PSYCHOLOGICAL SCIENCE

Research Article

The Prepared Mind

Neural Activity Prior to Problem Presentation Predicts Subsequent Solution by Sudden Insight

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ABSTRACT—*Insight occurs when problem solutions arise suddenly and seem obviously correct, and is associated with an "Aha!" experience. Prior theorizing concerning preparation that facilitates insight focused on solvers' problem-specific knowledge. We hypothesized that a distinct type of mental preparation, manifested in a distinct brain state, would facilitate insight problem solving independently of problem-specific knowledge. Consistent with this hypothesis, neural activity during a preparatory interval before subjects saw verbal problems predicted which problems they would subsequently solve with, versus without, self-reported insight. Specifically, electroencephalographic topography and frequency (Experiment 1) and functional magnetic resonance imaging signal (Experiment 2) both suggest that mental preparation leading to insight involves heightened activity in medial frontal areas associated with cognitive control and in temporal areas associated with semantic processing. The results for electroencephalographic topography suggest that noninsight preparation, in contrast, involves increased occipital activity consistent with an increase in externally directed visual attention. Thus, general preparatory mechanisms modulate problem-solving strategy.*

When Louis Pasteur said, "Chance favors only the prepared mind," he was likely referring to preparation for the sort of sudden illumination that enables one to solve a difficult problem or reinterpret a situation in a new light (Wallas, 1926). Psychologists later called this type of sudden comprehension *insight* (Smith & Kounios, 1996; Sternberg & Davidson, 1995), a phenomenon associated with performance on tests of intelligence and creativity (Ansburg & Hill, 2003; Davidson, 1995).

Although insights pop into awareness unexpectedly, or even unbidden (Kvavilashvili & Mandler, 2004; Metcalfe & Wiebe, 1987; Smith & Kounios, 1996), Pasteur apparently believed that some form of preparation facilitates insight. One type of preparation involves studying a problem or relevant background information (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995; Wallas, 1926). Such study is obviously helpful, but probably facilitates problem solving by both insight and noninsight analytic processing.

We hypothesized another type of preparation, one that does not depend on information related to specific problems, but that biases a person toward processing that facilitates solution by insight. Here, we demonstrate that preparation for problem solving can be associated with distinct brain states, one biasing toward solution with insight, the other biasing toward solution without insight. We examined neural activity associated with subjects' preparation immediately prior to the presentation of each problem and found that the spatial distribution and oscillatory frequency of this activity predicts whether the problem that follows will be solved with insight or noninsight processing, as marked by the presence or absence of an "Aha!" experience.

Insight has typically been studied by comparing performance on *insight problems*, which are often solved with an "Aha!" experience, with performance on *noninsight problems*, which are usually solved without an "Aha!" (Mayer, 1995; Weisberg, 1995). Unfortunately, such classification is not definitive, because any particular problem could be solved with or without insight (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Instead, in the present study, we used each subject's trial-by-trial judgments of whether each solution became available incrementally or as a sudden insight to classify solutions to individual

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problems as resulting from insight or noninsight processing. Using this approach, previous studies have demonstrated unique patterns of behavioral results (Bowden & Jung-Beeman, 2003a) and neural activity (Jung-Beeman et al., 2004) associated with insight versus noninsight solutions.

For several reasons, we have inferred that these self-reported "Aha!" experiences reflect the sudden conscious availability of a solution rather than some ancillary process. For example, (a) the associated neural activity, a sudden burst of gamma-band oscillatory activity in the right anterior superior temporal gyrus, does not reflect subjects' affective or surprise reactions following solutions, because the onset of this activity coincides with, rather than follows, the conscious availability of the solution; (b) task-related activity occurs in the same region when people first start processing a problem, before they experience any solution-related emotional response (Jung-Beeman et al., 2004); and (c) this region is a polymodal association area that has not been implicated in affective or novelty processing (Jung-Beeman, 2005).

