Dissociable neural mechanisms underlying response-based and familiarity-based conflict in working memory

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Cognitive control requires the resolution of interference among competing and potentially conflicting representations. Such conflict can emerge at different points between stimulus input and response generation, with the net effect being that of compromising performance. The goal of this article was to dissociate the neural mechanisms underlying different sources of conflict to elucidate the architecture of the neural systems that implement cognitive control. By using functional magnetic resonance imaging and a verbal working memory task (item recognition), we examined brain activity related to two kinds of conflict with comparable behavioral consequences. In a trial of our item-recognition task, participants saw four letters, followed by a retention interval, and a probe letter that did or did not match one of the letters held in working memory (positive probe and negative probe, respectively). On some trials, conflict arose solely because of the current negative probe having a high familiarity, due to its membership in the immediately preceding trial's target set. On other trials, additional conflict arose because of the current negative probe having also been a positive probe on the immediately preceding trial, producing response-level conflict. Consistent with previous work, conflict due to high familiarity was associated with left prefrontal activation, but not with anterior cingulate activation. The response-conflict condition, when compared with high-familiarity conflict trials, was associated with anterior cingulate cortex activation, but with no additional left prefrontal activation. This double dissociation points to differing contributions of specific cortical areas to cognitive control, which are based on the source of conflict.

Current accounts of the cognitive function of the anterior cingulate cortex (ACC) assign it a special role in instances of cognitive conflict. The model of ACC function most directly related to conflict is the conflict monitoring model (1, 2), which holds that the ACC monitors for conflict, and signals lateral frontal cortex to engage cognitive control (through excitatory or inhibitory mechanisms). Alternatively, the error detection hypothesis, stemming primarily from event-related potential work (3, 4), holds that the ACC is responsible for detecting errors by comparing correct and actual responses (5), or that the ACC provides an affective or motivational signal in response to errors (6). Given that errors are more likely to arise in situations of high conflict, this hypothesis would also predict greater ACC activation during high-conflict conditions.

However, a finding that runs contrary to the notion that the ACC detects conflict, comes from the verbal working memory task of Jonides and coworkers (refs. 7–9, based on Monsell, ref. 10). The researchers produced interference effects (lengthened reaction times) on a subset of trials, by requiring subjects to reject a probe letter that was a member of the target set on the immediately preceding trial, and hence was familiar. The authors attributed the decreased performance to the need to resolve interference arising from the high familiarity of the current probe, although it was not a member of the current target set. However, no activation in the ACC was found (11). Instead, interference was associated with activation in the left inferior frontal gyrus (IFG), in Brodmann's area 45. Similar activations of the left IFG have been commonly found in semantic retrieval tasks (12–16). An elegant interpretation of the semantic retrieval findings has emerged from the neuroimaging work by Thompson-Schill *et al.* (17), in which the role of the left IFG is characterized as mediating selection among competing alternatives, which is consistent with the conflict-related interference resolution interpretation of Jonides and coworkers (7–9).

We propose that these various findings can be explained by the existence of at least two separable sources of cognitive conflict; one that occurs at the level of response processing and depends on the ACC, and another that occurs at a preceding level of processing, and involves the left IFG. The latter may involve the need to resolve interference by selection from among competing attributes or associates of a stimulus.

Tasks in which conflict is easily interpreted as occurring at the response level do seem to consistently show ACC activation. One example is the Go/No-Go task (18–22), in which responses must be made to "Go" trials, which are randomly intermixed with "No-Go trials," in which responses must be withheld. This task is typically structured so that Go responses are strongly favored and must be made under high time pressure. ACC activation is typically associated with such Go/No-Go tasks. An instructive exception is that of Konishi *et al.* (23), in which No-Go trials had a 50% probability of occurring, thus reducing the prepotency of the Go response.

