Cognitive and Brain Consequences of Conflict

Jin Fan,*,[1] Jonathan I. Flombaum,† Bruce D. McCandliss,* Kathleen M. Thomas,*,[2] and Michael I. Posner*,‡

*Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University, New York, New York, 10021;
†Department of Psychology, Harvard University, Cambridge, Massachusetts 02138; and ‡Department of Psychology,
University of Oregon, Eugene, Oregon 97403

Tasks involving conflict between stimulus dimensions have been shown to activate dorsal anterior cingulate and prefrontal areas. It has been proposed that the dorsal anterior cingulate is involved a domain general process of monitoring conflict, while prefrontal areas are involved in resolving conflict. We examine three tasks that all require people to respond based on one stimulus dimension while ignoring another conflicting dimension, but which vary in the source of conflict. One of the tasks uses language stimuli (Stroop effect) and two use nonlanguage spatial conflicts appropriate for children and nonhuman animals. In Experiment 1, 12 participants were studied with event-related functional magnetic resonance imaging (fMRI) while performing each of the three tasks. Reaction times for each of the three tasks were significantly longer in the incongruent condition compared with the congruent condition, demonstrating that each task elicits a conflict. By studying the same people in the same session, we test the hypothesis that conflict activates a similar brain network in the three tasks. Significant activations were found in the anterior cingulate and left prefrontal cortex for all three conflict tasks. Within these regions, the conflict component demonstrated evidence for significant common activation across the three tasks, although the peak activation point and spatial extent were not identical. Other areas demonstrated activation unique to each task. Experiments 2–4 provide behavioral evidence indicating considerable independence between conflict operations involved in the tasks. The behavioral and fMRI results taken together seem to argue against a single unified network for processing conflict, but instead support either distinct networks for each conflict task or a single network that monitors conflict with different sites used to resolve the conflict. © 2002 Elsevier Science (USA)

INTRODUCTION

Many psychological tasks involve conflict between stimulus dimensions. The most widely studied is the classic Stroop conflict between a word name and its ink color (for a review, see MacLeod, 1991). Many variants of this task involve language as one of the two dimensions. Another commonly studied conflict task involves a conflict between location and the direction of response (Simon effect) (Simon and Berbaum, 1990). A version of the Simon task involves matching the identity of the stimulus with the assigned response and introduces conflict by presenting the stimulus on the same or opposite side as the matching response (Gerardi-Caulton, 2000). A third common conflict task involves responding to a central stimulus surrounded by flankers (Ericksen and Ericksen, 1974). A version of this task uses a central arrow pointing in one direction and flanker arrows that point in either the congruent or the incongruent direction (Botvinick et al., 2001; Casey et al., 2000; Fan et al., 2002).

The neural networks activated by two of these tasks have been studied in some detail using functional magnetic resonance imaging (fMRI). Meta-analyses of the Stroop task (Bush et al., 1998; Bush et al., 2000) have stressed activation of the dorsal anterior cingulate, but the various experiments have also activated a wide number of areas in the prefrontal cortex. Studies of the flanker effect (e.g. Botvinick et al., 2001; Casey et al., 2000) also show cingulate activity, in addition to prefrontal cortex activation. While both the flanker and the Stroop tasks have been shown activate some similar brain regions, these conflict tasks have yet to be examined within the same participants using identical scanning procedures. Furthermore, although the spatial conflict task used by Gerardi-Caulton (2000) produces evidence of cognitive conflict at the behavioral level, no direct evidence exists concerning the cortical regions associated with this particular form of conflict.

Suppose that all conflict tasks involve a common network, perhaps related to a single cognitive operation such as monitoring for conflict between neural areas (Botvinick et al., 2001) or the execution of operations that result in inhibiting

[1] To whom correspondence should be addressed at Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University, 1300 York Ave., Box 140, New York, NY 10021. E-mail: jif2004@med.cornell.edu.

[2] Current address: Institute of Child Development, University of Minnesota, Minneapolis, MN 55455.

conflicting activity (Posner and Raichle, 1994). What would be the behavioral consequences of having such operations instantiated in this common network? One theory is that operations that involve neural mechanisms in common regions or close proximity will interfere when executed at the same time but will prime each other when executed sequentially (Kinsboure and Hicks, 1978). Tests of this notion have been few, but what efforts have been made have supported the general idea (Fias *et al.,* 2001; Kinsbourne and Hicks, 1978; Posner *et al.,* 1989). Based on the extensive dual-task performance literature, it is clear that executing two similar operations simultaneously typically causes interference (Bourke, 1997; Bourke *et al.,* 1996). However, if the operation in question merely involves monitoring, such as monitoring for a target, there is evidence that several operations can be carried out simultaneously without interference (Duncan, 1980). Based on these insights, we reason that areas of the conflict network that carry out conflict monitoring operations should be able to be applied to several channels at once without showing interference. Conversely, we propose that areas related to active suppression of conflicting channels would be expected to interfere when applied to multiple channels. To investigate this, we conducted a series of experiments that combined tasks that have identifiable conflict components and examined patterns of dual task interference. We also examined correlations among the magnitude of conflict effects produced within these different cognitive conflict paradigms.

Experiment 1 examines the degree to which linguistic and spatial conflict paradigms activate a common brain network. Experiment 2 investigates a potential correlation among the magnitudes of various cognitive conflict scores, as assessed by the Stroop and flanker paradigms of the first experiment. Experiment 3 examines whether Stroop and flanker conflict produce evidence of interference when both conflict dimensions are present within the same task. Experiment 3 also tests the degree of correlation between Stroop and flanker conflict when stimuli potentially involved both sources of conflict. Finally, Experiment 4 examines potential interference between two different forms of spatial conflict when both are present in the same task.

EXPERIMENT 1

Materials and Methods

Participants

Twelve right-handed adults participated (mean age 24.7 years, SD 4.6 years, range 18–34 years; 6 women, 6 men). All participants reported normal or corrected to normal vision. A signed informed consent approved by the New York Presbyterian Hospital/Weill Medical College of Cornell University was obtained from each participant before the experiment.

Conflict Tasks

Flanker task. Stimuli consisted of a row of five visually presented arrows, pointing to the left or to the right, against a gray background (see the three flanker conditions in Fig. 1b of Fan *et al.,* 2002). The target was a leftward or rightward arrow at the center of the array. This target was flanked on both sides by two arrows pointed in the same direction (congruent condition), in the opposite direction (incongruent condition), or by lines without arrowheads (neutral condition). The participants' task was to indicate the direction of the center arrow by pressing one key for the left direction or a second key for the right direction.

Color-word Stroop task. Words were presented in four different ink colors: red, blue, green, or yellow. The participants' task was to indicate the color of ink by pressing one of four keys. There were four words: RED, BLUE, GREEN, and YELLOW. For congruent trials, the ink color and the word's meaning were consistent (e.g., word RED displayed in red ink). For incongruent trials, word meaning was inconsistent with the color (e.g., word RED displayed in blue ink). Neutral trials consisted of words selected to match the length and word frequency of the color words (LOT, SHIP, KNIFE, and FLOWER), while having neither congruency nor incongruency with the ink color.

Spatial conflict task. Targets consisted of color drawings of generic cartoon characters or objects (i.e., a lion or a dog) presented in one of three locations on the monitor: top left corner, top right corner, or top center. At the beginning of each trial, two drawings (response labels) appeared near the bottom left and right of the screen to indicate the proper mapping between object identity and side of response. The drawing on the bottom left side of the screen corresponded to a left button response, and the drawing on the bottom right side of the screen corresponded to a right button response. When the target appeared, the participant was required to press the key corresponding to the matching drawing, ignoring the physical location of the target. In the neutral condition, the target appeared in the central position. In the congruent condition, the target was presented on the same side as the matching response drawing. An incongruent condition consisted of a target presented on the opposite side of the matching response drawing. Each block consisted of equal proportions of congruent, incongruent, and neutral trials.

Apparatus and Stimuli

Stimuli were displayed on a LCD screen using the integrated functional imaging system (IFIS) for fMRI research (Psychology Software Tools, Inc., Pittsburgh, PA). Participants' responses were collected with IFIS's button response unit. An RF monitor was used to synchronize the initiation of each behavioral block with the beginning of each scan block.

For the flanker task, stimuli consisted of a row of five horizontal black lines with arrowheads pointing leftward or rightward, against a gray background. A single arrow or line subtended 0.58° of visual angle and the contours of adjacent arrows or lines were separated by 0.06°. The horizontal extent of each stimulus array (one central arrow plus four flankers) subtended 3.27° of visual angle.

For the color-word Stroop task, the words were displayed in capital letters (18-point size, Courier new font). Each letter subtended 0.58° vertically and 0.49° horizontally, and letters were separated by a space of 0.08°.

For the spatial Stroop task, stimuli consisted of paired picture objects (axe/fire truck, bear/goat, woman jumping rope/woman waving, kangaroo/lion, tennis ball/volleyball). Each of the objects subtended 2.29° of visual angle in both width and height. The two response objects were separated by 10.68° of visual angle. The fixation cross on the center and either left target object or right target object was 6.87° of visual angle above the bottom response objects. For the congruent trials, the target and response object were separated by 0° of visual angle horizontally. For the incongruent trials, the target and response object were separated by 12.82° of visual angle.