In two experiments, using electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), we assessed neural activity as people prepared to solve each problem in a series. We examined activity prior to the presentation of each problem in order to assess patterns independent of specific problems and their difficulty. Experiment 1 focused on EEG power within the alpha (8–13 Hz) frequency band. Alpha, the brain's dominant rhythm (Shaw, 2003), reflects cortical deactivation and is inversely related to hemodynamic and metabolic measures of neural activity (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998; Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Goldman, Stern, Engel, & Cohen, 2002; Laufs et al., 2003; Ray & Cole, 1985; Worden, Foxe, Wang, & Simpson, 2000). The topographic distribution of alpha across the scalp therefore mirrors the spatial distribution of neural activity (Pfurtscheller & Lopes da Silva, 1999). We focused on the low-alpha frequency band (8–10 Hz), because high alpha (10–13 Hz) is typically dominated by an occipital alpha rhythm reflecting gating of visual information (Gevins & Smith, 2000). Effects were also found in the gamma band (> 30 Hz), but could not be reliably distinguished from electromyograph artifact, so they are not discussed in this report.

EXPERIMENT 1

Method

After giving informed consent, 19 subjects attempted to solve 186 problems. On each trial (Fig. 1), they indicated by bimanual button press that they were prepared to begin working on a problem, thereby initiating the display of a visual fixation mark. This button press was the midpoint of the 2-s epoch selected as the *preparation interval* of interest. After 1 s, this fixation mark was replaced by the three words of a *compound remote-associates problem*. For each problem (e.g., *pine*, *crab*, *sauce*), subjects attempted to produce a solution word (e.g., *apple*) that could be combined with each of the three problem words to form a common compound or phrase (*pineapple*, *crabapple*, *applesauce*). These problems were used because a large number are available, they can be solved relatively quickly, and similar problems have been used successfully in numerous studies of insight and creativity (for review, see Bowden & Jung-Beeman, 2003b). Also, they can be solved either with insight or with noninsight analytic processes (Bowden & Jung-Beeman, 2003a; Jung-Beeman et al., 2004), so we could compare these two general strategies while holding task and problem type constant. Previous studies have shown that subjects solving such problems tend to use each of these strategies about half the time (Bowden et al., 2005).

If subjects achieved solution, they made an immediate bimanual button press indicating that they had solved the problem, verbalized the solution when prompted, and then, when prompted, pressed one of two buttons to indicate whether or not the solution had been achieved by insight. (Prior instructions to subjects explained the notion of insight as sudden awareness of the solution—Jung-Beeman et al., 2004). After a 2-s intertrial

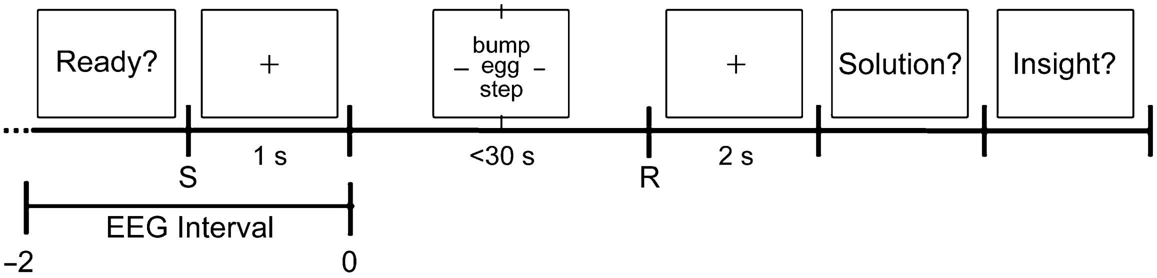

Fig. 1. Time line of events on a trial in Experiment 1. A "Ready?" message was displayed on a monitor, and the subject made a bimanual button press ("S") when he or she was prepared to start the trial and view the three words constituting a problem. The problem was displayed after a 1-s visual fixation mark. The subject responded with another button press ("R") as soon as he or she had solved the problem. This initiated a prompt to verbalize the solution (in this case, *goose*), followed by another prompt to make a button press to indicate whether the verbalized solution was accompanied by an experience of insight. This report presents electroencephalography (EEG) results for the bracketed preparatory interval consisting of the 2 s prior to the display of the problem.

interval, a "Ready?" prompt appeared; when ready, subjects initiated the next trial with a bimanual button press.