The ACC is typically characterized in conflict accounts as dealing with response conflict, (see also ref. 24 for a related account), but response conflict is rarely specifically contrasted with an alternate form of conflict. A rare explicit test of the specificity of ACC activation for response-based conflict is found in work by Milham *et al.* (25). They modified the classic Stroop task, which requires participants to name the color of the ink with which a word name is printed (e.g., the word BLUE printed in red ink would require the response RED). Incongruent trials, in which the word and the ink color do not match, are more difficult than congruent trials, in which the word and the ink color do match, or neutral trials, where the word is not a color name. The Milham *et al.* (25) version of the task included two types of incongruent conditions. In the incongruent-eligible condition, the ink colors to be named were blue, yellow, and green, and the words used were BLUE, YELLOW, and GREEN, so that the responses overlapped with the conflicting word information. In the incongruent-ineligible condition, the same ink colors were used but the words used were RED, ORANGE, and BROWN, so that responses did not overlap with possible responses, although they did conflict in semantic content (e.g., RED written in yellow ink). Whereas the lateral prefrontal cortex was active during both of these conditions

Abbreviations: ACC, anterior cingulate cortex; IFG, inferior frontal gyrus; ITI, intertrial interval; ROI, region of interest.

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(compared with congruent or neutral conditions), the ACC was active only during the incongruent-eligible condition, suggesting that the ACC monitors for conflict specifically at the response level. However, the eligible and ineligible conditions were blocked, and although there was not greater interference in eligible blocks, compared with ineligible blocks, reaction times in the eligible blocks (containing both conflict and nonconflict trials) were significantly longer overall. Thus, it remains a possibility that instead of being specific to response conflict, the ACC activation in this task may be more closely related to increased task difficulty, as ACC activation was associated with the most difficult trial type (incongruent-eligible).

In this article, we used a variant of the verbal working-memory task of Jonides *et al.* (7, 8) to shed further light on the role of the ACC in cases of cognitive conflict. The original behavioral interference effect arose from requiring subjects to reject a probe that was a member of the target set on the immediately preceding, but not the current, trial. This type of conflict was associated with increased left IFG activity, but not increased ACC activity. These familiarity-conflict trial types are included in the current experiment, and are supplemented with trials in which subjects were required to make a "no" response to a probe that had been previously given a "yes" response on the immediately preceding trial. Thus, in this latter type of trial, the current correct response conflicts with the preceding stimulus-response association. We hypothesized that if the ACC is involved in response-based conflict, these trials should produce ACC activation when examined by functional magnetic resonance imaging (fMRI). Specifically, this activation should be observed when comparing response-conflict trials to familiarity-conflict trials. This article addresses the need to distinguish among types of conflict beyond the Stroop task, in this case to the domain of working memory (cf. ref. 26).

Furthermore, the present task does not depend on comparisons between trials of disparate difficulty. By including a condition with increased conflict due to increased familiarity, we were able to match the difficulty of trials with response conflict to trials without response conflict. On these highly familiar trials, a probe letter had appeared not only in the previous trial, but also two trials before.

Materials and Methods

Participants. Seventeen participants (18–24 years old, mean age 21.1 years; 12 female and 5 male) took part in this study. Participants were recruited from the University of Michigan community through newspaper and posted advertisements. All participants signed an informed consent form approved by the University of Michigan Institutional Review Board. All were native English speakers and they either reported normal vision or wore contact lenses.

Tasks and Stimuli. Participants performed 192 trials of the task, divided into four runs of 48 trials each. Trials were pseudorandomized within each run, and half the participants received runs 1 and 2 of the pseudorandom list first, and half received runs 3 and 4 first. After the second and fourth runs, participants engaged in an 8-min run of a verb-generation task, the results of which will be the subject of a separate report. After initial instruction, participants also received a 10-trial practice session before entering the scanner.

