Brief Communications

Neural Mechanisms of Resistance to Peer Influence in Early Adolescence

Marie-Helène Grosbras,[2] Marije Jansen,[1] Gabriel Leonard,[5] Anthony McIntosh,[3] Katja Osswald,[1] Catherine Poulsen,[5] Laurence Steinberg,[4] Roberto Toro,[1] and Tomaš Paus[1,5]

[1]Brain and Body Centre, University of Nottingham, Nottingham NG7 2RD, United Kingdom, [2]Department of Psychology, Glasgow University, Glasgow G128QB, United Kingdom, [3]Rotman Research Institute of Baycrest Centre, University of Toronto, Toronto, Ontario, Canada M6A 2E1, [4]Department of Psychology, Temple University, Philadelphia, Pennsylvania 19122, and [5]Montreal Neurological Institute, McGill University, Montreal, Quebec, Canada H34 2B4

During the shift from a parent-dependent child to a fully autonomous adult, peers take on a significant role in shaping the adolescent's behavior. Peer-derived influences are not always positive, however. Here, we explore neural correlates of interindividual differences in the probability of resisting peer influence in early adolescence. Using functional magnetic resonance imaging, we found striking differences between 10-year-old children with high and low resistance to peer influence in their brain activity during observation of angry hand movements and angry facial expressions: compared with subjects with low resistance to peer influence, individuals with high resistance showed a highly coordinated brain activity in neural systems underlying perception of action and decision making. These findings suggest that the probability of resisting peer influence depends on neural interactions during observation of emotion-laden actions.

Key words: **adolescence; peer influence; fMRI; action observation; prefrontal cortex; connectivity**

Introduction

At the onset of adolescence, several key processes engaged during social interactions, such as face processing (Taylor et al., 1999), emotion recognition (Batty and Taylor, 2006), or perspective taking (Choudhury and Blakemore, 2006), are still immature. Given the amount of time adolescents spend with their peers, it is not surprising that peers are influential in modeling the adolescent emotional and social cognitive abilities (Steinberg and Silverberg, 1986; Steinberg, 2005). To date, little is known about the neural bases of social interactions during adolescence, despite a growing body of research on the structural and functional maturation of the adolescent brain (Paus, 2005; Blakemore and Choudhury, 2006). In particular, we do not know how interindividual differences in the susceptibility to social influences, such as peer pressure, might be linked to differential neural processing of socially relevant stimuli.

Here, we explore the relationship between the capacity to resist peer influence in early adolescence and brain activity during perception of face or hand movements performed with an emotion.

Human and non-human primates engage a number of cortical regions when observing con-specifics ("actors"). Two neural systems stand out: (1) regions in the temporal cortex involved in the processing of biological motion (Allison et al., 2000); and (2) frontoparietal regions involved in programming and executing motor actions (Rizzolatti and Craighero, 2004). The former extracts information from visual cues embedded in the actor's movements, whereas the latter may support computations used to infer the actor's intentions and/or to facilitate initiation, by the observer, of actions matching those of the actor.

To investigate possible links between the sensitivity to peers' actions and the recruitment of these neural systems during the observation of others, we scanned early adolescents while they watched video clips of hand or face movements. Those movements were performed either in a neutral way or with anger. We chose anger because it is the basic emotion that is best recognized from goal-directed (noncommunicative) hand actions (Pollick et al., 2001). Furthermore, perception of anger, and thereby of potential threat, is essential for social interactions. The analysis of functional magnetic resonance imaging (fMRI) data focused on the variations in both local and interregional patterns of brain activity as a function of resistance to peer influence (RPI). RPI was assessed with a self-report questionnaire for adolescents designed to minimize socially desirable responding (Steinberg and Monahan, 2007). This instrument has been used in a number of large sample studies. Scores stay low during early adolescence and increase linearly from 14 years of age to reach adult levels at 18 years of age; this pattern is consistent across ethnic groups, reflecting the reliability and generalization of the measure (Steinberg and Monahan, 2007). In a population of serious juvenile offenders, we found that the presence of antisocial peers in one's network predicts one's own criminal behavior to a significantly greater extent in individuals with low RPI scores than among those who have equally antisocial peers but score high on RPI (Monahan et al., 2007). This finding confirms construct validity

Received Dec. 7, 2006; revised May 2, 2007; accepted June 15, 2007.

This work was supported by the Santa Fe Institute Consortium and the Canadian Institutes of Health Research. We thank Candice Cartier, Elissa Golden, Valerie Legge, Kristina Martinu, Bruce Pike, Genevieve Richer, and Kate Watkins for assistance with subject recruitment and data collection.