Procedures

An event-related fMRI study with jittered trial durations was used. Durations were chosen from a set of discrete times approximating an exponential distribution with a mean of 6,000 ms and a range of 3,000 to 15,000 ms. Each scan session included four 38-trial blocks for each of the three tasks. The trial structure was similar for each task. Each block began with two buffer trials that had a fixed duration of 6,000 ms, followed by 36 trials with 12 trials for each of the three conflict conditions.

Each of the 12 trials in each conflict condition of each scan session was assigned a specific duration (3,000, 3,250, 3,500, 3,750, 4,000, 4,500, 5,000, 5,500, 6,500, 8,000, 10,000, and 15,000 ms). The 6 trial types formed by considering conflict condition (congruent, incongruent, and neutral) and response type (left or right) were presented in a predetermined counterbalanced order generated to ensure that each trial type followed every other trial type equally often. In total, there were 144 trials for each task and 48 trials for each conflict condition within each task.

The beginning of each trial was marked by the appearance of the stimulus array in the center of the screen. Stimuli remained present on the screen until participants entered a response or for a maximum duration of 2000 ms. Following a response, the fixation cross reappeared and remained present for a variable duration contingent on the duration of the participant's response time and the jittered duration. This duration of this postfixation was calculated by subtracting the reaction time (RT) from the predetermined jittered duration between the onset of the target and the end of the trial. For the spatial conflict task, two response objects appeared on the bottom of the screen 500 ms before the appearance of the target. The location of the target (left, central, right) and the location of the response objects were counterbalanced. Participants were asked to focus on a fixation cross in the center of the screen throughout the experiment.

Behavioral data collection and analysis. Behavioral data (reaction time and accuracy) were collected while participants performed the task in the scanner.

Acquisition of anatomic and functional MRI data. MR imaging was carried out using a 1.5-T GE scanner. Functional scans were collected using a T2*-weighted gradient echoplanar imaging (EPI) sequence [TE = 40 ms, TR = 2000 ms, flip angle 90° with an in-plane resolution of 3.44 × 3.44 mm (64 × 64 matrix; 220-mm field of view)]. To cover the whole brain, 24 slices, 5 mm thick (1-mm skip between slices), were acquired along the AC-PC plane as determined by the midsagittal section. Structural scans were collected using a T1-weighted sequence (TR = 500 ms, TE = 14 ms) in the same orientation as the functional sequences to provide detailed anatomic images aligned to the functional scans. A high-resolution structural MRI sequence (TR = 25 ms, TE = 5 ms, FOV = 220 mm, 256 × 256 matrix, thickness 1.5 mm, slice number 100) was acquired for cross-subject registration.

Analysis of functional MRI data. The goal of the data analysis is to extract the signal contribution owing to blood oxygenation properties that correlate with neuronal activity under different experimental conditions. Statistical analyses of the functional imaging data were conducted using statistical parametric mapping as provided in the practical academic software tool kit, SPM99, developed by the Wellcome Department of Cognitive Neurology in London.

During preprocessing, the EPI time-series images were reconstructed and processed. Because the slices of each volume were not acquired simultaneously, a timing correction procedure (using sync interpolation) was used to correct differences in image acquisition time between slices within each volume. A spatial alignment was performed to correct for subtle head motion. The time series of images acquired from an individual participant were realigned using a least squares approach and a six-parameter (rigid body) spatial transformation. All volumes from each participant were aligned to the first volume. The resultant movement parameters (six parameters: *x, y, z,* and three rotation angles) were used as covariates in the statistical analysis phase.

EPI images were registered to each participant's T1-weighted structural images and then to the high-resolution images for later localization of functional activity and coregistration across participants. To conduct the group analysis, the high-resolution structural images were normalized to a standard template supplied with SPM, which conforms to the space defined by the ICBM, NIH P-20 project, and approximates that of the space described in the atlas of Talairach and Tournoux (1988). The resultant transformation parameters were then applied to the EPI images. After normalization, voxels were resampled with 2-mm³ voxel size. An 8-mm³ full-width at half-maximum Gaussian kernel was applied to smooth the EPI images to remove spatial noise.

After preprocessing, statistical analysis was conducted based upon general linear modeling. High-pass filtering (default, 2 × min(max(intertrial interval)) over trial types) was applied to the time series of EPI images to remove the low-frequency drift in EPI signal. Global changes in signal intensity were removed by proportional scaling.

The data from each participant were analyzed using linear regression between the observed event-related EPI signals and a regressor to identify the relationship between the experimental parameters and the hemodynamic response. First, the default SPM basis function (hemodynamic response functions, HRF) was adopted for the purposes of conducting event-related analyses. Next, regressors were created by convolving a train of delta functions (representing the sequence of individual trials) with the fit functions. Each of the regressors represents one expected brain response to the stimuli. The linear combination of all of the regressors

was used for the modeling of the hemodynamic response to each conflict trial type within each task. The six realignment parameters were used as covariates. The base functions were a synthetic hemodynamic response function composed of two gamma functions and its derivative (Friston *et al.,* 1998). Note that this methodological approach may be somewhat prone to Type II error in cases in which cortical regions of interest demonstrate a hemodynamic function that significantly deviates from the SPM default HRF function employed here.

Group data analyses were conducted. Images for each participant were collapsed into a single image for each contrast. A random-effects analysis was carried out to make inferences to the population. The contrast images from each participant were used as the input data. Specifically, each participant contributed an incongruent minus congruent image. The resultant parameter estimates for each contrast at each voxel were tested using F tests to determine whether the voxel showed a significant difference in activity for congruent and incongruent conditions. An uncorrected P value for extent threshold of activated regions was used as the threshold for significance given an initial uncorrected height threshold. The conjunction analysis calculated the main effect and eliminated any voxels where there were significant differences between tasks.

Results

Behavioral Results

Figure 1 shows the RTs, error rates, and conflict effect for each of the three tasks. A criterion of $P < 0.01$ was used for all statistical tests. ANOVAs were conducted on RTs (correct trials only) for each of the three tasks. For the flanker task, the main effect of flanker type was significant, $F(2,22) = 16.29$, $P < 0.01$. The contrast between incongruent and congruent conditions was significant, $F(1,11) = 12.08$, $P < 0.01$, thus demonstrating conflict. The contrast between congruent and neutral conditions was not significant, $F(1,11) = 2.32$, ns. For the color Stroop task, the main effect of word type was significant, $F(2,22) = 6.29$, $P < 0.01$. The contrast between incongruent and congruent conditions was significant, $F(1,11) = 10.57$, $P < 0.01$, thus demonstrating conflict. The contrast between congruent and neutral conditions was not significant, $F(1,11) = 1.51$, ns. For spatial Stroop task, the main effect of spatial location was significant, $F(2,22) = 7.94$, $P < 0.01$. The contrast between incongruent and congruent conditions was significant, $F(1,11) = 9.81$, $P < 0.01$, thus demonstrating conflict. The contrast between congruent and neutral conditions was marginally significant, $F(1,11) = 8.36$, $P = 0.02$.

ANOVAs were also carried out for error rate for each of the three tasks. For the flanker task, the main effect of flanker type was significant, $F(2,22) = 7.5$, $P < 0.01$. The contrast between incongruent and congruent conditions was marginally significant, $F(1,11) = 7.28$, $P = 0.02$. The contrast between congruent and neutral conditions was not significant, $F(1,11) = 1.94$, ns. For the color Stroop task, the main effect of word type was not significant, $F < 1$. For the spatial conflict task, the main effect of spatial location was not significant, $F < 1$.
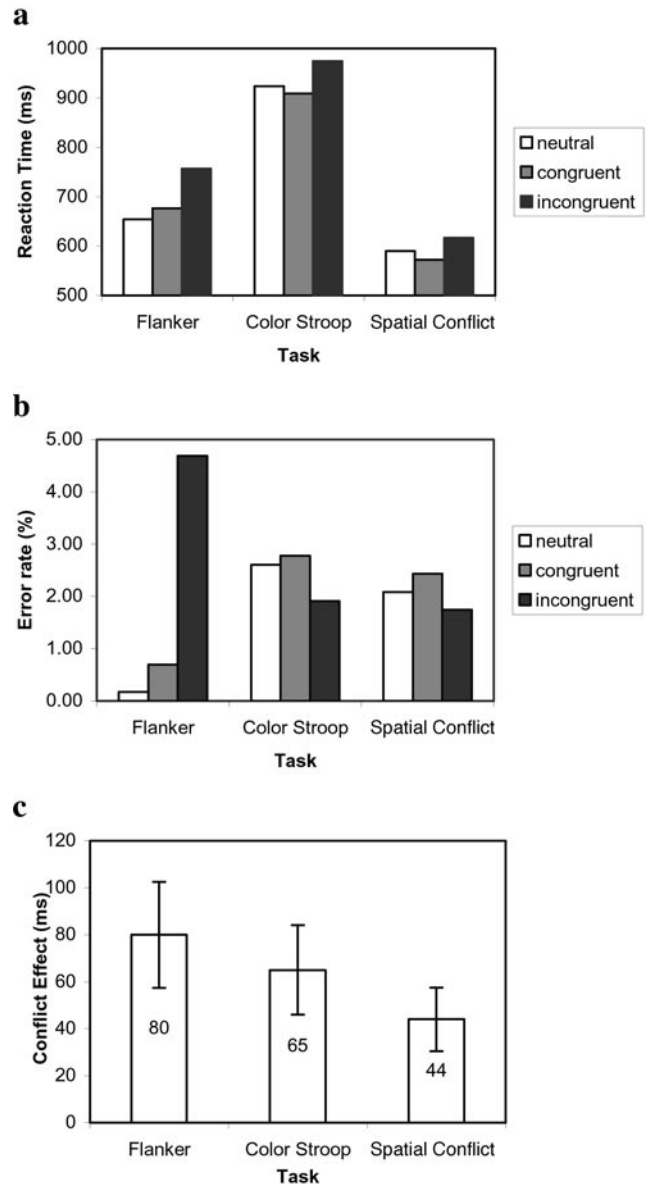
FIG. 1. Behavioral results. (a) Mean reaction times (RT) corresponding to neutral, congruent, and incongruent conditions for each task; (b) error rate (%) corresponding to neutral, congruent, and incongruent conditions for each task; and (c) conflict effects (RT incongruent − RT congruent). Bars, ± SEM.

