

Anterior cingulate cortex responds differentially to expectancy violation and social rejection

Leah H Somerville, Todd F Heatherton & William M Kelley

This study investigated human anterior cingulate cortex (ACC) involvement during a task that dissociated expectancy violation from social rejection. Across two studies, participants underwent functional magnetic resonance imaging while making social judgments and receiving fictitious feedback that was either positive or negative and consistent or inconsistent with their expectations. The results demonstrate that the dorsal ACC is sensitive to expectancy violations, whereas the ventral ACC is differentially responsive to social feedback.

The desire to avoid social rejection is a powerful motive. Humans are a social species, and individuals who were shunned by their social groups were unlikely to have survived on their own. Over the course of human evolution, therefore, it is likely that the brain adapted neural circuits to detect and cope with rejection by group members. Given the fundamental importance of social pain, it is perhaps not surprising that brain regions commonly associated with physical pain have been implicated as crucial for the experience of social pain¹. Specifically, a recent study found that a region of the dorsal anterior cingulate cortex (dACC) was responsive during a video game thought to elicit feelings of social rejection when the virtual players suddenly and surprisingly stopped cooperating with the research participant.

Although notable, the results of this previous study challenge a prevalent theory of a dorsal-cognitive/ventral-emotional functional dissociation within anterior cingulate cortex². Specifically, activity in the dACC often signals the occurrence of cognitive conflicts during a variety of tasks that encourage response competition (for example, the Stroop task), including those that involve the commission of errors^{3,4}. By contrast, activity in the ventral ACC (vACC) is more typically associated with social and emotional processes^{2,5}. A critical issue that complicates the interpretation of the social pain study¹ is that the method used to induce social rejection probably violated research participants' expectations. Put simply, the participants expected to participate in a ball-tossing game, and, when this expectation was violated, it probably created a situation high in cognitive conflict. Thus, the resulting activation patterns may have reflected either cognitive conflict or social pain. The current study was designed to allow for an independent examination of the neural

underpinnings of social rejection and expectancy violation. Here we demonstrate that the dACC is sensitive to expectancy violations independent of social rejection, whereas the vACC responds specifically to social feedback.

Forty-two right-handed subjects participated in two functional magnetic resonance imaging (fMRI) experiments in which we measured neural activity while subjects viewed a series of unfamiliar faces. Several weeks before scanning, subjects were photographed and led to believe that individuals at other institutions would be forming impressions of them during this interim period. In the scanner, subjects viewed faces and were asked to either form a first impression of these 'participants' from other universities (that is, "Do you think you would like this person?", experiment 1, $n = 20$) or to predict whether the 'participant' would accept or reject them (that is, "Do you think this person would like you?", experiment 2, $n = 22$; Fig. 1). The task judgment in experiment 2 provided a more explicit assessment of expectancy violation. All subjects provided written informed consent for their participation.

In both experiments, subjects were given false feedback for some of the faces, indicating that the person in the photo had previously formed a negative or positive first impression of the subject. This approach

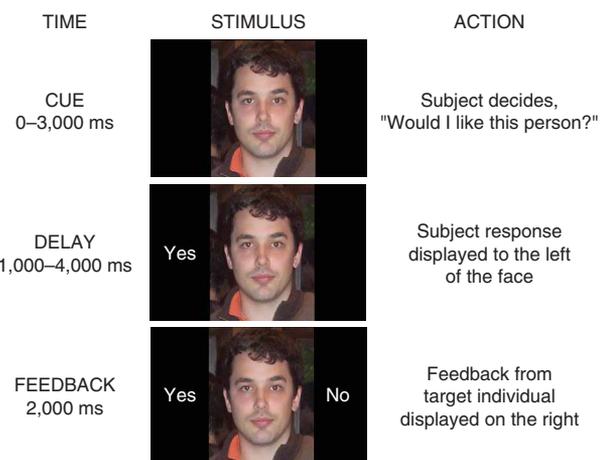


Figure 1 Representation of the subcomponents of a complete trial. Time indicates the duration of each subcomponent. During the CUE period, subjects viewed a target face and responded to the question, "Would I like this person?" (experiment 1) with a 'yes' or 'no' button press. The DELAY period began immediately following the button press, during which the subject's judgment appeared to the left of the face. Following the DELAY, subjects were given fictitious FEEDBACK (made up by the experimenters and believed by the subjects) indicating whether the subject was accepted or rejected by the pictured individual. This example represents an incongruent rejection trial. Experiment 2 trials were identical except for the CUE judgment, during which subjects answered the question, "Would this person like me?"