Correspondence should be addressed to Prof. Tomaš Paus, Brain and Body Centre, University of Nottingham, University Park, Nottingham NG7 2RD, UK. E-mail: tomas.paus@nottingham.ac.uk.

DOI:10.1523/JNEUROSCI.1360-07.2007

of the RPI measure and its predictive value in evaluating interindividual differences in peer relationships.

Materials and Methods

Subjects. Forty-six typically developing children (age, 10 years ± 4.4 months; age range, 9.4–10.8 years; 24 boys and 22 girls) participated in the study, which involved a questionnaire and a series of behavioral tests, including the Stroop test, a self-ordered pointing task (Petrides and Milner, 1982), and the Wechsler Intelligence Scale for Children (WISC-III) test battery, as well as an fMRI session. All participants filled out the Puberty Development Scale (Peterson et al., 1988), which is an eight-item self-report measure of physical development based on the Tanner stages with separate forms for males and females. For this scale, there are five categories of pubertal status: (1) prepubertal, (2) beginning pubertal, (3) midpubertal, (4) advanced pubertal, and (5) postpubertal. The mean (±SD) of the Tanner stages were 1.4 ± 0.7 (boys) and 2.2 ± 1.0 (girls).

Questionnaire. The RPI questionnaire (Steinberg and Monahan, 2007) consists of 10 pairs of opposite statements about interindividual interactions, such as "Some people hide their true opinion from their friends if they think their friends will make fun of them because of it" and "Other people will say their true opinion in front of their friends, even if they know their friends will make fun of them because of it." The participant has to indicate which one is more like her or him and to what degree ("sort of true of me" or "really true of me") he/she identifies with the statement. The scoring is such that a high score on a 1–4 scale indicates a high RPI, whereas a low score indicates a great susceptibility to peer influence. This questionnaire has been tested in four large samples (700–1350 individuals) from different populations for which inter-questions reliability (Cronbach's α) have proven adequate and highly similar (Steinberg and Monahan, 2007). These include the following: (1) a predominantly impoverished and ethnic minority sample of 1350 serious juvenile offenders in two U.S. cities, ages 14–18 years ($\alpha = 0.73$); (2) a sample of ~700 individuals aged 11–24 years in juvenile detention or jail, from four U.S. cities ($\alpha = 0.76$); (3) a predominantly poor and working-class sample of 700 individuals in the community in four U.S. cities living in the same neighborhoods as participants in sample 2 ($\alpha = 0.70$); and (4) a multiethnic working and middle class community sample of 935 individuals aged 10–30 years, from five U.S. regions ($\alpha = 0.74$).

fMRI. We acquired fMRI datasets while children watched short video clips of hand actions and facial expressions; the subjects had no other task while watching the video clips. The stimuli and experimental protocol were identical to those used previously in young adult subjects (Grosbras and Paus, 2006). Stimuli were presented in 18 s blocks. Hand actions consisted of reaching, grasping, and manipulating eight different objects (phone, pencil, spoon, computer mouse, glass, hammer, screwdriver, and cup) in either a neutral or an angry way (in separate blocks). Movements performed with anger differed from neutral movements in their acceleration profile, but both types of movements were matched for the mean duration of the reaching phase, as well as for the hand–object interaction. Angry face stimuli consisted of male or female faces starting from a neutral expression and moving to express anger. Neutral faces stimuli were extracted from periods of video recordings when the actors were not expressing any emotion but were nonetheless moving their face (e.g., twitching their nose, opening their mouth, blinking their eyes). The control stimuli consisted of black-and-white concentric circles of various contrasts, expanding and contracting at various speeds, roughly matching the contrast and motion characteristics of the faces and hands clips. Scanning was performed on a 1.5 tesla Siemens (Erlangen, Germany) Sonata scanner. First, we acquired a high-resolution, T1-weighted, three-dimensional structural image (matrix, 256 × 256 × 170; 1 mm^3 voxels) for anatomical localization and coregistration with the functional time series. A series of blood oxygen level-dependent (BOLD), T2*-weighted gradient-echo echo-planar images was then acquired (matrix size, 64 × 64; echo time, 50 ms; repetition time, 3 s; 180 32-slice frames collected after the gradients had reached steady state; voxel size, 4 × 4 × 4 mm^3). The images were assessed for head motion and realigned to the first frame using AFNI (Cox, 1996). Then, they were spatially smoothed using a 6 mm full-width at half-maximum Gaussian filter. We checked that motion did not exceed 1 mm or 1° in any direction. This was not the case in 11 of 46 children, and these subjects were excluded from the subsequent analyses; the final sample consists of 35 children (age, 10 years ± 4.5 months; age range, 9.4–10.7 years; 20 boys and 15 girls).