High-density (128-channel) EEG was continuously recorded (referenced to digitally linked mastoids) at 250 Hz (0.02–100 Hz). Eyeblink artifacts were removed using EMSE 5.0 (Source Signal Imaging, Inc., www.sourcesignal.com). Trials containing other artifacts were identified by visual inspection and deleted. EEG segments corresponding to the preparation intervals were extracted and, on the basis of subjects' performance on the following problem, were sorted into three types of preparation: preparation leading to solution with insight, preparation leading to solution without insight, or time-out (no response within 30 s). (Errors were rare, and trials with errors were deleted.) EEG power was estimated by computing power spectra on these segments. The University of Pennsylvania's institutional review board approved the study.

Results

Participants solved 46.2% (*SD* = 8.2) of the problems correctly within the 30-s time limit. Subjects labeled 56.2% (*SD* = 8.3) of solutions as insight solutions (average median response time = 7.70 s, *SD* = 2.60) and 42.5% (*SD* = 8.9) as noninsight solutions (7.48 s, *SD* = 3.08). Of all responses, 11.5% (*SD* = 11.3) were errors.

As predicted, distinct alpha topographies were associated with preparation for solving problems with insight versus noninsight processing. Moreover, visual inspection of power spectra suggested that insight preparation and noninsight preparation were associated with different peak oscillatory frequencies within the low-alpha frequency band. These observations were substantiated by two sets of analyses.

The first set contrasted insight preparation against preparation that led to time-outs, and separately contrasted noninsight preparation against time-out preparation. These analyses also allowed us to assess whether preparation preceding successful problem solving differed from preparation preceding unsuccessful problem processing. Two repeated measures analyses of variance (ANOVAs) were performed on log-transformed EEG power to examine anterior-posterior and hemispheric differences in two low-alpha subbands (the frequency factor: 8–9 Hz vs. 9–10 Hz, determined by visual inspection of the power spectra) for insight, noninsight, and time-out trials (the trial-type factor). The first ANOVA examined power at left and right anterior-frontal (AF1/2) and left and right occipital (O9/10) electrodes (allowing comparison of scalp topographies). These electrodes were chosen a priori in order to maximize distance between electrodes, thereby minimizing the influence of EEG volume conduction. Topographic factors with two levels were utilized in the initial ANOVA to avoid reduction in statistical power associated with correction for nonsphericity (Dien & Santuzzi, 2005). Relevant significant effects included a Frequency × Trial Type × Anterior-Posterior interaction, $F(2, 36) = 3.95$, $p_{\text{rep}} = .93$, $\varepsilon^2 = .18$. A second ANOVA utilized electrodes with more lateral placements (left and right frontal, F7/8; parietal, P7/8; and temporal, T7/8) in order to assess possible hemispheric effects; this analysis yielded a significant Trial Type × Hemisphere interaction, $F(2, 36) = 4.07$, $p_{\text{rep}} = .93$, $\varepsilon^2 = .18$.