Reaction times for each of the three tasks were significantly longer in the incongruent condition, thus demonstrating conflict (see Fig. 1c). The magnitude of the conflict scores were 80, 65, and 44 ms for the flanker task, color Stroop task, and spatial conflict tasks, respectively. All three were significantly greater then zero; however, the differences among conflict effects were not significant, $F(2,22) = 1.18$, ns.

The correlations among interference effects were calculated based on RTs. The correlation between the flanker task and the color Stroop task was 0.48; between the flanker task and the spatial conflict task was −0.02; and between the color Stroop and the spatial conflict was 0.30. However, none of these effects

TABLE 1

Regions Activated during the Flanker Task: Incongruent Minus Congruent

Region	BA[a]	x	y	z	Z score	P[b]	No. of voxels[c]
R postcentral gyrus	2	22	−38	68	3.67	0.000	153
L middle frontal gyrus	10	−34	54	10	3.63	0.000	175
R lingual gyrus	18	26	−64	6	3.35	0.000	142
L precentral gyrus	4	−32	−16	54	3.18	0.001	530
R inferior parietal lobule	40	62	−28	28	3.15	0.001	169
L and R cingulate gyrus	24/32	−8	28	24	3.15	0.001	639
L lingual gyrus	19	−16	−58	0	3.14	0.001	76
L postcentral gyrus	1	−60	−16	30	3.07	0.001	364
L superior frontal gyrus	6	−2	16	52	2.93	0.002	86
R inferior temporal gyrus	37	54	−54	−6	2.88	0.002	97
L superior temporal gyrus	41	−36	−34	10	2.85	0.002	84
L inferior temporal gyrus	37	−40	−70	2	2.79	0.003	74
R superior frontal gyrus	10	20	56	12	2.68	0.004	50
R precuneus	7	12	−46	54	2.53	0.006	57

[a] BA, Brodmann's area.
[b] Uncorrected.
[c] Voxel size, $2 \times 2 \times 2$ mm^3; height threshold, $P = 0.05$; extent threshold: $k = 50$ voxels.

were significant, $P > 0.05$, potentially a reflection of the small number of participants involved in the imaging study.

fMRI Results

Tables 1–3 show the significant activations observed during each of the tasks. Figure 2 shows the activations in anterior cingulate and brain surface corresponding to the flanker task, color Stroop task, and spatial conflict task.

We first examined all of the areas in which there was evidence of a conjunction between activation in the three tasks (see Table 4). A common conflict activation criterion was defined such that a region must show significant activation individually in each of the three conflict subtractions (Tables 1–3) and show evidence of a significant conjunction activation (Table 4) using a height (intensity) threshold of $P = 0.05$ and an extent threshold of $k = 50$ voxels, given a voxel size of $2 \times 2 \times 2$ mm^3.

Only two areas met this stringent criterion. These regions are illustrated in Fig. 3, which shows the points of maximum activity for each task and the computed conjunction. Overlap between tasks can be seen in Fig. 2. One common area was the left dorsal anterior cingulate (Brodmann's area 32, $x = -6$, $y = 38$, $z = 18$). While there was some overlap, the peaks of activation for each task were separate. We also found a region of the left middle frontal gyrus (Brodmann's area 10, $x = -30$, $y = 54$, $z = -4$) that was activated by all three tasks. Figures 3a and 3b show the points of peak activity in these two regions, respectively.

We tested the contrast between incongruent and congruent conditions for each task in both of the critical areas identified above. Orthogonal contrasts showed that ACC activation was greater for the flanker task in comparison with the Stroop and spatial conflict tasks. There was no significant difference in ACC activation between the Stroop and spatial conflict

TABLE 2

Regions Activated during the Color Stroop Task: Incongruent Minus Congruent

Region	BA	x	y	z	Z score	P	No. of voxels
L inferior frontal gyrus	47	50	36	−8	3.74	0.000	1621
L inferior parietal lobule	40	−50	−40	48	3.07	0.000	127
L precuneus	7	−4	−58	50	2.91	0.002	418
L middle frontal gyrus	10	−26	56	−2	2.72	0.003	145
R inferior parietal lobule	40	64	−32	36	2.67	0.004	108
R superior temporal gyrus	41	42	−22	2	2.59	0.005	105
R inferior parietal lobule	40	50	−46	32	2.45	0.009	226
L inferior frontal gyrus	45	−38	28	14	2.37	0.010	94
L superior temporal gyrus	41	−42	−24	0	2.29	0.011	239
L cuneus	18	−14	−80	34	2.29	0.011	77
R postcentral gyrus	1	40	20	44	2.19	0.014	67
R and L lingual gyrus	18	4	−84	−6	2.12	0.017	72
R superior temporal gyrus	22	42	−4	−18	2.12	0.017	132
L cingulate gyrus	32	−4	38	30	1.94	0.026	51

TABLE 3

Regions Activated during the Spatial Conflict Task: Incongruent Minus Congruent

Region	BA	x	y	z	Z score	P	No. of voxels
L superior temporal gyrus	39	−38	−52	28	3.13	0.001	405
R inferior temporal gyrus	20	40	−16	−24	2.73	0.003	141
L cingulate gyrus	32	−16	32	−4	2.72	0.003	95
R superior temporal gyrus	22	56	0	2	2.58	0.005	423
L superior temporal gyrus	12	−42	2	−8	2.57	0.005	63
L postcentral gyrus	40	−50	−18	14	2.57	0.005	226
L superior frontal gyrus	10	−12	64	12	2.36	0.009	240
R middle temporal gyrus	21	62	−16	−12	2.34	0.010	61
L and R precuneus	7	−2	−72	40	2.25	0.012	155
L middle frontal gyrus	9	−36	30	28	2.08	0.019	56
L cingulate gyrus	32	−6	46	12	1.96	0.025	63

tasks. There were no significant differences among the three tasks in amount of activation of area 10.

Discussion

The results of this study identified two general brain areas systematically involved in conflict during all three tasks: the anterior cingulate and the left prefrontal cortex. Similar, although not identical, areas have been identified in a number of prior studies and meta-analyses of tasks involving strong levels of effortful control (Bush *et al.,* 2000; Duncan and Owen, 2000).

In this study, the common activations were independent of whether the task was linguistic or spatial. Judging from overall reaction time and error rates in the neutral condition, the Stroop task was the most difficult behaviorally; however, there is no evidence that it produced more activation in either of the two common areas.

The flanker task seemed to produce the most interference when one considers both the conflict effect in RT shown in Fig. 1c and the high error rate specific to the incongruent trials. The flanker task also showed significantly more activation in the ACC and the largest number of active voxels overall.

Because the conflict within the three tasks leads to activation within the anterior cingulate and lateral prefrontal areas that is anatomically common across all three tasks, as well as patterns of activation that are task specific, it is important to determine from behavioral data whether the tasks are independent in terms of correlations across participants and whether or not they interfere when performed together. Experiments 2 through 4 are designed to explore these questions.

EXPERIMENT 2

In Experiment 2, we evaluate one possible implication of common and separate anatomy found in Experiment 1. Given that the flanker task, the Stroop task, and the spatial conflict task all activate the anterior cingulate cortex and left BA 10 during conflict trials, does a participant's performance on one task correlate with performance on another?

Experiment 1 suggested small but nonsignificant correlations between conflict scores on different tasks. However, this lack of effect may have arisen due to the low power produced by the small sample size. In Experiment 1, cognitive subtractions designed to isolate conflict sensitive components of the three tasks revealed two areas of common neural activity. Experiment 2 addresses whether participants' reaction times in these cognitive subtractions correlate across tasks.

Materials and Methods

Participants

A total of 40 paid adult volunteers between the ages of 20 and 44 (mean age, 30; 23 women and 17 men) participated in the experiment. All participants reported normal or corrected to normal vision. A signed informed consent approved by the New York Presbyterian Hospital/Weill Medical College of Cornell University was obtained from each participant before the experiment.

Apparatus and Stimuli

Stimuli were presented via E-Prime, a commercial experiment programming application, on an IBM-compatible personal computer running Windows 95, using a 14-in. NEC SVGA monitor. Participants viewed the screen from a distance of 65 cm, and responses were collected via two input keys for flanker task and four keys for color Stroop task.