Correlation analysis. First, we assessed, for each voxel, the differences in BOLD signal induced by neutral or emotional hand or face movements and the nonbiological movements baseline condition; this analysis was performed using the general linear model (GLM) as implemented in the fmristat Matlab (Mathworks, Natick, MA) toolbox (Worsley et al., 2002). Then, we computed, voxel by voxel, the correlation between these differences and scores obtained for the RPI questionnaire. The threshold for $p < 0.05$ corrected for multiple comparisons was determined using a method based on local discrete maxima, which was the most accurate for the effective smoothness of the data (Worsley, 2005). This analysis allows us to identify brain regions, engaged during the passive observation of others' movements, where the variations in BOLD signal are related to RPI scores.

Partial least-square analysis. Second, we analyzed the fMRI datasets with a multivariate technique, partial least squares (PLS), with the aim of extracting coordinated patterns of brain activity influenced by RPI (McIntosh and Lobaugh, 2004). For each of the five experimental conditions, namely neutral hand actions, angry hand actions, neutral facial expressions, angry facial expressions, and nonbiological visual motion, we computed the correlation between the time series of each voxel during this condition and the score each subject obtained with the RPI questionnaire. These correlation matrices are put into one large matrix and subjected to singular value decomposition. This produces orthogonal latent variables (LVs), each consisting of a behavioral LV and a brain LV, as well as a singular value, which indicates the strength of the covariance between the pattern of brain activity and the questionnaire score. The brain LV identifies a pattern of voxels that, as a whole, show covariation between fMRI signal and behavior. The behavioral LV contains weights for the correlation images obtained for the five different conditions, therefore representing how much each condition contributes to the brain LV. This allows us to produce maps of similarities or differences in brain–behavior correlations between conditions. The significance of each pair of behavioral and brain LVs is assessed by a permutation test: 500 matrices are created shuffling the condition labels at each time point and subjected to decomposition. Exact statistics are derived assessing how often a singular value higher than the one derived from the data could be observed by chance. Then, to estimate the reliability of the spatial pattern identified by an LV, 100 bootstrap samples were used to identify those voxels whose correlation with behavior is the most robust.

To visualize the pattern on interregional correlations, we have generated an interregional correlation matrix for the angry hand actions, a condition identified by the PLS as distinguishing the low from high RPI subjects (see below). We have done so separately for the subjects with high and low RPI (i.e., above or below the median). The high-RPI group consisted of 6 girls (mean ± SD; 10.1 ± 0.37 years, 1.8 ± 1.1 Tanner stage) and 11 boys (10 ± 0.36 years, 1.2 ± 0.4 Tanner stage), and the low-RPI group consisted of 9 girls (10 ± 0.4 years, 2.4 ± 1 Tanner stage) and 9 boys (10 ± 0.4 years, 1.8 ± 0.8 Tanner stage).

Results

The average score in the RPI questionnaire for the 35 subjects included in the analysis was 2.88 (SD, 0.44; median, 2.84).

Using the standard univariate analysis based on the GLM, we found similar BOLD response to hand (neutral, angry) and face (neutral, angry) stimuli as observed in adults previously (Grosbras and Paus, 2006). In short, the observation of hand movements engaged frontoparietal and middle temporal regions. Angry hand movements also recruited part of the parietal operculum/supramarginal gyrus, the medial prefrontal cortex, and the amygdala. The observation of angry or neutral faces engaged the premotor cortex, various parts of the inferior and medial frontal cortex, the fusiform cortex, the superior temporal sulcus, and the amygdala.

