17.91%	16.93%	18.34%	17.27%	16.84%

Note: Means and standard deviations for social feedback conditions across all participants and between adolescents and young adults.

these did not pass our threshold for statistical significance ($t(151) = -1.95, p = .053, \beta = -0.16, CI = [-0.15, 0.00]$) (Fig. 4). On the other hand, young adults (compared to late adolescents) showed significant increased activation in regions associated with conflict monitoring ($t(151) = 2.94, p = .004, \beta = 0.23, CI = [0.05, 0.24]$).³ Full results are reported in Table 2.

In addition, we examined tests of variance to determine whether late adolescents showed more variability in their neural responses to social feedback compared to young adults. We did not find any significant differences between late adolescents and young adults, $p > .05$.

3.2.2. Neural correlates associated with conformity and development

Next, we examined whether activity in regions associated with mentalizing, positive valuation, and conflict monitoring when conforming to being misaligned with others compared to not conforming when misaligned with others were associated with differences across age groups (late adolescents versus young adults). This contrast examines 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. Activity in regions associated with conflict monitoring were significantly associated with age groups ($t(139) = 2.21, p = .029, \beta = 0.18, CI = [0.02, 0.34]$),⁴ such that young adults displayed significantly greater activity in conflict monitoring regions ($M = 0.33, SD = 0.64$) compared to late adolescents ($M = -0.03, SD = 0.94$) when conforming to social feedback. Neural activity in regions associated with positive valuation and mentalizing during conformity were not associated with age groups, $p > .05$ (Fig. 5). Full results are reported in Table 3.

In addition, we examined tests of variance to determine whether late adolescents showed more variability in their neural response to conformity compared to young adults. We did not find any significant differences between late adolescents and young adults in regions associated with mentalizing and positive valuation ($p > .05$), however, adolescents did show significantly more variability in regions associated with conflict monitoring compared to young adults ($F(1, 139) = 2.13, p = .010$).

3.2.3. Control ROI analyses

To addressed whether activation differences witnessed between late adolescents and young adults is attributed to increased activity across the brain rather than our hypothesized ROIs we examined our control attention ROI. Results confirmed that no significant differences existed in the attention ROI between late adolescents and young adults for the contrasts (misaligned > aligned; $t(151) = 1.04, p = .301, \beta = 0.08, CI = [-0.04, 0.12]$) and (misaligned + behavior change > misaligned + no behavior change; $t(139) = 0.84, p = .402, \beta = 0.07, CI = [-0.08, 0.19]$).

3.3. Whole brain analyses

3.3.1. Neural correlates associated with social feedback and development

Next, we conducted exploratory whole brain analyses to determine whether regions outside of our hypothesized ROIs associated with

³ Note: Given our young adult sample included two individuals aged 30 and 31 that were potential outliers we reanalyzed the analyses removing these participants to confirm they were not driving the results. When removing these outliers, the young adult sample ranged from 18 to 26.98 years old ($M = 21.83, SD = 2.73$). Results remained consistent for all findings (positive valuation ($t(149) = -2.02, p = .045, \beta = -0.16, CI = [-0.18, -0.00]$); mentalizing ($t(149) = -1.96, p = .052, \beta = -0.16, CI = [-0.15, 0.00]$); and conflict monitoring ($t(149) = 3.05, p = .003, \beta = 0.24, CI = [0.05, 0.25]$).

⁴ Note: Results remained consistent for all findings with the 30 and 31 year old participants removed (conflict monitoring ($t(137) = 2.17, p = .032, \beta = 0.18, CI = [0.02, 0.35]$); positive valuation and mentalizing, $p > .05$).

processing social feedback significantly differed by age groups (young adults compared to late adolescents). Findings indicated that among late adolescents, exposure to social feedback that suggests one is misaligned with peers compared to aligned with peers was significantly more strongly associated with increased activity in the vmPFC, caudate, and subgenual anterior cingulate (subACC), compared to young adults. Young adults displayed significantly increased activity in the anterior insula, amygdala, and putamen (Table 4; Fig. 6), compared to late adolescents. All results are reported at FDR $p = .05, K \geq 5$.