The flanker task was altered to allow the addition of cue conditions to measure alerting and orienting aspects of attention (see Fan *et al.,* 2002, for details), and the visual angles were different given the change in monitors between Experiments 1 and 2. A single arrow or line subtended 0.55° of visual angle and the contours of adjacent arrows or lines were separated by 0.06° of visual angle. The stimuli (one central arrow plus four flankers) subtended a total 3.08° of visual angle. There were three test blocks with a total of 288 trials. In this article, we report only the conflict scores with cue condition collapsed. For the color Stroop task, the visual angles were also slightly different. A single letter subtended 0.58° of visual angle in height and 0.49° in width. Between each letter there was a 0.08° of visual angle blank. A 32-trial practice session followed by a short break preceded the 144 experimental
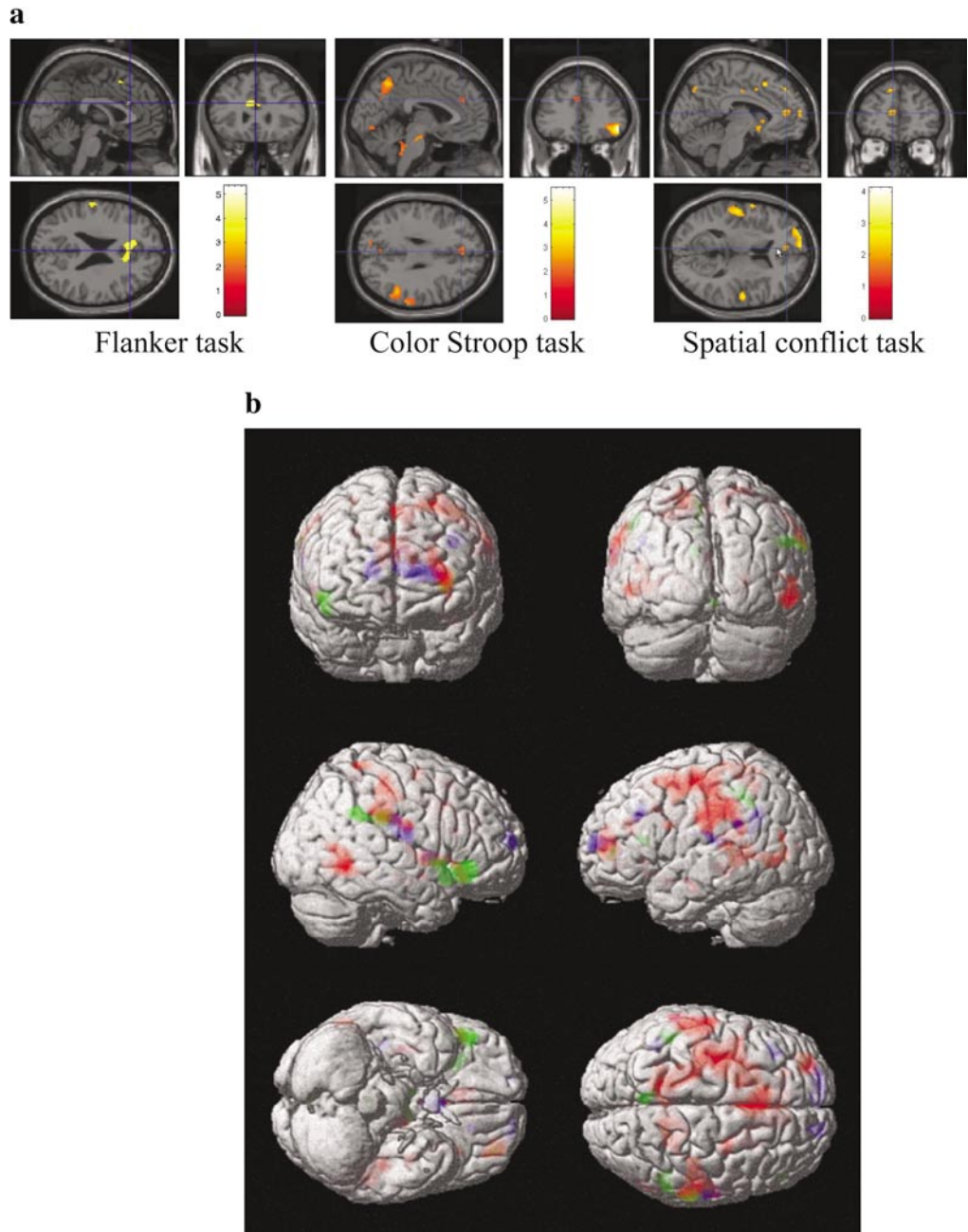
FIG. 2. View of activations corresponding to flanker task, color Stroop task, and spatial conflict task. (a) Cross-section view of activations in anterior cingulate; (b) activations seen on the brain surface. For the surface map, the red color indicates flanker task, the green color indicates color Stroop task, and the blue color indicates the spatial conflict task.

trials. For the spatial conflict task, all of the objects subtended 3° of visual angle in horizontal and vertical extents. The two response objects at the bottom of the screen appeared 14° from the central fixation cross (measured diagonally) and were separated horizontally by 11° of visual angle. In the congruent trials a target was horizontally aligned with its matching response object and separated from it by 9° of visual angle. In incongruent trials, the target was situated directly above its mismatched response object and separated from it by 17° of visual angle

(measured diagonally). Twenty-four practice trials were administered to every participant using a single pair of pictures (axe/ fire truck). This session was followed by a short break and then by 48 experimental trials consisting of the other four stimulus pairs.

Procedure

Each participant was tested in all three tasks in the same order. First, participants completed one session of the flanker
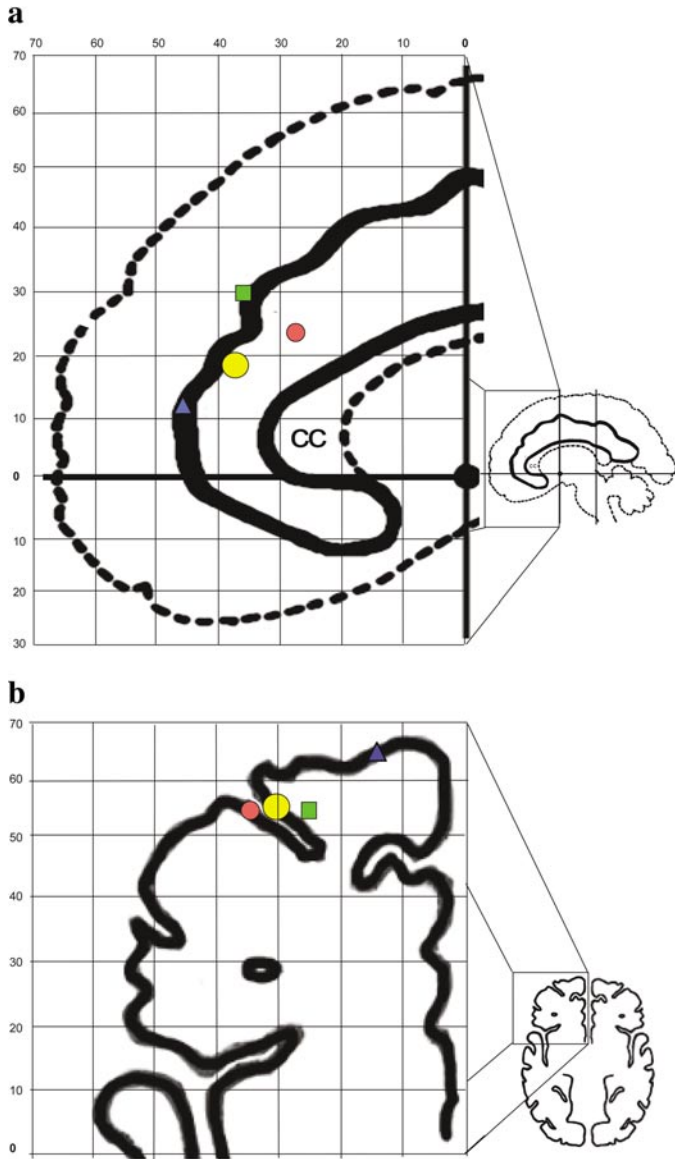
FIG. 3. Conjunction analysis results. (a) Sagittal view of ACC activations corresponding to each task; (b) axial view of prefrontal activations. Small circle indicates flanker task, square indicates color Stroop task, triangle indicates spatial conflict task, and large circle indicates the conjunction of the three conflict tasks.

task. Next they were administered the color Stroop task followed by a second session of the flanker task. Finally, they were tested with the spatial conflict task. The duration of the entire experiment was approximately 1 h.

Results

Table 5 shows the mean RT; specifically, we calculated medians for each condition, and then the mean was calculated based on these medians. An ANOVA was carried out for RT with task (flanker, color Stroop, spatial Stroop) as one factor and trial type (congruent, incongruent, neutral) as the other. The main effect of task was significant, $F(2,78) = 76.28$, $P < 0.01$. Contrasts showed that the mean RT for the flanker task (501 ms) was significantly different from the mean RT for the color Stroop (712 ms), $F(1,39) = 135.03$, $P < 0.01$. The difference between the color Stroop and spatial conflict (595 ms) was also significant, $F(1,39) = 43.51$, $P < 0.01$. The main effect of trial type was also significant, $F(2,78) = 131.94$, $P < 0.01$. Contrasts showed that the difference between congruent and incongruent conditions was significant, $F(1,39) = 172.50$, $P < 0.01$. The difference between congruent and neutral conditions was marginally significant, $F(1,39) = 7.18$, $P = 0.01$. The interaction between task and trial type was significant, $F(4,156) = 19.69$, $P < 0.01$.