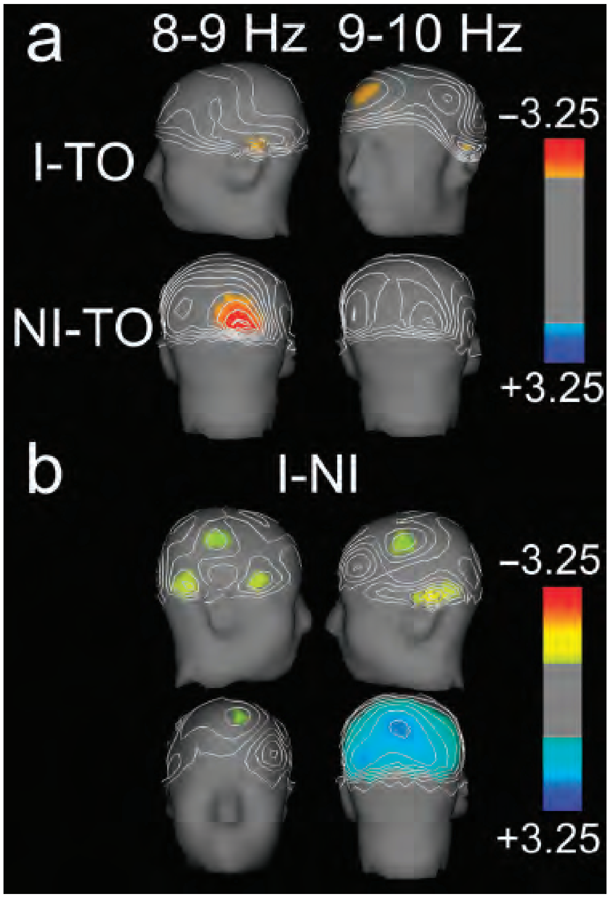

Fig. 2. Results from Experiment 1: alpha-band electroencephalographic (EEG) topography during the 2-s preparatory interval before the problem was displayed. Plotted values are *t* scores of electrode-by-electrode comparisons. The maps in (a) show results for comparisons between unsolved problems (time-outs, or TOs) and problems solved with insight processing (I) or with noninsight processing (NI); the left column shows maps for comparisons in the 8- to 9-Hz frequency band, and the right column shows maps for comparisons in the 9- to 10-Hz band. Red and orange regions indicate electrode sites at which I or NI trials exhibited less alpha power (i.e., more neural activity) than TO trials; the middle 66% of the color scale is grayed out. The maps in (b) show comparisons between insight preparation at peak power (9–10 Hz) and noninsight preparation at peak power (8–9 Hz; insight preparation minus noninsight preparation). Yellow regions show electrode sites at which insight preparation exhibited less alpha power than noninsight preparation. Blue regions show electrode sites at which noninsight preparation exhibited less alpha power than insight preparation. The middle 33% of the color scale is grayed out.

To specify the topographic differences driving the interactions in the omnibus ANOVAs, we computed the statistical parametric maps shown in Figure 2a as follow-up tests. The use of these follow-up tests to specify effects driving the interaction is justified by the presence of the interaction in the overall

ANOVA.[1] Compared with time-out preparation, insight preparation was associated with greater neural activity (i.e., less alpha power) peaking over midfrontal cortex (9–10 Hz; Fig. 2a, top right) and left anterior-temporal cortex (8–9 Hz and 9–10 Hz; Fig. 2a, top row). In contrast, noninsight preparation, compared with time-out preparation, was associated with greater neural activity (decreased 8- to 9-Hz alpha; Fig. 2a, bottom left) peaking over occipital cortex.

Notably, insight and noninsight preparation (i.e., the two forms of successful preparation) showed no common differences from time-out (i.e., unsuccessful) preparation. This suggests that subjects did not fail to prepare on some trials (e.g., by not attending); rather, they failed on some trials because they could not solve those particular problems (quickly enough). They likely engaged in more insight processing than noninsight processing on some unsuccessful trials and in more noninsight processing than insight processing on others, though we have no way of sorting those trials.