3.3.2. Neural correlates associated with conformity and development

Finally, we conducted exploratory whole brain analyses to determine whether regions outside of our hypothesized ROIs associated with processing conformity to social feedback significantly differed by age groups (young adults compared to late adolescents). Findings indicated that conforming compared to not conforming to being misaligned with peers was associated with significantly greater activity in the vmPFC and caudate in late adolescents than young adults. Young adults displayed significantly greater increased activity in the anterior insula, amygdala, and putamen (Table 5; Fig. 7) than late adolescents. All results are reported at FDR $p = .05, K \geq 5$.

4. Discussion

Overall, the current study aimed to examine whether people in late adolescence versus young adulthood differed in how their brains process social feedback and make decisions to conform. First, we examined whether late adolescents and young adults differed in their behavioral rates of conformity. As expected, we found that participants conformed more often after learning that they were misaligned with their peers compared to aligning with their peers or when they received no social feedback. In addition, conformity rates were significantly greater for late adolescents than for young adults when misaligned with peers. Next, results from the current study offer initial evidence that late adolescent and young adult men exhibit different neural processes when exposed to social feedback and when conforming. Specifically, late adolescents show greater activity in regions associated with positive valuation (VS, vmPFC) when exposed to feedback that they are misaligned with others and showed increased activation in mentalizing regions (TPJ, dmPFC) that approached but did not meet our threshold for statistical significance. Meanwhile, young adults show increased activity in regions associated with conflict monitoring (AI, dACC) when exposed to feedback that they are misaligned and conform to that feedback. These results are discussed in detail below.

4.1. Social feedback and development

The current study found that neural processes associated with positive valuation and conflict detection during social feedback differed by age group. Late adolescents showed increased activity in regions associated with positive valuation in response to misaligned compared to aligned social feedback, where young adults showed increased activity in regions associated with conflict monitoring. These findings are consistent with the idea that when confronted with social feedback that they are misaligned with others, adolescents may use that feedback to make a value calculation (Campbell-Meiklejohn et al., 2010; Nook and Zaki, 2015), compared to young adults. Though it narrowly failed to pass our threshold for statistical significance, our observation that adolescents exhibit increased activation in mentalizing regions while processing misaligned social feedback echoes past research suggesting adolescents have less certainty about their own opinions and look to peers until their preferences become more fixed (Reiter et al., 2021).