The conflict effect in each of the three tasks was calculated in two ways: the difference between median RT in incongruent trials and congruent trials (I-C) and between median RT in incongruent trials and neutral trials (I-N). In all three tasks, the conflict effects were significant, $P < 0.01$. The interaction between the conflict effect (congruent versus incongruent) and task was significant, $F(1,39) = 12.93$, $P < 0.01$. For I-C, the conflict effect of the color Stroop was greater than flanker task, $F(1,39) = 12.93$, $P < 0.01$. The conflict effect of the flanker task was greater than spatial conflict, $F(1,39) = 34.48$, $P < 0.01$. For I-N, the conflict effect of the color Stroop was not significantly different from flanker task, $F < 1$. The conflict effect of the flanker task was greater than spatial conflict, $F(1,39) = 11.33$, $P < 0.01$.

For the error rate data, the main effect of task was significant, $F(2,78) = 11.09$, $P < 0.01$. The mean error rate for the flanker task (1.82%) was significantly smaller than the mean error rate on the color Stroop (3.73%), $F(1,39) = 25.32$, $P < 0.01$; the difference between flanker task errors and spatial conflict errors (3.00%) was not significant, $F(1,39) = 3.90$, ns. The main effect of trial type was also significant, $F(2,78) = 15.10$, $P < 0.01$. Congruent trials showed significantly fewer errors than incongruent trials, $F(1,39) = 18.76$, $P < 0.01$. The difference between congruent and neutral conditions was not significant, $F < 1$. The interaction between task and trial type was not significant, $F(4,156) = 2.05$, ns.

As shown in Table 6, overall reaction times across the three tasks were significantly correlated. These correlations ranged between 0.50 and 0.68. Table 6 also shows correlations between the measures of conflict resolution (median incongruent RT minus median congruent RT, I-C;

Flanker Type	Word Type		
	Congruent	Neutral	Incongruent
Congruent	XXX RED XXX	XXX LOT XXX	XXXXX GREEN XXXXX
Neutral	RED	LOT	GREEN
Incongruent	XXX RED XXX	XXX LOT XXX	XXXXX GREEN XXXXX

FIG. 4. Examples of stimuli from the color-word Stroop with color flanker task.

TABLE 4

Cognitive Conjunction Analysis of Three Tasks: Incongruent Minus Congruent

Region	BA	x	y	z	Z score	P	No. of voxels
R superior temporal gyrus	22	50	6	0	4.34	0.000	1415
R inferior parietal lobule	40	66	−22	30	4.34	0.000	401
L inferior parietal lobule	40	−60	−40	24	3.64	0.000	829
R superior frontal gyrus	10	14	60	20	3.36	0.000	323
L cuneus	18	−4	−78	24	3.19	0.001	1718
R fusiform gyrus	20	42	−18	−18	2.97	0.002	72
L middle frontal gyrus	10	−30	54	−4	2.83	0.002	416
R inferior temporal gyrus	37	56	−50	−12	2.83	0.002	165
R inferior frontal gyrus	45/46	40	24	20	2.50	0.006	68
L superior frontal gyrus	9	−30	34	32	2.49	0.006	190
L cingulate gyrus	32	−6	38	18	2.42	0.008	177
L fusiform gyrus	20	−36	−12	−24	2.42	0.008	120
R inferior frontal gyrus	44	50	14	32	2.42	0.008	54
R superior frontal gyrus	9	30	38	30	2.30	0.011	123

median incongruent RT minus median neutral RT, I-N) provided by each of the three tasks. No significant correlations were found for conflict measures among any of the three tasks.

Discussion

We found a significant difference between the reaction times for incongruent and congruent trials (a conflict effect) in all three tasks. These effects provide a measure of one's ability to resolve cognitive conflict in a variety of contexts. The neuroimaging data in Experiment 1 suggest that the incongruent trials in all three tasks activate the anterior cingulate cortex and left BA 10 more than congruent trials. If the activation within these regions is common and they are responsible for resolving a cognitive conflict, there should be strong correlations between tasks. However, this prediction was not confirmed. Correlations among conflict scores in the three tasks were not significant. One reason for the lack of correlation might be that the subtracted conflict RT might not be sufficiently reliable to produce significant correlations. However, in a previous study of the flanker task (Fan *et al.,* 2002), we found the test–retest reliability for conflict scores to be 0.7, which should have been sufficient to produce significant correlations. Moreover, in a twin study addressing the heritability of attentional measures, we found correlations between conflict measures of 0.89 for MZ twins (Fan *et al.,* 2001).

If one considers the activation of Experiment 1 to arise from a common anatomy, the results of Experiment 2 are not predicted by the hypothesis proposed by Kinsbourne and Hicks (1978) and by Posner and colleagues (1989), suggesting that tasks sharing a specific neural circuitry place demands upon similar cognitive resources. Alternatively, these results might suggest that the conflict network plays a more passive role in the resolution of cognitive conflict than has been suggested elsewhere (Posner and Petersen, 1990; Posner and Raichle, 1994). Posner and Petersen (1990) argue that the anterior cingulate is the place where computations associated with resolving a cognitive conflict occur. They term this process "executive control" and argue that in response to incongruent conditions within a conflict task, the anterior cingulate actively performs the steps necessary for a participant to resolve the conflict to make an appropriate response. The finding that conflict effects in our three tasks do not correlate significantly, even though each task requires a form of conflict resolution and engages the anterior cingulate, is

TABLE 5

Mean Reaction Times and Error Rates for Congruent, Incongruent, and Neutral Conditions in Experiment 2[a]

Task	Congruent	Incongruent	Neutral	Mean	I-C	I-N
Flanker						
RT (ms)	475 (41)	559 (53)	470 (40)	501 (44)	83 (4)	89 (4)
Error rate (%)	0.48 (0.07)	4.04 (3.76)	0.94 (1.460)	1.82 (1.72)		
Color stroop						
RT (ms)	650 (116)	790 (183)	696 (134)	712 (139)	139 (16)	94 (14)
Error rate (%)	2.86 (3.82)	5.26 (4.5)	3.00 (3.77)	3.73 (2.97)		
Spatial conflict						
RT (ms)	589 (100)	618 (120)	579 (105)	595 (103)	30 (10)	40 (9)
Error rate (%)	2.00 (5.04)	3.00 (4.48)	2.00 (3.33)	3.00 (2.60)		

[a] Number in parentheses is SD.

TABLE 6

Correlations between Mean Reaction Times and Conflict Subtraction Scores Based on Reaction Times in Experiment 2

	Flanker			Color Stroop		
	I-C	I-N	Mean	I-C	I-N	Mean
Color Stroop						
I-C	0.13	0.24	0.45**			
I-N	0.09	0.19	0.33*			
Mean RT	0.03	0.17	0.68**			
Spatial conflict						
I-C	0.23	0.17	0.00	−0.05	−0.02	−0.04
I-N	0.22	0.28	0.19	0.10	0.10	0.33*
Mean RT	0.04	0.09	0.50**	0.42**	0.28	0.57**

Note. I-C, incongruent minus congruent; I-N, incongruent minus neutral.

* Correlation is significant at the 0.05 level (two-tailed).

** Correlation is significant at the 0.01 level (two-tailed).

surprising by this hypothesis. Alternatively, Botvinick and colleagues (2001) argue that the anterior cingulate plays a more passive role in resolving the conflicts present in these three tasks and similar ones. They propose that the anterior cingulate is involved in "conflict monitoring." By this hypothesis, the ACC is functionally involved in only the process of detecting cognitive conflict when it occurs and then sends a signal to other networks responsible for resolving the conflict. These researchers designed a computational model with a conflict-monitoring node and were able to use this model to simulate many notable behavioral results for both the color Stroop task and the classic flanker task (Eriksen and Eriksen, 1974). In this case, the anterior cingulate, while playing a critical role in the ultimate improvement of performance during instances of conflict, does not play an active role in the resolution of any particular conflict. While low correlations among our three tasks cannot be taken as evidence proving one theory of ACC function or disproving another, these data are more consistent with the conflict-monitoring hypothesis (Botvinick et al., 2001). However, because these conflict tasks also activated overlapping prefrontal areas, this more passive domain general monitoring function might involve a larger network of areas rather than just the ACC.

EXPERIMENT 3

In Experiment 2 we found that, despite areas of shared activity, performance in the conflict conditions of the flanker task, the Stroop task, and the spatial conflict task did not correlate. However, correlations in performance data (conflict scores) might be a rather weak test of common mental operations. Although the three tasks may share some form of conflict operation, they also have a number of unique aspects that could influence the relative difficulty individual participants experience with conflict operations within each of the tasks.

While both the flanker task and the color Stroop task measure a response latency emerging from conditions in which participants must inhibit a response to irrelevant

stimulus information, these tasks could represent fundamental differences in the way conflict is instantiated (Hazeltine et al., 2000).

Experiment 3 was designed to address two goals. First, we wanted to investigate possible reasons for the low correlation found in Experiment 2 between the conflict effects in the flanker and Stroop task. It is possible that some participants employ a specific strategy known to be effective in the Stroop task looking away from the display. We introduced a hybrid flanker and color Stroop that reduced this possibility by making the surrounding stimuli incongruent with the target; thus, participants were discouraged from focusing on locations other than the target stimulus. In addition to participating in the hybrid Stroop/flanker task, participants were also tested with the same flanker task used in Experiment 1. If the reason for the low correlation found in Experiment 1 between the flanker task and the Stroop task was that the flanker and the Stroop task require the resolution of fundamentally different types of conflict, then we should expect a low correlation between the two tasks in this experiment. However, if the low correlations were attributable to strategic effects that are reduced in the present design, we might expect higher correlations between flanker and Stroop under the current conditions.