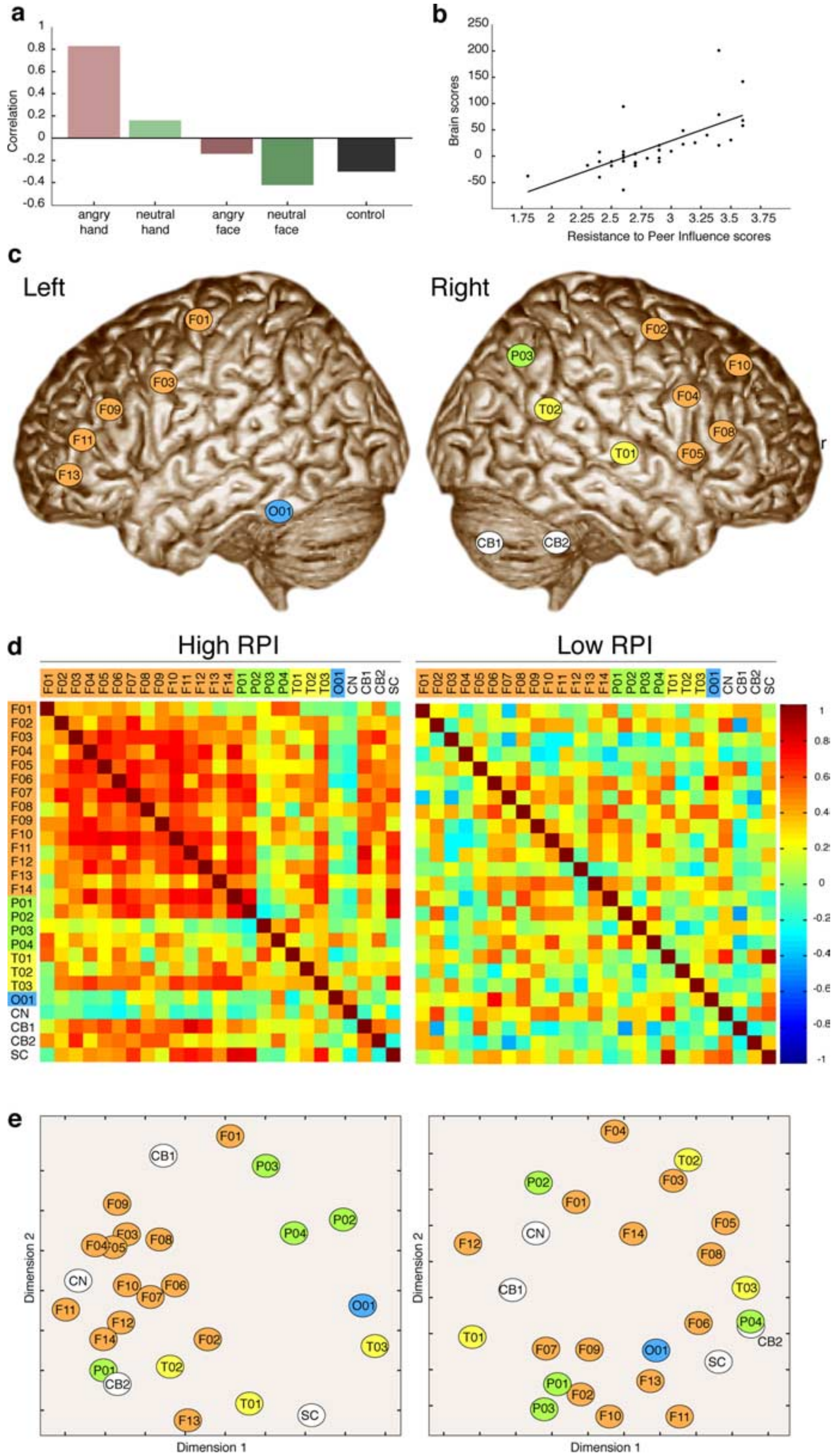

Figure 1. Interregional correlations in fMRI signal during the observation of angry hand movements. ***a***, LV1 identified a combination of brain regions that, as a whole, correlated with the RPI scores. Note that high correlations are observed only for fMRI signal measured during the observation of angry hand movements. ***b***, Brain scores (weighted sum of all voxels in an image for each subject, using the weights derived from the brain LV1) derived from the fMRI signal measured during angry hand movements plotted as a function of RPI. ***c***, Locations of brain regions identified by LV1; only regions visible on the lateral surface of the left and right hemispheres are shown. ***d***, Correlation matrices depicting interregional correlations of fMRI signal measured during the observation of angry hand movements, as revealed by LV1, in subjects with high (left) and low (right) RPI. The high- and low-RPI subgroups correspond to the subjects with RPI scores above and below the group median, respectively. The region labels match those included in Table 1. ***e***, Multidimensional scaling (MDS) representations of the interregional correlations of the 26-deletions matrix depicted above; in the MDS 2-deletions plots, strongly correlated regions are placed close together. Note, for example, the close grouping of premotor (F03 and F04) and prefrontal (F08 and F09) frontocortical regions. The region labels match those included in Table 1. F01, Premotor cortex, dorsal, left; F02, premotor cortex, dorsal, right; F03, premotor cortex, ventral, left; F04, premotor cortex, ventral, right; F05, frontal operculum, right; F06, cingulate motor area, left; F07, insula, anterior, left; F08, prefrontal cortex, ventrolateral, right; F09, prefrontal cortex, dorsolateral, left; F10, prefrontal cortex, dorsolateral, right; F11, prefrontal cortex, ventrolateral, left; F12, anterior cingulate cortex, right; F13, orbitofrontal cortex, lateral, left; F14, prefrontal cortex, medial; P01, posterior cingulate cortex; P02, precuneus, left; P03, parietal cortex, dorsolateral, right; P04, parietal cortex, dorsomedial, right; T01, superior temporal sulcus, middle, right; T02, superior temporal sulcus, posterior, right; T03, hippocampus, right; O01, fusiform gyrus, left; CN, caudate nucleus, right; CB1, cerebellum, right; CB2, cerebellum, right; SC, superior colliculus, right.