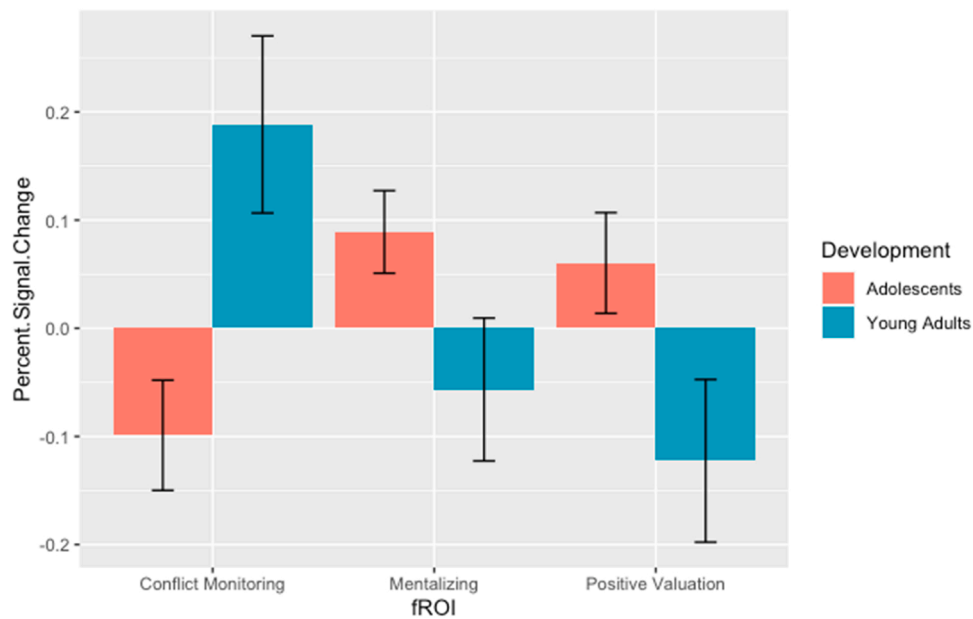


Fig. 4. ROI activity during social feedback by age groups, Note: Percent signal change score for neural activity during exposure to social feedback when misaligned compared to aligned with peers in conflict monitoring, mentalizing, and positive valuation regions between adolescents and young adults. Error bars represent standard errors.

Table 2
Regions of interest (*misalignment* > *alignment*) by age groups.

Region of interest	Adolescents		Young adults		t(151)	β	p	p FDR	95% CI
	Mean	Std dev	Mean	Std dev					
positive valuation	0.06	0.49	-0.12	0.48	-2.05	-0.16	0.042	0.053	[- 0.18, - 0.00]
mentalizing	0.09 *	0.40	-0.06	0.42	-1.95	-0.16	0.053	0.053	[- 0.15, 0.00]
conflict monitoring	-0.10 *	0.54	0.19 *	0.52	2.94	0.23	0.003	0.009	[0.05, 0.24]

Note: Regression results, means, and standard deviations for regions of interest (percent signal change) when participants are exposed to social feedback that they are *misaligned* with peers compared to *aligned* with peers between adolescents and young adults. Significant results ($p \leq .05$) for one sample t-tests examining whether means are different from zero are identified by * .

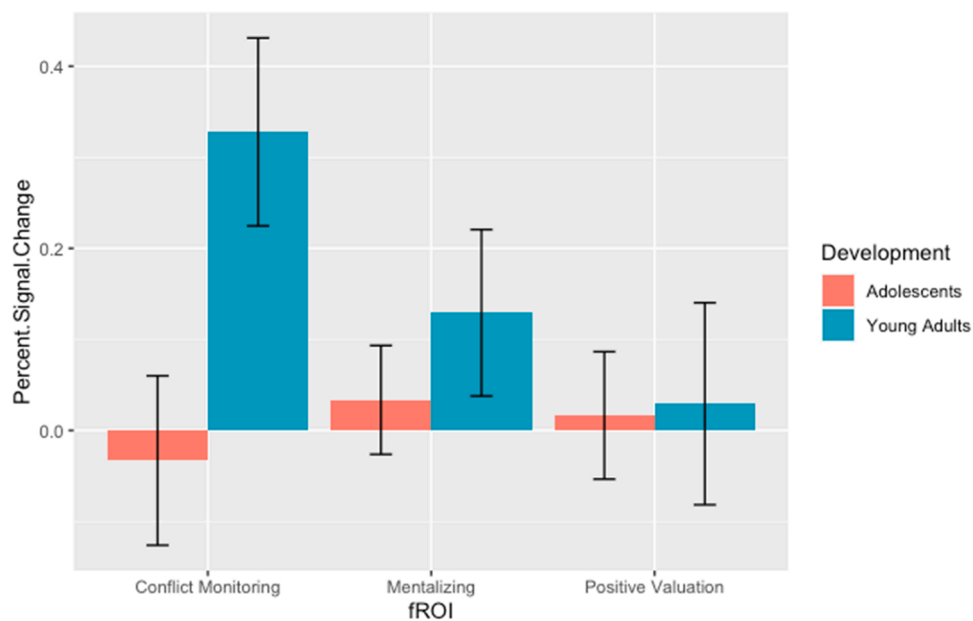


Fig. 5. ROI activity during conformity by age groups, Note: Percent signal change score for neural activity during conformity to social feedback when misaligned compared to maintaining one’s own opinion in conflict monitoring, mentalizing, and positive valuation regions between adolescents and young adults. Error bars represent standard errors.