Second, in considering whether the various conflict tasks share a common mental operation related to conflict, we were interested in whether having to resolve two forms of conflict within the same trial would produce increased interference in comparison with single conflict trials. Under the logic of dual-task performance experiments, if two tasks draw on the same limited-capacity mental operation simultaneously, that shared process should impose a bottleneck in processing, delaying time to completion. Even if participants differ in their strategies under single task conditions, one would expect interference when they must perform two conflict operations together.

To achieve both of these goals, Experiment 3 introduces a novel hybrid between the Stroop task and an element of the flanker task that requires participants to ignore nearby peripheral stimuli that might otherwise introduce response conflict. By placing colored flanker stimuli above and below the central Stroop stimulus, we discouraged participants from engaging in strategies that involved looking away, and we also introduced the possibility of making the color flankers congruent or incongruent with the response. The task included two dimensions with which a word's display color could conflict at the same time. The hybrid Stroop/flanker task includes a conflict element that competes with the target stimulus along a spatial dimension.

By comparing RT in conditions with a single incongruency compared with conditions with two incongruencies, we expect that we will be able to investigate the degrees to which shared brain areas result in interference between two tasks. The hypothesis that a greater sharing of neural anatomy results in greater interference predicts that conditions with two conflict parameters should produce an additive delay in

reaction time compared with conditions with only a single conflict parameter.

Materials and Methods

Participants and Apparatus

Twenty-four paid adult volunteers participated in both tasks of Experiment 3. Informed consent was collected as in Experiment 2, and the apparatus used to administer computerized tasks in Experiment 3 was identical to that of Experiment 2.

Flanker task. The methodology for the flanker task in Experiment 3 was identical to that of Experiment 2, except that only one session of the flanker task was administered in this experiment. Measures of conflict were calculated in the same way reported in Experiment 2.

Hybrid Stroop/flanker task. Stimuli in the hybrid Stroop/flanker task consisted of a centrally appearing word in one of four ink colors and surrounded above and below by color flankers (see Fig. 4). Color flankers were a row of X's, also in one of four ink colors, matched to the stimulus word for length. Neutral and color stimulus words were the same in both Experiment 1 and Experiment 2.

Three stimulus conditions were available in this experiment based on flanker categories. In a congruent condition, stimulus words and flankers were the same ink color. In the incongruent condition, the word and flankers were in different colors of ink. A neutral flanker condition was defined by the absence of color flankers making this condition comparable to Experiment 2.

The addition of color flankers resulted in a 3×3 factorial design. The first factor was the color and word congruency of the central target (i.e., standard Stroop effect). The second factor was the congruence of the color flankers and word ink color (congruent, incongruent, or neutral). Therefore, there were a total of nine possible conditions in this experiment.

There were four blocks in this experiment. Each participant began with a short practice block followed by three experimental blocks each lasting approximately 10 min. The practice block included 27 trials and each experimental block included 144 trials. Within each block, the trials were randomly presented with equal numbers of trials for each of the nine conditions.

Results

Flanker Task

An ANOVA was carried out for the RTs from the flanker task. The main effect of flanker type was significant, $F(2,46) = 268.15$, $P < 0.01$. The contrasts of I-C and I-N were significant, $F(1,23) = 276.14$, $P < 0.01$, and $F(1,23) = 323.54$, $P < 0.01$, respectively. The difference between congruent and neutral conditions was not significant, $F < 1$.

An ANOVA on error rate showed a significant main effect of flanker type, $F(2,46) = 11.39$, $P < 0.01$. The contrasts of I-C and I-N were significant, $F(1,23) = 12.92$, $P < 0.01$, and $F(1,23) = 10.21$, $P < 0.01$, respectively. The difference be-
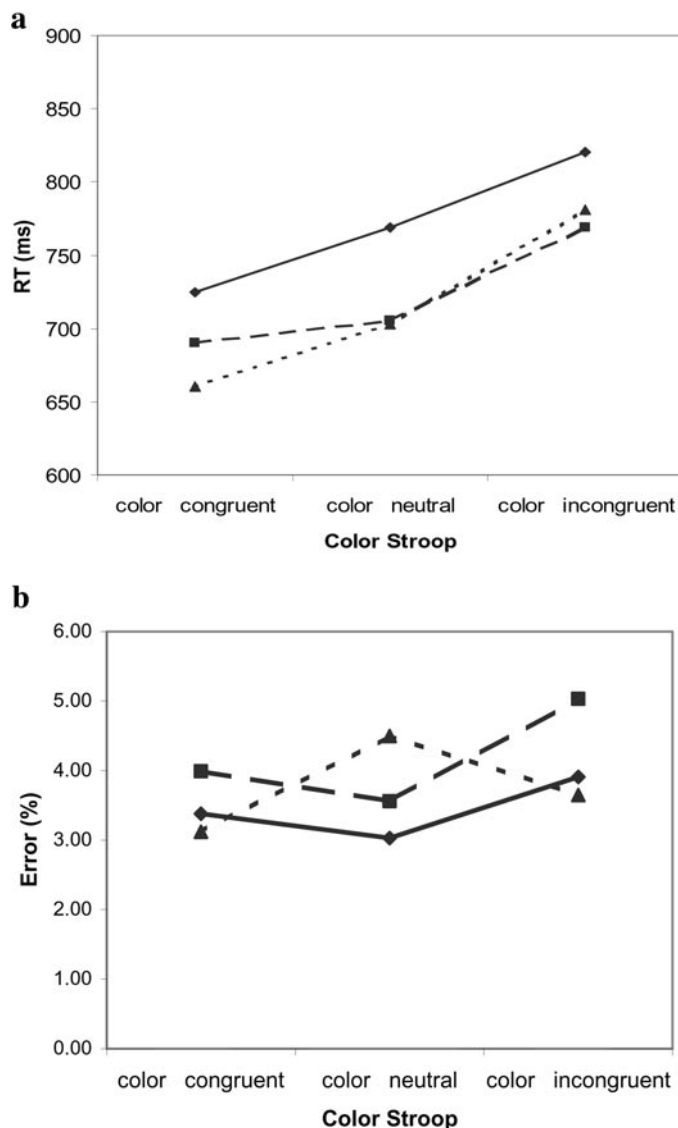

FIG. 5. Results of Experiment 3. (a) The RTs for each condition; (b) the error rates for each condition. (◆) flanker incongruent; (■) flanker congruent; (▲) flanker neutral.

tween congruent and neutral conditions was marginally significant, $F(1,23) = 5.13$, $P = 0.03$.

Hybrid Stroop/Flanker Task

Figure 5 shows the RT (Fig. 5a) and error rate (Fig. 5b) for each condition. An analysis of variance on RT shows a significant main effect of word type (congruent, incongruent, or neutral), $F(2,46) = 42.13$, $P < 0.01$, and a significant main effect of flanker type (congruent, incongruent, or no flanker), $F(2,46) = 56.95$, $P < 0.01$. The interaction between these two factors was significant, $F(4,92) = 3.55$, $P = 0.01$. To further examine the nature of the interaction, neutral conditions for both words and color flankers were excluded. The interaction of word type (congruent, incongruent) by color flanker type (congruent, incongruent) was not significant, $F(1,23) = 2.13$, ns.

TABLE 7

Magnitude of Conflicts in RT and Correlations among Conflict Effects in Experiment 3

	Effect (ms)	Color flanker[a]		Color Stroop		Color Stroop (no flanker)		Mean[c]
		I-C[b]	I-N	I-C	I-N	I-C	I-N	
Flanker task								
I-C	92	−0.02		0.53**		0.47*		0.58**
I-N	94		−0.32		0.53**		0.51**	0.51*
Mean	514							0.68**
Color flanker								
I-C	50			0.09		0.38		0.19
I-N	57				−0.13		−0.03	0.10
Color Stroop								
I-C	99					0.86**		0.39
I-N	64						0.82**	0.46*
Color Stroop (no flanker)								
I-C	121							0.48*
I-N	78							0.36
Mean[a]	733							

[a] The design is a 3×3 factorial design with color flanker and color word as the two factors. Here the "color flanker" means the main effect of the color flanker and "color Stroop" means the main effect of color word. "Color Stroop (no flanker)" is just for the neutral flanker condition.
  [b] I-C, incongruent minus congruent; I-N, incongruent minus neutral.
  [c] Mean of color word with color flanker together.
  * Correlation is significant at the 0.05 level (two-tailed).
  ** Correlation is significant at the 0.01 level (two-tailed).

Contrasts were conducted to examine the conflict effects (I-C and I-N). Table 7 shows the effects of conflict in the hybrid Stroop/flanker task. For the flanker effect, the I-C conflict effect was significant, $F(1,23) = 59.03$, $P < 0.01$. The I-N conflict effect also was significant, $F(1,23) = 146.49$, $P < 0.01$. For the word effect, the I-C conflict effect was significant, meaning that participants were slower for words that were incongruent with the ink color, $F(1,23) = 56.00$, $P < 0.01$; the I-N conflict effect also was significant, $F(1,23) = 28.44$, $P < 0.01$. For the no flanker conditions, the conflict effects for the words (traditional color Stroop) were significant, $F(1,23) = 55.71$, $P < 0.01$, and $F(1,23) = 22.81$, $P < 0.01$, for I-C and I-N, respectively.

An ANOVA was carried out for the error data. The effect of word type (congruent, incongruent, or neutral) was not significant, $F(2,46) = 1.10$, ns, and the effect of flanker type (congruent, incongruent, or no flanker) was not significant, $F(2,46) = 1.10$, ns. The interaction between these two factors was also not significant, $F(4,92) = 1.45$, ns.