We explored the data further in a set of more focused analyses. An ANOVA compared power values for insight trials (in the 9- to 10-Hz range) and noninsight trials (in the 8- to 9-Hz range) at left and right anterior-frontal (AF1/2) and occipital (O9/10) electrodes. Direct comparison of the topography corresponding to the peak low-alpha frequency associated with insight preparation against the topography corresponding to the peak low-alpha frequency associated with noninsight preparation optimized the spatial resolution of the comparison. Relevant findings included a significant Insight × Anterior-Posterior interaction, $F(1, 18) = 8.46$, $p_{\text{rep}} = .97$, $\varepsilon^2 = .32$. There were also marginally significant Insight × Hemisphere, $F(1, 18) = 4.04$, $p_{\text{rep}} = .91$, $\varepsilon^2 = .18$, and Insight × Anterior-Posterior × Hemisphere, $F(1, 18) = 3.04$, $p_{\text{rep}} = .88$, $\varepsilon^2 = .14$, interactions. To specify the topographic differences underlying these interactions, we computed a statistical parametric map as a follow-up test (Fig. 2b). Direct comparison of peak low-alpha topographies associated with insight preparation (9–10 Hz) versus noninsight preparation (8–9 Hz) showed greater neural activity (i.e., less alpha) associated with insight preparation peaking over midfrontal, left temporal, right temporal, right inferior frontal, and bilateral somatosensory cortex and greater activity associated with noninsight preparation over a broad region of posterior cortex (Fig. 2b). (The somatosensory activation likely reflects activity associated with the bimanual button press subjects made to initiate a trial.)

It is possible that a subject's brain state changes slowly over the course of an experimental session, because of practice or fatigue. However, the proportion of problems solved by insight did not change from the first to the second half of the session ($F < 1$). Another possibility is that a subject's brain state varies on a shorter time scale, perhaps over the course of a few trials, entering an insight or a noninsight mode for some time before changing state. This would result in temporal clustering of trial types. However, temporal clustering of trial types in our data did not differ from that of simulated random data (all Fs < 1.0). These results suggest that activity associated with insight versus noninsight processing changed within the few seconds between trials. Given that subjects initiated the presentation of each problem when they felt prepared, these trial-by-trial changes in neural activity likely reflect differential preparation prior to the presentation of individual problems.

EXPERIMENT 2

EEG allowed us to isolate the preparatory interval with high precision, but provided less precise spatial information about the relevant brain regions. In Experiment 2, fMRI confirmed and specified the brain regions involved in preparation, though with less precise isolation of the preparatory interval.

Method

After giving informed consent, 25 subjects attempted to solve 135 compound remote-associate problems during fMRI scanning; the time limit for each problem was 15 s. Five subjects were replaced: Four showed excessive movement or poor MRI signal, and one responded "noninsight" on only two trials.

The paradigm described for Experiment 1 was modified slightly to optimize fMRI data acquisition. The preparation interval preceding each problem comprised a rest period (with a fixation cross) of varying length (2, 4, 6, or 8 s, randomly chosen) that followed the insight judgment (after a solved problem) or the time-out event (after an unsolved problem). No button press was required to initiate a trial, and subjects could not predict the length of the rest period, so the preparation was likely somewhat more passive than in Experiment 1.

Scanning was performed at Northwestern University's Center for Advanced MRI using a 3-T Siemens Trio scanner with standard head coil. Head motion was restricted with plastic calipers built into the coil and a vacuum pillow. Anatomical high-resolution T1-weighted images were acquired in the axial plane at the end of every session. In-plane functional images were acquired using a gradient echo-planar sequence (time to repetition, TR = 2 s for 38 slices that were 3 mm thick, time to echo = 20 ms, matrix size of 64 × 64 in a 220-mm field of view). Each of five runs began with an 8-s saturation period; then participants solved problems for up to 10 min, 20 s (the final run was truncated when subjects finished solving problems).