Table 3
Regions of interest (conforming > not conforming to misaligned social feedback) by age groups.

Region of interest	Adolescents		Young adults		t (139)	β	p	p FDR	CI
	Mean	Std dev	Mean	Std dev					
positive valuation	0.02	0.71	0.03	0.69	0.10	0.01	0.923	0.923	[- 0.12, 0.14]
mentalizing	0.03	0.60	0.13	0.57	0.85	0.07	0.394	0.591	[- 0.06, 0.16]
conflict monitoring	-0.03	0.94	0.33 *	0.64	2.21	0.18	0.029	0.087	[0.02, 0.34]

Note: Regression results, means, and standard deviations for regions of interest (percent signal change) when participants conform to social feedback that they are *misaligned* with peers compared to when they maintain their own opinion between adolescents and young adults. Significant results ($p \leq .05$) for one sample t-tests examining whether means are different from zero are identified by *.

Table 4
Whole brain analysis (misaligned > aligned social feedback) by age groups.

Young Adults > Adolescents						
Region	Hemisphere	x	y	z	k	t
anterior insula, amygdala, putamen	L	-37	8	-8	212	10.38
anterior insula, amygdala, putamen	R	39	5	-8	242	10.15
vmPFC, caudate, subACC	R/L	-2	19	4	213	-6.03

Note: Exploratory whole brain analysis examining exposure to social feedback (misaligned > aligned) by age groups. All results are reported at FDR= 0.05, $K \geq 5$.

These findings are consistent with previous research that has associated mentalizing with social influence among adolescent samples (Welborn et al., 2016), but has not found evidence of this association in adult samples (Cascio et al., 2015).⁵

On the other hand, regions associated with conflict monitoring may be more sensitive or salient among young adults when they are exposed to social feedback that they are misaligned with others. This may explain some of the inconsistent findings between activity in the AI and dACC and social influence among adolescent samples (Berns et al., 2010; Cascio et al., 2015; van der Meulen et al., 2017; Welborn et al., 2016). In comparison to adolescent women, previous research has also found that women in late adolescence (18–19 years old) show increased activity in

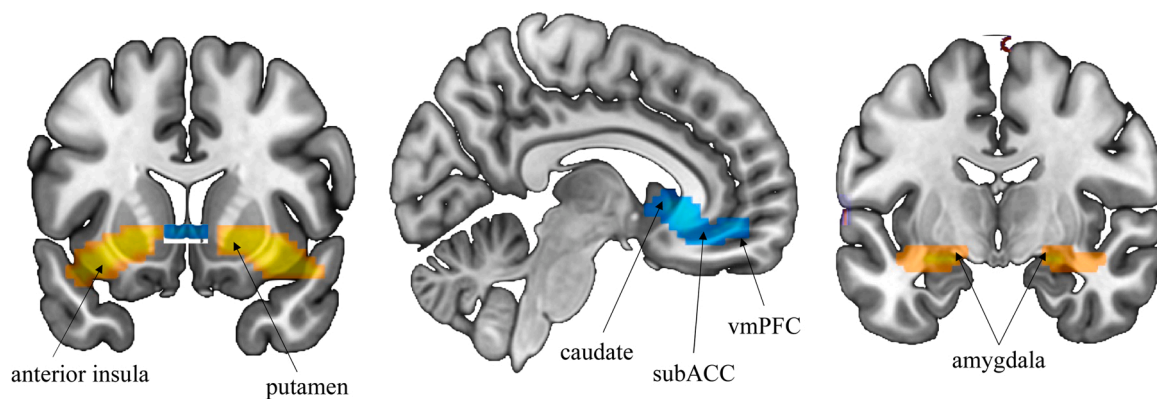


Fig. 6. Whole brain analysis (misaligned > aligned social feedback) by age groups, Note: Exploratory whole brain analysis examining exposure to social feedback (misaligned > aligned) by age groups. All results are reported at FDR= 0.05, $K \geq 5$. Yellow indicates neural activity that is significantly greater in young adults than adolescents; blue indicates neural activity that is significantly greater in adolescents than young adults.