Correlation Analysis

Table 7 shows the conflict effects measured in RT in these tasks and the correlations among them. As in previous experiments, all of the contrasts show significant effects of conflict (i.e., incongruent RT > congruent or neutral RT).

Correlations between conflict effects within the standard flanker task and the hybrid Stroop/flanker task were significant. However, within the hybrid Stroop/flanker task, the conflict effect generated by the color flankers was not significantly correlated to the conflict generated by words, $r = 0.09$ and $r = -0.13$ for I-C and I-N, respectively.

Discussion

Correlation between the Two Tasks

We designed Experiment 3, in part, hoping that it would illuminate possible reasons for the low correlation found in Experiment 2 between the flanker task and the color-word Stroop task. We expected that a Stroop task with distracting elements near the target stimulus would show a strong correlation with the flanker task because both these tasks require the active selection of relevant from irrelevant information based on the spatial location of stimuli with similar qualities. This expectation was confirmed. We found a significant correlation between conflict effects in the flanker task and the Stroop task with color flankers.

This finding is consistent with our starting assumption that by discouraging strategies such as looking away during the Stroop task, we might eliminate one source of variance that prevented us from demonstrating a correlation between conflict components in the Stroop and flanker tasks. However, this pattern of results was restricted to flanker conflict as estimated by the standard flanker task. When flanker conflict was assessed within the hybrid Stroop/flanker task, flanker conflict was uncorrelated with Stroop conflict. This second set of findings mitigates against any strong claims that participants' performance in the conflict component of the flanker task is systematically related to their performance in the conflict component of the Stroop task.

Interference between Different Conflict Parameters

The Stroop task with color flankers used in Experiment 3 had two conflict parameters, incongruent words and incongruent spatial flankers, which both could conflict with the

color of the target in this task. Kinsbourne and Hicks (1978) and Posner *et al.* (1989) argue that when two simultaneous operations share a brain area, they should interfere with each other. By this hypothesis, the double incongruent condition in Experiment 3 should show a larger degree of interference compared with conditions including only a single conflict. As demonstrated in Experiment 1, the conflict in these two tasks activates a common anterior cingulate–prefrontal network. Nonetheless, this prediction was not confirmed. There was no significant interaction between manipulations that influenced conflict via the target word and manipulations that influenced conflict via the color flankers.

These data are consistent with the low correlation found in Experiment 1 between the flanker task and the Stroop task. Together, these findings suggest that despite some shared anatomy, the two tasks can be relatively independent and not engage the same, limited cognitive resources.

EXPERIMENT 4

In Experiment 4 we wanted to look further into time sharing between two conflict dimensions when they are merged in a single task. Therefore, we developed a task including incongruent flankers as one conflict parameter and spatial incompatibility as a second conflict parameter.

The task required that participants respond to arrow stimuli like those in the flanker task in Experiments 2 and 3. In this experiment, however, the array of arrows appeared to the left or to the right of a vertical line bisecting the display screen. Therefore, there were conditions in which the directional response implicated by the central arrow stimulus was different from the side of the screen on which the arrows appeared.

These two types of conflict both activate the cingulate–prefrontal network as shown in Experiment 1. If carrying out the two operations involve the same network, we should find an interaction between flanker and spatial conflict that reflects the increased effect of carrying out both at the same time.

Materials and Methods

Participants

Twelve paid adult volunteers participated in this experiment. They signed an informed consent approved by the Weill/Cornell Medical College before participating.

Apparatus and Stimuli

Stimuli were presented on a 15-in. laptop display using E-prime software (Psychology Software Tools, Inc.). The stimuli were identical to those in the flanker task used in Experiments 2 and 3, except that no neutral stimuli were included in this experiment, and the central arrow was two times wider vertically than flanker arrows.

Stimuli appeared at the vertical center of the screen, just to the left or right of its horizontal center. A vertical line divided the screen through its horizontal center and with a visual angle of 1.05° between the central target arrow and the line

regardless of whether the target appeared on the left or on the right. The vertical line remained present throughout the experiment, and a small horizontal line bisected the vertical in the center of the screen to create a fixation cross.

Procedure and Design

Participants were instructed to foveate on the central fixation cross throughout the experiment. In every trial, a row of target arrows appeared to the left or to the right of fixation. Participants responded to the direction of the central target arrow while ignoring the placement of the stimuli and the direction of the flanker arrows. Responses were entered with the participant's left index finger on the "Z" key for a left response and with a participant's right index finger on the "?" key for a right response. They were instructed to respond as quickly and as accurately as possible. The duration of each trial was 4 s. Stimuli remained on the screen until the participant responded or for a maximum of 1.7 s.

The experiment began with a practice block containing 24 trials followed by five blocks, each consisting of 96 trials. Speed and accuracy feedback was provided only during practice trials. The 480 experimental trails comprised four conditions in a two (two flanker types: congruent and incongruent) by two (two location types: congruent and incongruent) factorial design.

Results

Figure 6 shows the results. The median RTs were calculated for correct trials for each condition for each participant and were then averaged across both conditions and participants or across conditions to create a grand mean RT. The grand mean RT was 560 ms and SD was 41 ms. The mean error rate was 3.54% with a SD of 2.85%. ANOVAs were carried out for RT and error rate data separately. For the RT data, the main effect of flanker conflict (I-C, 80 ms, SD = 15 ms) was significant, $F(1,11) = 343.03$, $P < 0.01$. That is, participants responded faster for trials with congruent flankers than incongruent flankers. However, the main effect of side of presentation (7 ms, SD = 17 ms) was not significant, $F(1,11) = 1.89$, ns. The interaction between flanker type and side of presentation was marginally significant, $F(1,11) = 7.11$, $P = 0.02$. To further explore the nature of the interaction, simple comparisons were conducted. Within the congruent flanker condition, the comparison between congruent and incongruent side of presentation was marginally significant, $F(1,11) = 6.69$, $P = 0.03$, meaning that participants responded faster for congruent side of presentation than incongruent side of presentation. The side of presentation congruence was not significant for the incongruent flanker condition, $F < 1$.

For the accuracy data, there was a marginally significant main effect of side of presentation congruence $F(1,11) = 7.24$, $P = 0.02$. The main effect of flanker was significant, $F(1,11) = 25.97$, $P < 0.01$. Moreover, there was a marginally significant interaction, $F(1,11) = 4.02$, $P = 0.07$. To further explore the interaction, simple comparisons were conducted. The side of presentation congruence effect was not significant under the congruent flanker con-
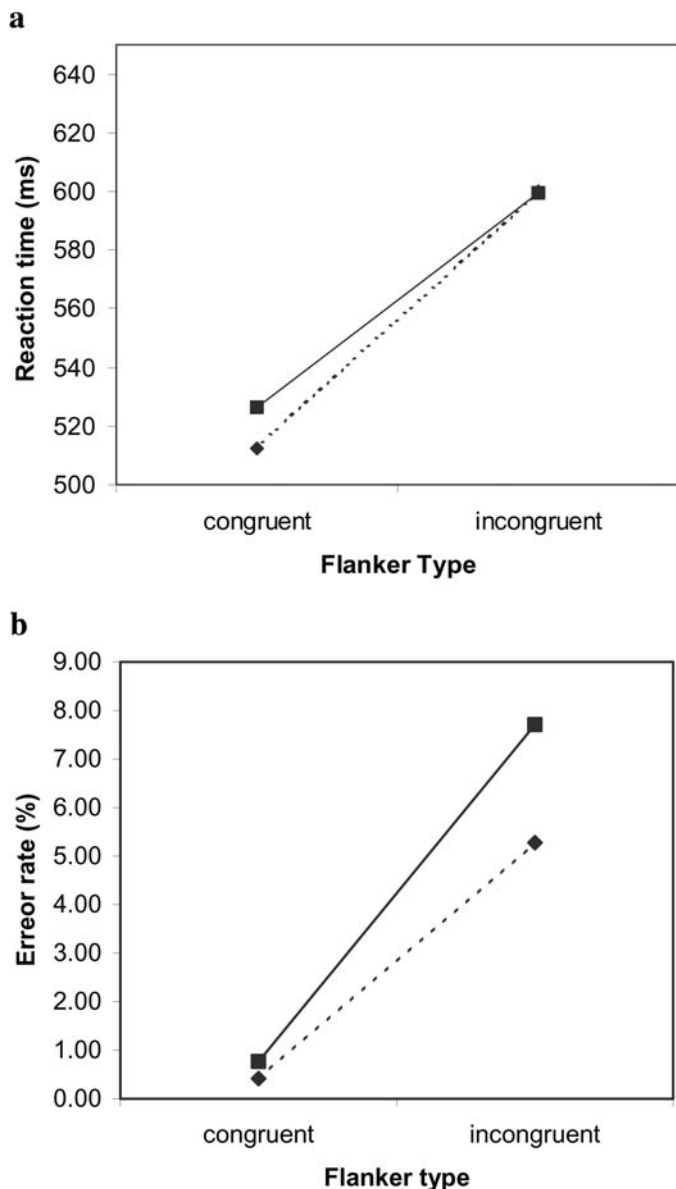
a

b

FIG. 6. Results of Experiment 4. (a) The RTs for each condition; (b) the error rates for each condition. (♦) location congruent; (■) location incongruent.

dition, $F(1,11) = 1.76$, ns. The side of presentation congruence was marginally significant under the incongruent flanker condition, $F(1,11) = 5.88$, $P = 0.03$. Participants made more errors for incongruent flanker trials when they were on the incongruent side.