At the start of a trial, four lowercase letters (consonants only, excepting l and y) and a central fixation cross were presented in a square pattern for 1,500 ms. After a 3,000-ms delay, a 1,500-ms probe followed, which consisted of a single uppercase letter. On 50% of the trials, this probe was a member of the current trial's set of four letters, and on 50% of the trials it was not. Disregarding case, subjects responded with a "yes" for a match (positive trial), with their right index finger, or with a "no" for a mismatch (negative trial), with their right middle finger. A variable length intertrial interval (ITI) followed (96 ITIs of 1.5 sec, 48 ITIs of 3 sec, 24 ITIs of 4.5 sec, 16 ITIs of 6 sec, 4 ITIs of 7.5 sec, and 4 ITIs of 9 sec). Subjects never received more than two positive or two negative trials in a row.

The target sets were constructed so that each contained one letter in common with the preceding trial's target set, but with no other letter in common with the previous two trials. Positive trials comprised 50% of the total, and each of four types of negative trials comprised 12.5% of the total. The probe letter for positive trials was a member of the current target set, but was not a letter in common with either the preceding or subsequent trial's target set. The probe for nonfamiliar negative trials was a letter neither in the current target set nor the target set of the previous two trials. The probe for familiar negative trials was a letter in the previous target set, but not in the set before that. The probe for highly familiar negative trials was a letter in the previous two trials. The probe for response-conflict trials was a member of the previous target set, and was also a positive probe on the previous trial. Refer to Fig. 1 for examples of probe types.

Image Acquisition and Neuroimaging Data Analysis. Images were acquired by using a 3T whole-body MRI scanner (General Electric), which was equipped with the standard quadrature headcoil. Functional T2* blood oxygenation level-dependent (BOLD) images were acquired by using a spiral sequence with 25 contiguous axial 5-mm slices [repetition time (TR) = 1,500 ms, echo time (TE) = 25 ms, flip angle = 90°, and field of view (FOV) = 24 cm]. A T1-weighted gradient echo (GRE) anatomical image was also acquired by using the same FOV and slices as were used in the functional scans (TR = 275 ms, TE = 35 ms, and flip angle = 90°). In addition, a 60-slice, high-resolution set of anatomical images was acquired by using spoiled GRASS (gradient-recalled acquisition in steady state; SPGR) imaging (TR = 35ms, TE = 3ms, flip angle = 35°, and FOV = 24 cm, 2.5-mm slice thickness). The T1 GRE images were acquired at the start of the scanning session, and the SPGR images were acquired at the end of the scanning session. Experimental tasks were presented by using E-PRIME (BETA VERSION 5.0) software (Psychology Software Tools, Pittsburgh) and the IFIS 9.0 system (MRI Devices, Waukesha, WI), by using a 10-button response unit for response collection. Head movement was minimized with foam padding, as well as a restraint that was strapped across participants' foreheads. Images were corrected for slice-acquisition timing differences, by using a local, 17-point sinc interpolation program (27). Head movement was corrected by using the realignment routines in the Automated Image Registration (AIR) package (28). Subsequent processing and analysis was done by using SPM99 (Wellcome Department of Cognitive Neurology, London). SPGR images were corrected for signal inhomogeneity, by using the program developed by G. Glover and K. Christoff (Stanford University, Stanford, CA), which can be accessed at www-psych.stanford.edu/~kalina/SPM99/Tools/vol_homocor.html, and was then coregistered to the T1 images. The skull was removed from the SPGR images by using the BET (brain extraction tool) method from FSL (29) and these images were then normalized to the SPM99 T1 template, which is in the Montreal Neurological Institute (MNI; Montreal) space. The same normalization parameters were then applied to the functional images. After spatial normalization, functional images were smoothed with an 8-mm full width at half maximum Gaussian filter. All of the analyses included a temporal high-pass filter, and each image was scaled to have a global mean intensity of 100.