Correlation analysis

Using univariate GLM-based analysis, we detected a negative correlation between the RPI scores and the increase in BOLD signal, compared with the baseline, during the observation of angry (but not emotionally neutral) hand or face movements, in the right dorsal premotor cortex (MNI152 coordinates: $x = 40$, $y = 8$; $z = 44$). Thus, children with lower RPI had higher BOLD response to angry movements in this region than children with higher resistance. Moreover, the RPI scores correlated negatively with the increase in BOLD signal in the left mid-dorsolateral prefrontal cortex ($x = -52$, $y = 36$, $z = 28$) during the observation of angry hand (but not face) movements. This latter region, together with the right intraparietal sulcus ($x = 36$, $y = -40$, $z = 60$), the left frontal eye field ($x = -24$, $y = -16$, $z = 51$), and anterior cingulate cortex ($x = 4$, $y = 12$, $z = 44$) also showed a correlation between RPI scores and the BOLD response measured in the direct contrast between angry and neutral hand movements when the threshold was set at $p < 0.001$, uncorrected for multiple comparisons.

Partial least-square analysis

Multivariate PLS-based analysis revealed two significant ($p < 0.05$; 500 permutations, 100 bootstraps) LVs: (1) LV1 ($p < 0.006$) explained 29% of the covariance between the fMRI data and the RPI scores and showed a strong positive correlation ($r = 0.68$) between the scores and fMRI signal measured during the observation of angry hand actions; and (2) LV2 ($p < 0.034$) explained 20% of the covariance and indicated a strong negative ($r = -0.94$) correlation between RPI scores and fMRI signal measured during the

Table 1. Brain regions identified by partial least-square analysis (brain LV1 and LV2)