Table 5
Whole brain analysis (conforming > not conforming to misaligned social feedback) by age groups.

Young Adults > Adolescents						
Region	Hemisphere	x	y	z	k	t
anterior insula, amygdala, putamen	R	35	-2	-11	246	10.56
anterior insula, amygdala, putamen	L	-37	5	-8	232	10.80
vmPFC	L	-2	32	-14	7	-3.12
vmPFC	L	-2	50	-11	5	-3.13
caudate	R/L	1	19	4	11	-4.81

Note: Exploratory whole brain analysis examining conformity to social feedback (conforming > not conforming to misaligned social feedback) by age groups. All results are reported at FDR= 0.05, $K \geq 5$.

the dmPFC, dACC, and AI when women received misaligned feedback about their attitudes toward female body types (van der Meulen et al., 2017). Again, activity in the dmPFC, a region associated with mentalizing, is consistent with our observations in adolescents. However, increased activity in the dACC and AI is in line with the current findings in young adult men. Given the age range it may suggest that women, unlike men, continue to consider the mental states of others when social feedback suggests they are misaligned. Comparing the current findings with the only other known direct comparison of adolescent and young adult women is difficult given no differences were found for social disagreement (Knoll et al., 2020).

Late adolescents in our samples also showed greater activity in regions associated with positive valuation during social influence. Previous research has found mixed results on the relationship between regions associated with positive valuation during social influence. For example, some studies have found that activity in regions associated

⁵ Though it should be noted that the data from Cascio et al. (2015) are included in the current investigation, and thus these findings are not independent.

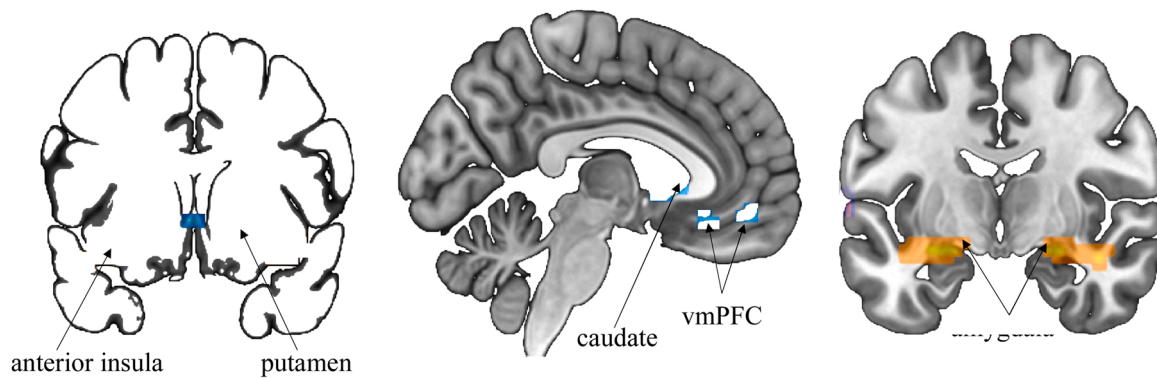


Fig. 7. Whole brain analysis (conforming > not conforming to social feedback) by age groups, Note: Exploratory whole brain analysis examining conformity to social feedback (conforming > not conforming to misaligned social feedback) by age groups. All results are reported at FDR= 0.05, $K \geq 5$. Yellow indicates neural activity that is significantly greater in young adults than adolescents; blue indicates neural activity that is significantly greater in adolescents than young adults.