All analyses were performed by using the general linear model implemented in SPM99, with separate regressors and intercepts for each run. Event-onset times for the probes of the five trials types (positive probes, and four kinds of negative probe types:

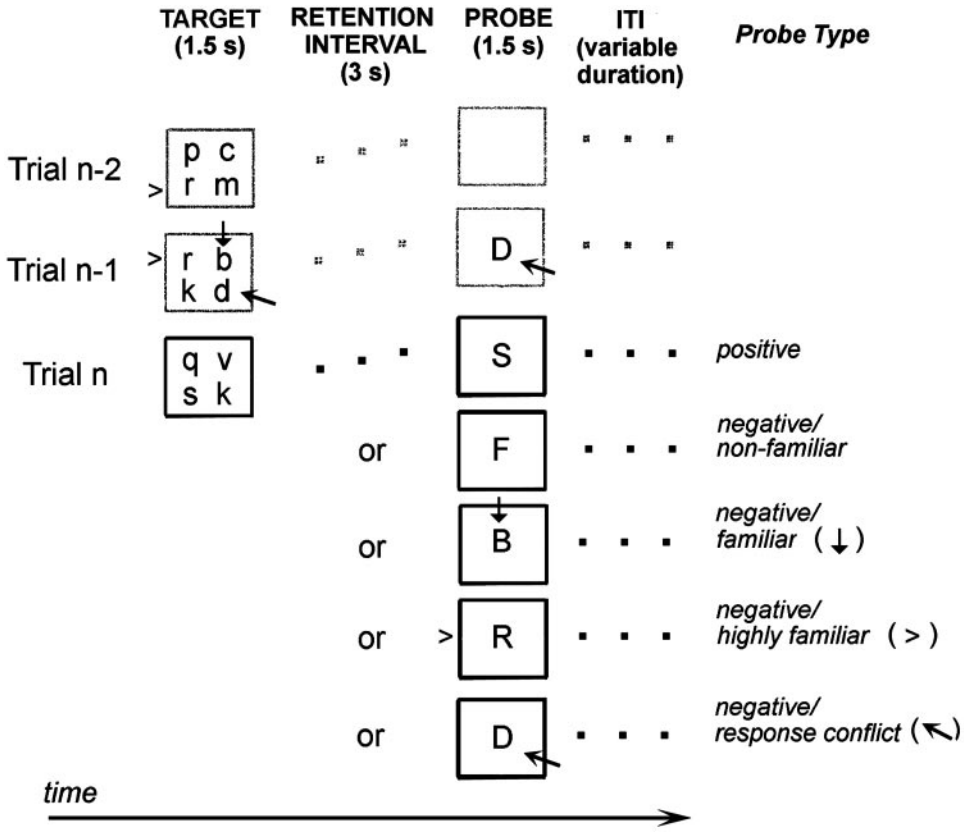

Fig. 1. Trial structure and examples of trial conditions. Trials n-2 and n-1 provide the necessary context for properly classifying possible probe types in trial n. Arrows point out relevant probes and associated prior targets and/or associated prior probes.

nonfamiliar, familiar, highly familiar, and response-conflict) were convolved with the canonical hemodynamic response function. Statistical models were fit for each participant, and contrasts of interest were estimated. Contrast images for each participant were subjected to a random-effects analysis, and region of interest (ROI) analyses were then conducted with small volume correction at $P < 0.05$. ROI analyses were conducted on activation contrast maps thresholded at a level of $P < 0.01$, which were uncorrected for multiple comparisons.

The areas used as ROIs were derived from earlier studies. Specifically, we used ROIs derived from Jonides *et al.* (8) for the left IFG site (Talairach coordinates: $x = -51, y = 21, z = 11$, and radius of ROI = 10 mm), and from Milham *et al.* (25) for the ACC site (two relevant sites: $x = 8, y = 20, z = 42$; also $x = 0$, $y = 10, z = 44$, and radius of ROI = 10 mm). This latter article was chosen as the most direct previous test of response-based conflict processing in the ACC.

Coordinates reported in Talairach coordinates were converted from MNI space by using a transform developed by M. Brett (Medical Research Council Cognition and Brain Sciences Unit, Cambridge, U.K.), which can be accessed at www.mrc-cbu.cam.ac.uk/Umaging/mnispace.html.