Department of Psychological and Brain Sciences and Center for Cognitive Neuroscience, Dartmouth College, Hanover, New Hampshire 03755, USA. Correspondence should be addressed to W.M.K. (william.kelley@dartmouth.edu).

Received 10 February; accepted 25 May; published online 2 July 2006; doi:10.1038/nn1728

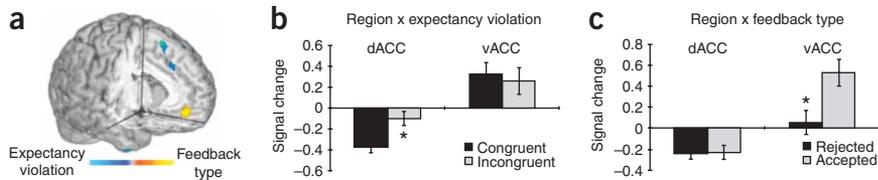


Figure 2 Differential ACC response to expectancy violation and social feedback. **(a)** A three-dimensional rendering of the medial surface of the brain illustrates a functional dissociation between dorsal (dACC) and ventral (vACC) anterior cingulate. A whole-brain voxel-by-voxel analysis of variance (ANOVA) was used to identify voxels that showed a significant main effect ($P < 0.001$, uncorrected) of expectancy violation (blue) and a main effect of feedback type (yellow). **(b,c)** Voxels in the dACC (BA 32: -6, 28, 32; 13 voxels) demonstrated greater sensitivity to expectancy violation (incongruent > congruent) **(b)**, whereas voxels in the vACC (BA 32/10: -6, 49, -13; 16 voxels) demonstrated greater sensitivity to feedback (accepted > rejected) **(c)**. Error bars denote s.e.m.

line; whole-brain activation patterns are summarized in **Supplementary Table 1** online).

Taken together, these findings support a general role for dACC in the processing of cognitive conflict and demonstrate a more specific role for vACC in social and emotional evaluation—both of which are consistent with current theories^{2,3} of ACC functioning. To the extent that people expect consistency in social exchange^{6,7}, dACC activity reported in the present study and elsewhere¹ may well reflect violations of the fundamental expectation of social inclusion.

Note: Supplementary information is available on the Nature Neuroscience website.

permitted a factorial analysis that examined neural responses specific to feedback as a function of expectancy violation (that is, when feedback matched versus did not match subjects' first impressions or predictions) and social feedback (that is, when feedback was negative versus positive; details in **Supplementary Methods** online).

Results revealed a double dissociation between dorsal and ventral ACC regions (**Fig. 2a**). Whereas a dACC region (Brodmann's area, BA, 32) was sensitive to expectancy violation (incongruent > congruent), a region of the vACC was sensitive to feedback type (accepted > rejected). This was evidenced by significant interactions between region and expectancy violation ($F_{1,40} = 8.0$, $P < 0.01$; **Fig. 2b**) and between region and feedback type ($F_{1,40} = 12.3$, $P < 0.005$; **Fig. 2c**). Additionally, these interactions were not modulated by study (region \times expectancy violation \times study: $F < 1$; region \times feedback \times study: $F < 1$). That is, the functional dissociation between dACC and vACC was independently present in both studies (**Supplementary Fig. 1** on-

ACKNOWLEDGMENTS

We thank E. Cross, J. Dobson, T. Johnstone, N. Magoon, T. Moran, J. Van Horn and P. Whalen. Supported by the National Institute of Mental Health (MH59282, MH66720). L.H.S. is a National Science Foundation Graduate Research Fellow.

COMPETING INTERESTS STATEMENT

The authors declare that they have no competing financial interests.

Published online at <http://www.nature.com/natureneuroscience>

Reprints and permissions information is available online at <http://npg.nature.com/reprintsandpermissions/>

1. Eisenberger, N.I., Lieberman, M.D. & Williams, K. *Science* **302**, 290–292 (2003).
2. Bush, G., Luu, P. & Posner, M.I. *Trends Cogn. Sci.* **4**, 215–222 (2000).
3. Botvinick, M.M., Cohen, J.D. & Carter, C.S. *Trends Cogn. Sci.* **8**, 539–546 (2004).
4. Carter, C.S. *et al. Science* **280**, 747–749 (1998).
5. Whalen, P.J. *et al. Biol. Psychiatry* **44**, 1219–1228 (1998).
6. Condon, J.W. & Crano, W.D. *J. Pers. Soc. Psychol.* **54**, 789–797 (1988).
7. Newcomb, T.M. *The Acquaintance Process* (Holt, Reinhart and Winston, New York, 1961).