	x (mm)	*y* (mm)	*z* (mm)	Bootstrap ratio	Cluster size (mm^3)	Lobe/structure	Region	Label
LV1								
	−32	−12	60	6.82	608	Frontal	Premotor dorsal	F1
	36	−4	56	6.04	776	Frontal	Premotor dorsal	F2
	−54	4	32	6.14	192	Frontal	Premotor ventral	F3
	60	10	26	6.45	272	Frontal	Premotor ventral	F4
	46	12	0	7.73	992	Frontal	Operculum	F5
	−14	12	36	6.26	440	Frontal	Cingulate motor area (rostral)	F6
	−34	14	−4	6.22	424	Frontal	Insula (anterior)	F7
	44	26	10	6.56	1112	Frontal	Ventrolateral prefrontal (posterior)	F8
	−38	28	20	6.53	1424	Frontal	Dorsolateral prefrontal (mid)	F9
	28	34	40	6.54	3088	Frontal	Dorsolateral prefrontal (mid)	F10
	−42	40	6	6.73	1344	Frontal	Ventrolateral prefrontal (anterior)	F11
	8	40	12	6.54	960	Frontal	Cingulate anterior	F12
	−42	46	−10	6.26	368	Frontal	Orbito-frontal lateral	F13
	0	52	18	6.14	2640	Frontal	Prefrontal medial	F14
	0	−28	38	6.07	904	Parietal	Cingulate posterior	P1
	−12	−78	50	6.42	1080	Parietal	Precuneus	P2
	38	−64	44	6.68	224	Parietal	Dorsolateral	P3
	2	−50	66	7.21	568	Parietal	Dorsomedial	P4
	54	−18	0	6.74	120	Temporal	STS middle	T1
	58	−52	20	6.30	1432	Temporal	STS posterior	T2
	30	−34	−10	6.46	560	Temporal	Hippocampus	T3
	−38	−48	−26	7.40	248	Occipital	Fusiform	01
	10	8	16	6.60	736	Caudate nucleus	Head	CN
	24	−78	−40	7.69	496	Cerebellum		CB1
	44	−48	−40	6.81	104	Cerebellum		CB2
	2	−40	−4	6.09	424	Colliculus	Superior	SC
	24	−56	−6	−6.41	152	Occipital	Fusiform (medial)	02
LV2								
	−10	22	56	6.18	3168	Frontal	Superior frontal gyrus	
	−2	32	16	6.78	7072	Frontal	Cingulate anterior	
	−60	−10	16	6.90	616	Parietal	Postcentral gyrus	
	50	−14	24	6.16	1008	Parietal	Postcentral gyrus	
	22	−38	46	6.54	256	Parietal	Intraparietal sulcus (anterior)	
	18	−42	72	6.57	88	Parietal	Medial superior	
	12	−74	−4	6.43	2864	Occipital	Extrastriate visual cortex (V2/V3)	
	−20	−66	−14	6.08	1960	Occipital	Fusiform	
	−22	−4	2	6.02	192	Putamen		
	30	4	48	−6.19	2088	Frontal	Premotor dorsal	
	−34	14	6	−6.36	352	Frontal	Insula (anterior)	
	40	14	46	−6.12	280	Frontal	Premotor dorsal anterior	
	34	22	4	−6.08	3984	Frontal	Insula (anterior)	
	−4	−28	52	−6.44	2552	Parietal	Medial	
	44	−48	62	−6.63	2992	Parietal	Superior lateral	
	6	−18	8	−6.01	736	Thalamus	Midline	

Voxel coordinates are listed only for regions with absolute values of bootstrap ratio $>$ 6. Positive and negative bootstrap ratio indicates, respectively, positive and negative correlation with RPI.

observation of angry facial expressions. Note that this pattern of coordinated brain activity differentiating children more or less able to resist peer influence was found only when they watched emotion-laden video clips. Figure 1 illustrates these findings, and Table 1 contains a list of brain regions identified by LV1 and LV2. Three features stand out here. First, many of these regions are part of the two neural systems outlined in the Introduction, namely the temporal regions involved in the processing of biological motion and frontoparietal regions involved in the programming and execution of movement. But LV1 also identified a set of prefrontal regions that are involved in various aspects of executive functions and decision making. Second, the degree of interregional correlations (i.e., functional connectivity) is higher in children with high versus low RPI (Fig. 1*d*,*e*); the two groups differed significantly in the mean pairwise correlation coefficients calculated across all 26 regions ($F_{(1,649)} = 72.6$; $p < 0.0001$). Third, the above pattern of coordinated brain activity differentiating children more or less able to resist peer influence is found only when they watched video clips of hand actions performed with anger; no such relationships were observed for the remaining experimental conditions (Fig. 1*a*).

Other behavioral measures

Would children with high resistance to peer influence differ from those with low resistance if asked explicitly to perform "executive" tasks? We found significant differences between the two groups in the number of corrected errors made during the Stroop test of interference in language domain ($F = 8.04$; $p < 0.01$) and in the number of errors in the self-ordered pointing test of working memory ($F = 8.2$; $p < 0.01$); both results suggest better self-monitoring abilities of children with high RPI. The two groups did not differ significantly in their general intelligence, as assessed by the WISC-III (mean ± SD; low RPI, 117 ± 9; high RPI, 113 ± 12).

Discussion

Correlation between frontal cortex activity and peer-influence resistance

We observe a correlation between the sensitivity to peer influence and the engagement of two frontal regions, the right dorsal premotor cortex and the left dorsolateral prefrontal cortex, while the children watched angry hand actions or face movements. The dorsal (unlike ventral) premotor cortex is not very often reported in studies of action observation. Its recruitment might reflect the automatic engagement of the motor preparation system when we observe an action performed with someone else or even just the outcome of this action (Cisek and Kalaska, 2004; Grosbras and Paus, 2006). Therefore, it is possible that motor preparation induced by angry movement will be more solicited in children more sensitive to peer pressure. The dorsolateral prefrontal cortex is involved in attentional control and inhibition of prepotent responses. Its activity during attentional tasks, in particular antisaccades, changes during adolescence together with the activity in other parts of the attentional network such as frontal eye field and anterior cingulate cortex (Luna et al., 2001). More sensitive children might engage more attentional resources when presented with salient stimuli such as angry hand movements.