with positive valuation is associated with being misaligned with others (Welborn et al., 2016), where other research has found that activity in regions associated with positive valuation is associated with alignment with others (Campbell-Meiklejohn et al., 2010; Nook and Zaki, 2015). The finding in young adults is consistent with past research that suggests social influence is associated neural regions involved in prediction error in reinforcement learning (Klucharev et al., 2009) and conflict monitoring (Berns et al., 2010; Klucharev et al., 2011; Tomlin et al., 2013), which has been primarily carried out in adult samples. As mentioned above, our late adolescent findings are consistent with the idea that when confronted with social feedback that they are misaligned with others, late adolescents may be thinking more about the mental states of others and using that feedback to make a value calculation (Campbell-Meiklejohn et al., 2010; Nook and Zaki, 2015), compared to young adults. Alternatively, given the role of the VS and vmPFC in reward processing (McClure et al., 2004), it may be that late adolescents may be thinking more about the mental states of others and using that feedback to calculate expected reward of fitting in with others. Overall, these results suggest that late adolescents and young adults differ in the ways they process social feedback.

4.2. Conformity and development

Next, we examined whether people in different age groups differed in the neural correlates associated with conforming to social feedback that participants were misaligned with others. We found that young adults recruited regions associated with conflict monitoring more when conforming compared to late adolescents. However, unlike processing social feedback, neural regions associated with positive valuation and mentalizing were not significantly different when conforming to being misaligned with others between late adolescents and young adults in our ROI analyses. However, exploratory whole brain analyses suggest that late adolescents did show increased vmPFC and caudate activity when conforming to being misaligned with peers compared to maintaining their own opinion. Although the relationship between activation of regions associated with conflict monitoring and conformity has been established in both adolescents (Falk et al., 2014) and adults (Berns et al., 2005; Klucharev et al., 2009), our data suggest that regions associated with conflict monitoring are recruited to a greater extent among young adults compared to late adolescents when conforming to being misaligned with others.

The differences we observe may relate to the social transition from high school to early adulthood. For example, young adult men are gaining independence from their parents during this social transition (Yelle et al., 2009) and are socialized more into male gender norms that suggest they should be independent rather than interdependent (Courtenay, 2000). This move towards independence may be one reason

neural regions associated with conflict monitoring during social influence are more salient among young adult men. Activity in the AI and dACC is also associated with both negative and positive valuation (Bartra et al., 2013), thus, it may be that young adults negatively value being misaligned with others and conform due to compliance while maintaining their own opinion internally. Future research would need to test these possibilities.

Alternatively, the current findings may indicate that processing of social feedback is more consistent among young adults — though late adolescents seem to have strong reactions to being misaligned to social feedback in regions associated with positive valuation and mentalizing, it is possible that they have not yet developed consistent ways of dealing with that feedback (i.e., whether to conform versus not) compared to young adults. This may be one reason why the current results do not find any neural regions in our ROI analyses more strongly associated with conformity among late adolescents, particularly in conflict monitoring regions which found that adolescents displayed significantly more variance compared to young adults. Similar studies have tasked participants with rating faces (Klucharev et al., 2009; Zaki et al., 2011), or pieces of music (Berns et al., 2010; Campbell-Meiklejohn et al., 2010), which participants could be more likely to see as relevant to their social identity or self-concept. Thus, it is possible that responses to social feedback in our study were different because participants in this study were less likely to see their choices as emotionally salient. In addition, this may further support the idea that teens that have less certainty about their own opinions and look to peers until their preferences become more fixed (Reiter et al., 2021) and do not consistently perceive misalignment as a conflict with peers. However, future research would need to further examine this finding.

Although we did not observe robust differences in activation within our a priori defined regions of interest (positive valuation, mentalizing) between age groups that tracked conformity, in our whole brain analysis, we did observe activation within sub-regions of the value system including vmPFC and parts of the striatum in both late adolescents and young adults. We also observed activation in superior temporal gyrus in young adults, a region previously implicated in mentalizing. Thus, although not revealed by our main region of interest analyses, our results remain broadly consistent with prior literature on conformity in adolescent and young adult samples.