The correlation between side of presentation conflict (as measured by I-C of side of presentation) and flanker conflict (as measured by I-C of flanker) was not significant, $r = -0.47$, ns.

Discussion

We designed Experiment 4 to investigate the relative independence of the flanker and spatial conflict. Unfortunately the side of presentation conflict effect was very small. Despite this difficulty, the RT data showed less interference when two sources of conflict were present together, directly opposite from our prediction of overadditivity (interaction) based on the common anatomy of these two domains of conflict.

The accuracy data provided a different picture. There were more errors in conditions with both incongruent flankers and an incompatible spatial arrangement compared with conditions including a single conflict parameter. This effect was overadditive in the direction of an increase in difficulty when the two forms of conflict were processed simultaneously rather than with either one alone.

Why would there be a dissociation between accuracy and RT data in this experiment? Often, in paradigms like this one, a dissociation between accuracy and RT is interpreted as a speed accuracy tradeoff. That is, participants performing very quickly on a particular task tend to make mistakes in the more difficult conditions. In such cases, both RT and errors need to be considered in evaluating the degree of interference between the two tasks. The interaction effect for errors and RT are both quite small. Even if the double incongruent condition is slightly more difficult than either single condition, as suggested by the higher error rate, this does not appear to be a sufficiently strong interaction to provide strong evidence of a common underlying limitation or mechanism. Perhaps the side of presentation manipulation does not produce conflict effects that are robust enough to be used as an effective probe within dual task interference paradigms.

GENERAL DISCUSSION

All tasks in this series of experiments produced longer RTs in the incongruent than in the congruent condition. We found that all three tasks also activated two areas that were in common: the left dorsal anterior cingulate (area 32) and left prefrontal cortex (area 10).

Previous work (e.g., Botvinick *et al.,* 2001; Bush *et al.,* 2000; Duncan and Owen, 2000) has shown that the anterior cingulate and prefrontal cortex are involved in aspects of handling conflict. The form of conflict was somewhat different across our three tasks, and although we found some evidence of common activation in cingulate and left prefrontal cortex, there were other active brain areas that differed between tasks. Based on this finding and the previous literature we examined some of the behavioral implications of the anatomy found active in the fMRI study.

In Experiment 2 we found no significant correlations among the conflict measures of the three tasks used in Experiment 1. Only in the limited circumstances in Experiment 3, when we surrounded the standard color Stroop with flanker stimuli, did we find a correlation between flanker conflict and color Stroop conflict. This finding was only true when we related color Stroop effect to the standard flanker and not with the color-flanker condition in the hybrid task which combined the two tasks. Thus, there is little or no evidence of a significant relationship between the various forms of conflict that we have studied, despite their common activation within cingulate and prefrontal regions.

In Experiments 3 and 4 we also examined the degree of interference between two forms of conflict when they were embedded in a common task and were processed simultaneously. We found no evidence of interaction between the flanker and Stroop conflict effects in Experiment 3. In fact, when both forms of conflict were present, the RT was less than the sum of the two individual conflict effects (underadditivity). When the word and color were incongruent, the flanker effect was actually reversed. That is, participants made more errors in ink color naming during congruent flanker conditions than during incongruent flanker conditions. This result suggests that the Stroop conflict and flanker conflict could generally be resolved in parallel.

In Experiment 4 we studied the flanker effect together with spatial conflict. Once again there was no evidence of an increase in RT when both conflicts had to be handled together. There was a small tendency for the error rates to be higher in the double conflict condition. If participants had to slow down to avoid excessive error in the double conflict case, it is possible that there might be a slight tendency for increased interference in RT for the double conflict condition, but this would be only a very small effect.

We anticipated, based on the idea of Kinsbourne and Hicks (1978), that when two tasks both involved the resolution of conflict to the extent they shared a common anatomy they would produce very strong interference when performed together. The fact that this was not the case led us to seek some explanation.

Of course the proposed connection between common anatomy, priming, and interference outlined by Kinsbourne and Hicks (1987) could be false despite its appealing simplicity and generality. There are also many other ways to try to fit together the current results that indicate relative behavioral independence between different conflict tasks. For example, because the overlap between tasks within the cingulate and lateral prefrontal cortex was only partial we might suggest that the computations are actually made in separate brain areas.

Another possibility is that the entire ACC-PFC network, as argued by Botvinick *et al.* (2001) for the cingulate, only monitors for conflict, but does not execute operations that resolve conflict. Previous work on monitoring sensory input suggests that multiple inputs can be monitored in parallel, but when even the simplest action is associated with a target there is interference when actions toward two targets must occur in parallel (Duncan, 1980). If the same holds true for the monitoring of conflict, we might expect simultaneous monitoring to take place in parallel and interference to occur only when multiple tasks require the same area for execution or resolution of the conflict. If this network involves only monitoring, one might expect the operations to be carried out in parallel. In that case, the areas involved in suppression would be expected to differ among the tasks, which would also be consistent with the low correlations between tasks. While this explanation appears consistent with our finding, the issue of the behavioral consequences of common activation certainly requires more attention from investigators.

REFERENCES

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., and Cohen, J. D. 2001. Conflict monitoring and cognitive control. *Psychol. Rev.* **108:** 624–652.

Bourke, P. A., Duncan, J., and Nimmo-Smith, I. 1996. A general factor involved in dual task performance decrement. *Q. J. Exp. Psychol. A* **49:** 525–545.

Bourke, P. A. 1997. Measuring attentiona demand in continuous-dual-task performance. *Q. J. Exp. Psychol. A* **50:** 821–840.

Bush, G., Luu, P., and Posner, M. I. 2000. Cognitive and emotional influences in the anterior cingulate cortex. *Trends Cogn. Sci.* **4:** 215–222.

Bush, G., Whalen, P. J., Rosen, B. R., Jenike, M. A., McInerney, S. C., and Rauch, S. L. 1998. The counting Stroop: An interference task specialized for functional neuroimaging—Validation study with functional MRI. *Hum. Brain Map.* **6:** 270–282.

Casey, B. J., Thomas, K. M., Welsh, T. F., Badgaiyan, R., Eccard, C. H., Jennings, J. R., and Crone, E. A. 2000. Dissociation of response conflict, attentional selection, and expectancy with functional magnetic resonance imaging (fMRI). *Proc. Natl. Acad. Sci. USA* **97:** 8728–8733.

Duncan, J. 1980. The locus of interference in the perception of simultaneous stimuli. *Psychol. Rev.* **87:** 272–300.

Duncan, J., and Owen, A. M. 2000. Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends Neurosci.* **23:** 475–483.

Eriksen, B. A., and Eriksen, C. W. 1974. Effects of noise letters upon the identification of target letter in a nonsearch task. *Percept. Psychophys.* **16:** 143–149.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., and Posner, M. I. 2002. Testing the efficiency and independence of attentional networks. *J. Cogn. Neurosci.* **14:** 340–347.

Fan, J., Wu, Y., Fossella, J., and Posner, M. I. 2001. Assessing the heritability of attentional networks. *BioMed. Centr. Neurosci.* **2:** 14.

Fias, W., Lauwereyns, J., and Lammertyn, J. 2001. Irrelevant digits affect feature based attention depending upon the overlap of neural circuits. *Cogn. Brain Res.* **12:** 415–423.

Friston, K. J., Fletcher, P., Josephs, O., Holmes, A., Rugg, M. D., and Turner, R. 1998. Event-related fMRI: Characterizing differential responses. *NeuroImage* **7:** 30–40.

Gerardi-Caulton, G. 2000. Sensitivity to spatial conflict and the development of self-regulation in children 24–36 months of age. *Dev. Sci.* **3:** 397–404.

Hazeltine, E., Poldrack, R., and Gabrieli, J. D. E. 2000. Neural activation during response competition. *J. Cogn. Neurosci.* **12:** 118–129.

Hommel, B. 1993. The relationship between stimulus processing and response selection in the Simon task: Evidence for a temporal overlap. *Psychol. Res.* **55:** 208–222.

Kinsbourne, M., and Hicks, R. E. 1978. Functional cerebral space: A model for overflow, transfer, and interference effects in human performance. In *Attention and Performance VII* (J. Requin, Ed.), pp. 345–362. Lawrence Erlbaum, Hillsdale, NJ.

MacLeod, C. M. 1991. Half a century of research on the Stroop effect: An integrative review. *Psychol. Bull.* **109:** 163–203.

Posner, M. I., and Petersen, S. E. 1990. The attention systems of the human brain. *Annu. Rev. Neurosci.* **13:** 25–42.

Posner, M. I., Petersen, S. E., Fox, P. T., and Raichle, M. E. 1988. Localization of cognitive operations in the human brain. *Science* **240:** 1627–1631.

Posner, M. I., and Raichle, M. E. 1994. *Images of Mind.* Scientific American Books, New York.

Posner, M. I., and Rothbart, M. K. 1998. Attention, self regulation and consciousness. *Phil. Trans. R. Soc. Lond. B* **353:** 1915–1927.

Posner, M. I., Sandson, J., Dhawan, M., and Shulman, G. L. 1989. Is word recognition automatic? A cognitive-anatomical approach. *J. Cogn. Neurosci.* **1:** 50–60.

Simon, J. R., and Berbaum, K. 1990. Effect of conflicting cues: The "Stroop effect" vs. the "Simon effect." *Acta Psychol.* **73:** 159–170.

Talairach, J., and Tournoux, P. 1988. *Co-Planar Stereotaxic Atlas of the Human Brain.* Theime, New York.