Differences in functional connectivity in relation to peer-influence resistance

The PLS analysis allowed us to go one step further and to observe that a degree of functional connectivity across a set of cortical regions predicts RPI. In this context, the most significant prediction emerged when subjects watched angry hand actions. The pattern of interregional correlations identified by this method includes both (1) regions involved in action observation, from the frontoparietal as well as from the temporo-occipital system discussed in the Introduction, and (2) regions in the prefrontal cortex. The most striking finding is that the functional connectivity between these regions during a passive task differentiates children with high or low RPI. The children simply watched the video clips as they would watch their peers in a situation in which no clear goals have been formulated in advance, and yet, a number of prefrontal regions showed coordinated changes in the fMRI signal that correlated with those in the other two neural systems involved in action observation. Typically, prefrontal cortex is engaged when the subject performs an explicit task requiring, for example, manipulation of information in working memory, inhibition of prepotent responses and/or suppression of interference, or planning and decision making (Petrides, 2005). No such demands were explicitly made in this study. It is important to note the difference between the findings obtained with univariate and multivariate analyses here. Univariate, voxel-by-voxel correlation between the fMRI signal and RPI scores showed a more robust response in low-resistance children independently in the premotor cortex and the prefrontal cortex. The multivariate analysis, in contrast, revealed stronger interregional correlations, or functional connectivity, between these and other regions in high-resistance children. We speculate that these two phenomena reflect, respectively, higher sensitivity of low-resistance children to socially relevant input and higher interregional integration of such inputs in high-resistance children. It is possible that the brains of the children with high RPI engage automatically executive processes when challenged with relatively complex and socially relevant stimuli. Interestingly, the children with higher RPI were also those who performed better in (explicit) executive tasks.

Generalization to other emotions

The brain–behavior correlations were observed when children observed movements performed with anger but not for neutral movements. Emotionally neutral movements of peers, although socially relevant, might not require as much processing resources as angry movements. One can easily imagine that interacting, or avoiding an interaction, with a peer displaying anger, and thereby a potential threat, will require additional self-control over one's behavior. Our results show that "low-resistance" ("peer-sensitive") children present a more robust fMRI response to anger during action observation compared with "high-resistance" children. Our data also indicate that children who are more able to resist peer influence show also a more coordinated brain activity during the processing of anger. Our results do not, however, allow us to tease apart whether these differences are specifically linked to the observation of anger or could be attributable to the efficient processing of any other strong emotion. Future studies should investigate whether RPI also determines brain coordination during the processing of other basic or complex emotions that are more (e.g., trustworthiness) or less (e.g., surprise) related to peer interactions.

RPI and other behavioral characteristics

Individuals with high and low RPI scores are likely to differ in a number of cognitive and behavioral characteristics. In our sample, for example, they differed in the number of corrected errors in the Stroop test. In analyses of questionnaire-based data from the MacArthur Juvenile Culpability Study (L. Steinberg, E. Cauffman, J. Woolard, S. Graham, and M. Banich, unpublished data), we observed that, after controlling for age, RPI scores were significantly, albeit very modestly, negatively correlated with widely used measures of impulsivity [the Barratt Impulsiveness Scale (Patton et al., 1995)] and antisocial risk taking [the Benthin Risk Perception Measure (Benthin et al., 1993)]. In analyses of data from the Pathways to Desistance Study (Schubert et al., 2004), RPI scores were significantly positively correlated with a measure of impulse control [from the Weinberger Adjustment Inventory (Weinberger and Schwartz, 1990)] and significantly negatively correlated with responses to the item "I worry what others think of me," from the Revised Children's Manifest Anxiety Scale (Reynolds and Richmond, 1985). Together, it appears that individuals with high versus low RPI scores may be characterized by better abilities required to control impulsive behavior in social context. Additional work is required to dissect these behavioral traits on a cognitive level in different adolescent populations.

Conclusion

Overall, our results suggest that enhanced neural interactions across brain regions involved in processing nonverbal socially relevant cues, planning, programming, and executing motor behavior underlie, at least in part, RPI in early adolescence. These findings provide the first step toward exploring the neural factors that may make children and adolescents more sensitive to peer influence. They also offer insights that may inspire the development of strategies aimed at enhancing resistance to peer pressure (Donaldson et al., 1995) such that the adolescent can maintain his/her autonomy in a group of peers. Additional studies are required to examine this relationship throughout adolescence to evaluate the effects of age, sex, and sexual maturation.