Results

Behavioral. Conflict was manipulated in two distinct ways: familiarity of the negative probe, and whether or not the negative probe had a conflicting positive response associated with it from the preceding trial (see Fig. 1). The stimulus lists were constructed so that negative probes could be nonfamiliar (the probe letter did not appear in the current or in the previous two trials), familiar (the probe letter did not appear in the current target set, but did appear in the preceding trial's target set), highly familiar (the probe letter did not appear in the current target set, but did appear in the previous *two* target sets), or include response conflict (not only did the probe appear in the previous target set, like the familiar trials, but was also a positive probe in that preceding trial). Results from a behavioral pilot experiment indicated that highly familiar and response-conflict trials elicited similar performance from subjects, a finding which was replicated here (see behavioral results, Fig. 2). Planned comparisons confirmed a replication of the increased reaction time to familiar

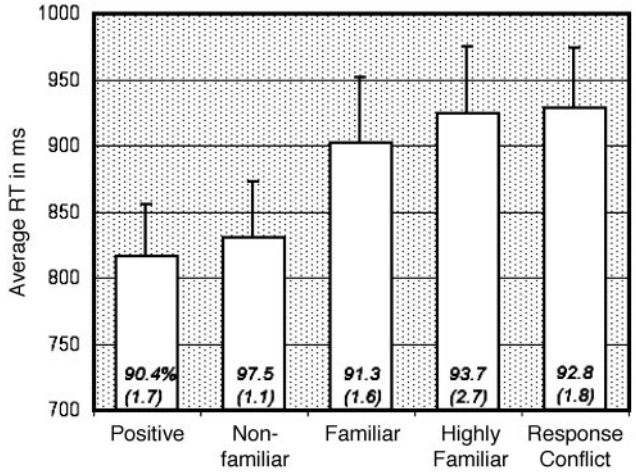

Fig. 2. Mean reaction times for the various probe types. Error bars indicate SE. Mean accuracy and SE of mean accuracy for each condition is indicated at the base of each bar.

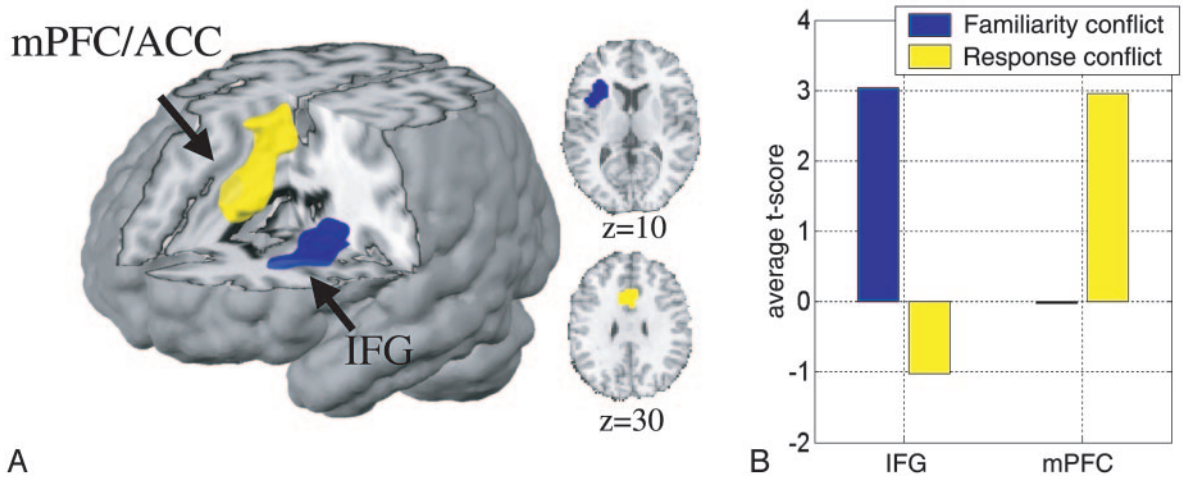

Fig. 3. (*A*) Identified clusters of activation that overlap with ROIs in the response-conflict contrast (yellow) and the familiarity-conflict contrast (blue). Indicated *Z*-coordinates refer to MNI space. (*B*) The average *t* values of voxels within the identified clusters of activation in the key contrasts of interest. mPFC, medial prefrontal cortex.

versus nonfamiliar negative probes [one-tailed *t* test; $t(1,16) = 3.09$, $P = 0.003$), as well as decreased accuracy $t(1,16) = 4.3$, $P = 0.0002$)]. Neither the highly familiar nor response conflict probes were significantly different from familiar probes in this behavioral sample, for either reaction time or accuracy.