4.3. Strengths, limitations, and future research

Overall, this is one of the first studies to directly compare differences in neural mechanisms associated with processing social feedback and conformity in young adult and late adolescent men, filling an important gap. However, one limitation of this study is the lack of women, non-binary (or other non-men) participants. Thus, generalizations can only

be extended to men 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. In addition, our adolescent sample is limited to 16- and 17-year-old participants, thus the current findings may be missing key developmental processes associated with younger adolescents. Future research should extend the current findings to include women participants and a wider range of ages. Along these lines, an alternative analysis approach would have been to examine age as a continuous measure rather than collapse groups based on the transition period between high school and early adulthood. This comparison was not possible in the current study due to a large amount of missing age data due to errors in data collection and participants failing to respond. Future research should address this question to determine whether the neural differences witnessed between men in high school and early adulthood are due to the social transition or due to age.

In addition, brain results in the current study were tested by examining exposure to social feedback and contrasting feedback type (misaligned > aligned) and behavior (misaligned + behavior change > misaligned + no behavior change). This approach accounts for whether there are neural differences between adolescent and young adult men during exposure to social feedback. Another interesting approach may be to examine differences in neural activity when making behavioral decisions. Although the current study had these different trial components, they were not independent trials that would allow us to properly examine this question. Thus, future conformity research may benefit from taking this design approach to identify whether different neural processes are associated with exposure compared to the decision-making process.

Finally, though the associations between our a priori regions of interest have established associations with the cognitive and affective experiences we have attributed to their activation, it is difficult to say with certainty what cognitive or affective processes are represented by activity in these networks (Poldrack, 2006). Future research might test our assumptions by incorporating localizer tasks for conflict detection, mentalizing, and positive valuation.

5. Conclusions

Our results offer initial evidence that late adolescent men process social feedback and conformity differently than young adult men. Participants in both age groups were more likely to change their ratings after finding they were misaligned with others, and late adolescents were significantly more likely to conform to being misaligned than young adults. Regarding neural processes, we found that late adolescents showed more activation in regions associated with mentalizing and positive valuation than young adults in response to misalignment with others, but young adults showed more activation in regions associated with conflict monitoring when conforming to being misaligned with others. These results are the first to our knowledge that directly compare social influence processes in the brains of young adult and late adolescent men. Young adults may be more likely to conform as a response to perceived conflict, where late adolescents who find themselves misaligned with others devote more resources to considering the others' perspective and re-evaluating the target of their value judgments. Due to the novelty of this research and important role social interactions and feedback play in the lives of adolescents, more research is needed to explore the significance of these differences in processing and how they relate to real world behaviors.

Overall, our results offer initial evidence that late adolescent and young adult men exhibit different neural processes when adjusting their opinions to align with those of misaligned others, and this difference appears to be most pronounced in the activation of regions associated with conflict monitoring. This may explain the tendency of adolescents to conform more frequently than adults, but more research is needed to explain the implications of these findings on cognitive and affective

processes.

Funding

This research was supported by the intramural research program of the Eunice Kennedy Shriver National Institute of Child Health and Human Development contract #HHSN275201000007C (PI: Bingham); University of Michigan Injury Center Pilot Grant (PI: Falk); NIH Director's New Innovator Award #1DP2DA03515601 (PI: Falk); Defense Advanced Research Projects Agency #D14AP00048 (PI: Falk); and Office of Naval Research #0875GSA495 (PI: Falk). The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the funders.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Emily B. Falk reports financial support was provided by National Institute of Child Health and Human Development. Emily B. Falk reports financial support was provided by National Institutes of Health. Emily B. Falk reports financial support was provided by Defense Advanced Research Projects Agency.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.dcn.2023.101215](https://doi.org/10.1016/j.dcn.2023.101215).

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