References

Allison T, Puce A, McCarthy G (2000) Social perception from visual cues: role of the STS region. Trends Cogn Sci 4:267–278.

Batty M, Taylor MJ (2006) The development of emotional face processing during childhood. Dev Sci 9:207–220.

Benthin A, Slovic P, Severson H (1993) A psychometric study of adolescent risk perception. J Adolescence 16:153–168.

Blakemore SJ, Choudhury S (2006) Development of the adolescent brain: implications for executive function and social cognition. J Child Psychol Psychiatry 47:296–312.

Choudhury S, Blakemore SJ (2006) Social cognitive development during adolescence. Soc Cogn Affect Neurosci, in press.

Cisek P, Kalaska JF (2004) Neural correlates of mental rehearsal in the dorsal premotor cortex. Nature 431:993–996.

Cox RW (1996) AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. Comput Biomed Res 29:162–173.

Donaldson SI, Graham JW, Piccinin AM, Hansen WB (1995) Resistance-skills training and onset of alcohol use: evidence for beneficial and potentially harmful effects in public schools and in private Catholic schools. Health Psychol 14:291–300.

Grosbras M, Paus T (2006) Brain networks involved in viewing angry hands or faces. Cereb Cortex 16:1087–1096.

Luna B, Thulborn KR, Munoz DP, Merriam EP, Garver KE, Minshew NJ, Keshavan MS, Genovese CR, Eddy WF, Sweeney JA (2001) Maturation of widely distributed brain function subserves cognitive development. NeuroImage 13:786–793.

McIntosh AR, Lobaugh NJ (2004) Partial least squares analysis of neuroimaging data: applications and advances. NeuroImage 23 [Suppl 1]:S250–S263.

Monahan K, Steinberg L, Cauffman E (2007) Peer groups and deviant behavior: the role of friendship quality and resistance to peer influence. Paper presented at Biennial Meetings of the Society for Research in Child Development, Boston, MA, March.

Patton J, Stanford M, Barratt E (1995) Factor structure of the Barratt Impulsiveness Scale. J Clin Psychol 51:768–774.

Paus T (2005) Mapping brain maturation and cognitive development during adolescence. Trends Cogn Sci 9:60–68.

Peterson AC, Crockett L, Richards M, Boxer A (1988) A self-report measure of pubertal status: reliability, validity, and initial norms. J Youth Adolesc 17:117–133.

Petrides M (2005) Lateral prefrontal cortex: architectonic and functional organization. Philos Trans R Soc Lond B Biol Sci 360:781–795.

Petrides M, Milner B (1982) Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. Neuropsychologia 20:249–262.

Pollick FE, Paterson HM, Bruderlin A, Sanford AJ (2001) Perceiving affect from arm movement. Cognition 82:B51–B61.

Reynolds C, Richmond B (1985) Revised Children's Manifest Anxiety Scale. RCMAS Manual. Los Angeles: Western Psychological Services.

Rizzolatti G, Craighero L (2004) The mirror-neuron system. Annu Rev Neurosci 27:169–192.

Schubert C, Mulvey E, Cauffman E, Steinberg L, Losoya S, Hecker T, Chassin L, Knight G (2004) Operational lessons from the Pathways to Desistance Study. Youth Violence Juvenile Justice 2:237–255.

Steinberg L (2005) Cognitive and affective development in adolescence. Trends Cogn Sci 9:69–74.

Steinberg L (2006) A new approach to the study of adolescent cognitive development. Paper presented at Biennial Meetings of the Society for Research on Adolescence, San Francisco, CA, March.

Steinberg L, Monahan K (2007) Age differences in resistance to peer influence. Dev Psychol, in press.

Steinberg L, Silverberg SB (1986) The vicissitudes of autonomy in early adolescence. Child Dev 57:841–851.

Taylor MJ, McCarthy G, Saliba E, Degiovanni E (1999) ERP evidence of developmental changes in processing of faces. Clin Neurophysiol 110:910–915.

Weinberger DA, Schwartz GE (1990) Distress and restraint as superordinate dimensions of self-reported adjustment: a typological perspective. J Personality 58:381–417.

Worsley KJ (2005) An improved theoretical P value for SPMs based on discrete local maxima. NeuroImage 28:1056–1062.

Worsley KJ, Liao CH, Aston J, Petre V, Duncan GH, Morales F, Evans AC (2002) A general statistical analysis for fMRI data. NeuroImage 15:1–15.