Neuroimaging. We used an event-related fMRI analysis, focusing on predefined ROIs (see *Materials and Methods*) to examine our key predictions. First, we predicted that familiarity-related conflict would result in left IFG activation, but not ACC activation. For this familiarity contrast, we compared familiar and highly familiar negative probes to nonfamiliar negative probes (combining the familiar and highly familiar trials increased sensitivity, decreasing the likelihood of a false rejection of ACC activation). Second, we predicted that introducing response-based conflict would result in ACC activation, but would not increase activation of the left IFG. For this response-conflict contrast, we compared response-conflict trials with highly familiar trials. The rationale for using highly familiar trials in this subtraction was that these trials were best matched in overall familiarity of the probe (both types of trials had two recent appearances of the probe letter), and they were best matched in subject performance in terms of reaction time and accuracy. Thus, any activation observed in this case could not be attributed to greater difficulty of the response-conflict trials.

The results supported our predictions. The analysis of the familiarity contrast revealed significant activation within the left IFG ROI, but revealed no activation within either ACC ROI, whereas analysis of the response-conflict contrast revealed the opposite pattern of no left IFG activation, but of significant ACC activation. The dissociation noted does not depend on the specific familiarity conflict contrast used, which combines familiar and highly familiar probes. This contrast was used to help increase statistical power to find any subthreshold ACC activity; however, using contrasts based on these probe types separately also replicates the findings of increased IFG activity (and no increased ACC activity). Additionally, although the increase in reaction time associated with highly familiar trials did not differ statistically from familiar trials, the performance change was mirrored by significantly increased left IFG activity in highly familiar trials, when using the same left IFG ROI previously used in testing the overall familiarity-conflict contrast.

The response-conflict contrast tells us only that no additional left IFG activation occurs due to a negative probe having a conflicting response association on the previous trial. It does not tell us whether the left IFG is activated at all on response-conflict trials, as compared with baseline. An ROI analysis on a contrast of response-conflict probes versus nonfamiliar probes does, in fact, indicate left IFG activation, in addition to the ACC-related activations; this result is expected in that response-conflict trials also contain familiarity-based conflict.

The preceding analysis constitutes *a priori* hypothesis testing, in which we statistically confirmed our predictions. We now present a post hoc descriptive analysis of the actual, relevant clusters of activation on the contrast maps (the same contrast maps used in the ROI analysis; see *Materials and Methods*), which had overlapped with the spherical ROIs used in hypothesis testing. Coordinates of peak activation for the left IFG cluster were: $x = -49$, $y = 19$, and $z = 17$; and coordinates for the peak activation of the ACC cluster were: $x = 4$, $y = 20$, and $z = 22$. The peak activation for the left IFG site is similar to the left IFG ROI location. However, the peak medial activation is inferior to either of the medial ROIs used, and is closer to the corpus callosum. The area of medial activation extends superior to this peak location, into areas adjacent to and overlapping with the ROIs (see Fig. 3*A*).

To characterize the selectivity of the identified regions, we examined the average *t* value of the clusters for each contrast of interest (see Fig. 3*B*). We found no evidence of any relationship between left IFG activation and the presence of response conflict, nor of any relationship between ACC (and neighboring medial prefrontal cortex) activation and the presence of familiarity conflict alone.

Discussion

The results provide evidence that the left IFG and the ACC are both involved in conflict resolution, but for different types of conflict. The IFG is involved when a subject is faced with the need to resolve interference among potentially conflicting attributes of a stimulus to select the most context-appropriate attribute, whereas the ACC is involved when a subject is faced with conflicting stimulus–response associations. The relatively close match in trial difficulty between the two conflict types, and the fact that a double dissociation was found between the conflict types and the sites of activation, argue strongly against strength of conflict or task difficulty as an explanation of the results.

The results of the present study differ from that of Milham *et al.* (25) in three important ways. First, we found ACC activation in a contrast between conditions of matched difficulty. Second, we show a dissociation of response- versus nonresponse-related sites of frontal activation. This finding contrasts with the Milham *et al.* (25) results, which showed an involvement of left prefrontal cortex in both response and nonresponse interference. These features of this article provide a stronger argument for the specificity of the ACC for response-related conflict processing, effectively ruling out trial difficulty or degree of conflict as an explanation; additionally, our results show insensitivity of the left IFG to response conflict, not demonstrated in the Milham *et al.* (25) results. Third, the present response-related conflict was produced by subtle trial-to-trial variation in the probe's positive versus negative status, unlike the fixed designation of particular stimuli as response-eligible or -ineligible as required in a Stroop-like task. As such, the present results reveal the exquisite sensitivity of the ACC to online variations in stimulus–response associations.

Jonides *et al.* (8) proposed two processes appropriate to an item-recognition paradigm: inhibition of the familiarity-based representation that leads to conflict, or temporal tagging of memory items. In our results, we found greater activation with increased familiarity of the probe. Furthermore, activation was found during the probe epoch. These attributes are consistent with the proposed inhibitory mechanism, which is also parsimonious with the results from semantic retrieval paradigms (17).

Are there other explanations for the dissociation found in this study? One possibility is that the subjects are more aware of the response-conflict manipulation than the familiarity manipulation, and that the ACC is correlated with conscious monitoring of conflict. Bunge *et al.* (30) suggest a similar explanation for their results. In a similar working-memory paradigm, they manipulated familiarity and set size, and found lateral prefrontal activity was positively correlated with the size of the behavioral effect among subjects due to the familiarity manipulation, whereas, in contrast, medial prefrontal activity was positively correlated with the decrement in performance, due to increased target set size. Bunge *et al.* (30) note that although the target-set size manipulation was readily apparent to subjects, subjects were not aware of the familiarity manipulation, which is consistent with previous studies. Although our debriefing interviews showed only occasional and vague knowledge of the task manipulations on the part of some participants, it remains a possibility that there may be differences in conflict awareness during our task conditions. Careful probing, perhaps during the task itself, might be necessary to detect this difference.

However, we believe the explanation with the most potential to unify diverse findings is that of a special role for the ACC in the processing or resolution of response conflict compared with conflict at other stages of processing, and that our results provide the clearest confirmation of this hypothesis to date. Further work is needed and continues to be done to specify the nature and specificity of processing of the left IFG as well as the ACC, and their functional relationship to other areas of the frontal cortex.

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1. Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D. & Cohen, J. D. (1998) *Science* **280,** 747–749.
2. Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S. & Cohen, J. D. (2001) *Psychol. Rev.* **108,** 624–652.
3. Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E. & Donchin, E. (1993) *Science* **4,** 385–390.
4. Dehaene, S., Posner, M. I. & Tucker, D. M. (1994) *Science* **5,** 303–305.
5. Bernstein, P. S., Scheffers, M. K. & Coles, M. G. H. (1995) *J. Exp. Psychol. Hum. Percept. Perform.* **21,** 1312–1322.
6. Gehring, W. J. & Knight, R. T. (2000) *Nat. Neurosci.* **3,** 516–520.
7. Jonides, J., Smith, E. E., Marshuetz, C., Koeppe, R. A. & Reuter-Lorenz, P. A. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 8410–8413.
8. Jonides, J., Marshuetz, C., Smith, E. E., Reuter-Lorenz, P. A. & Koeppe, R. A. (2000) *J. Cognit. Neurosci.* **12,** 188–196.
9. D'Esposito, M., Postle, B. R., Jonides, J. & Smith, E. E. (1999) *Proc. Natl. Acad. Sci. USA* **96,** 7514–7519.
10. Monsell, S. (1978) *Cognit. Psychol.* **10,** 465–501.
11. Jonides, J., Badre, D., Curtis, C., Thompson-Schill, S. L. & Smith, E. E. (2002) in *The Frontal Lobes*, eds. Stuss, D. T. & Knight, R. T. (Oxford Univ. Press, Oxford), pp. 233–245.
12. Gabrieli, J. D. E., Desmond, J. E., Demb, J. B., Wagner, A. D., Stone, M. V., Vaidya, C. J. & Glover, G. H. (1996) *Psychol. Sci.* **6,** 76–82.
13. Kapur, S., Craik, F. I., Tulving, E., Wilson, A. A., Houle S. & Brown, G. M. (1994) *Proc. Natl. Acad. Sci. USA* **91,** 2008–2011.
14. Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M. A. & Raichle, M. A. (1989) *J. Cognit. Neurosci.* **1,** 153–170.
15. Wise, R., Chollet, F., Hadar, U., Friston, K., Hoffner, E. & Frackowiak, R. (1991) *Brain* **114,** 1803–1817.
16. Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L. & Ungerleider, L. G. (1995) *Science* **270,** 102–105.
17. Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K. & Farah, M. J. (1997) *Proc. Natl. Acad. Sci. USA* **94,** 14792–14797.
18. Kawashima, R., Satoh, K., Itoh, H., Ono, S., Furumoto, S., Gotoh, R., Koyama, M., Yoshioka, S., Takahashi, T., Takahashi, K., *et al.* (1996) *Brain Res.* **728,** 79–89.
19. Casey, B. J., Trainor, R. J., Orendi, J. L., Schubert, A. B., Nystrom, L. E., Giedd, J. N. & Rapoport, J. L. (1997) *J. Cognit. Neurosci.* **9,** 835–847.
20. de Zubicary, G. I., Andrew, C., Zelaya, F. O., Williams, S. C. R. & Dumanoir, C. (2000) *Neuropsychologia* **38,** 1280–1291.
21. Garavan, H., Ross, T. J. & Stein, E. A. (1999) *Proc. Natl. Acad. Sci. USA* **96,** 8301–8306.
22. Kiehl, K. A., Liddle, P. F. & Hopfinger, J. B. (2000) *Psychophysiology* **37,** 216–223.
23. Konishi, S., Nakajima, K., Uchida, I., Sekihara, K. & Miyashita, Y. (1998) *Eur. J. Neurosci.* **10,** 1209–1213.
24. Paus, T., Petrides, M., Evans, A. C. & Meyer, E. (1993) *J. Neurophysiol.* **70,** 453–469.
25. Milham, M. P., Banich, M. T., Webb, A., Barad, V., Cohen, N. J., Wszalek, T. & Kramer, A. F. (2001) *Cognit. Brain Res.* **12,** 467–473.
26. Fan, J., Flombaum, J. I., McCandliss, B. D., Thomas, K. M. & Posner, M. I. (2003) *NeuroImage* **18,** 42–57.
27. Oppenheim, A. V., Schafer, R. W. & Buck, J. R. (1999) *Discrete Time Signal Processing* (Prentice–Hall, Englewood Cliffs, NJ), 2nd. Ed.
28. Woods, R. P., Grafton, S. T., Holmes, C. J., Cherry, S. R. & Mazziotta, J. C. (1998) *J. Comput. Assist. Tomogr.* **22,** 141–154.
29. Smith, S. (2002) *Hum. Brain Mapp.* **17,** 143–155.
30. Bunge, S. A., Hazeltine, E., Scanlon, M. D., Rosen, A. C. & Gabrieli, J. D. E. (2002) *NeuroImage* **17,** 1562–1571.