Functional and anatomical images were co-registered through time, spatially smoothed with a 7.5-mm Gaussian kernel, and fit to a common template. The data were analyzed using general

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[1] Topographic ANOVAs provide relatively sensitive statistical tests because they pool variance across electrodes, but they provide relatively coarse topographic information. In contrast, t-score mapping provides more specific topographic information about the effects driving ANOVA results, though with less statistical power because variance is not pooled across electrodes.

linear model analysis that extracted average estimated response to each trial type, correcting for linear drift and removing signal changes correlated with head motion. For each participant, an event-related analysis contrasted fMRI signal for insight versus noninsight preparation intervals (for 4 TRs reflecting 4.1–12.0 s following the onset of the preparation period). Between-subjects consistency in difference scores (insight preparation minus noninsight preparation) was analyzed in a second-stage random-effects analysis. The significance threshold combined cluster size and t values for every voxel within a cluster: Clusters exceeded 1,000 mm^3 in volume, with each voxel reliably different across participants, $t(24) = 3.374, p < .0025$, uncorrected. This combination threshold yields very low false-positive rates in simulations.

Signal acquisition and initial data analyses for this experiment are described in detail elsewhere (Virtue, Haberman, Clancy, Parrish, & Jung-Beeman, in press). Northwestern University's institutional review board approved the study.

Results

Participants solved 47% ($SD = 9.9$) of the problems correctly within the 15-s time limit and labeled 55.8% ($SD = 13.9$) of solutions as insight solutions (median response time = 5.84 s, $SD = 1.24$) and 43.4% ($SD = 13.6$) as noninsight solutions (median response time = 7.81 s, $SD = 1.79$). Of all responses, 6.6% ($SD = 5.4$) were errors.

The fMRI signal changed in several brain areas during the preparation interval. Most areas showed decreasing signal during preparation, as neural activity returned to baseline. A few areas showed increased signal, indicating increasing neural activity during "rest." This increase was strongest in anterior cingulate cortex (ACC). Small regions within posterior cingulate cortex (PCC) and bilateral posterior middle and superior temporal gyri (M/STG) also showed slightly increasing or sustained activity during preparation.

Of greater interest is that signal change during the preparation interval varied systematically according to whether the subsequent problem was solved with insight versus noninsight (Fig. 3, Table 1). The fMRI results essentially replicate those observed with EEG in Experiment 1. In ACC, preparation that preceded solutions with insight increased fMRI signal more than did preparation that preceded solutions without insight. In PCC and bilateral posterior M/STG, signal was stronger for insight than noninsight preparation, mostly because signal *decreased* more for noninsight than insight preparation. Both significant temporal clusters appeared to comprise several smaller clusters (a small subregion in each hemisphere showed greater signal increase for insight preparation; the remainder of each cluster showed greater signal decrease for noninsight preparation). There were also small, nonsignificant clusters in the anterior-temporal region. No clusters showing the opposite effect exceeded our combined significance threshold. However, at lower t thresholds, the largest cluster (375 mm^3 at $p < .01$, 1,344 mm^3 at $p < .05$) showing stronger signal for noninsight than insight preparation was in left middle and inferior occipital cortex (Table 1).

GENERAL DISCUSSION

The observed effects on EEG topographies, peak low-alpha frequencies, and fMRI signal all demonstrate that the neuronal populations active prior to the presentation of problems subsequently solved with insight are different from the neuronal populations active prior to the presentation of problems subsequently solved with noninsight processing. Note that differences in brain activity during preparation were not influenced by the specific content of the problems, which were not displayed until after the epoch examined. Thus, subjects engaged distinct patterns of mental preparation.

Although the mere demonstration of such preparatory states is important, the anatomical pattern evident across the two experiments also suggests specific preparatory mechanisms facilitating insight. The convergence across methods is critical, as the fMRI data, providing specific anatomical information, replicate the effects of insight preparation observed with EEG.[2]

We begin with the ACC region identified with fMRI. This is the likely source of the insight-related midfrontal activity observed with EEG.[3] Beyond showing an insight-noninsight difference, this region showed the most robust pattern of increasing fMRI signal during the preparation period, that is, during "rest." ACC has been associated with monitoring for competition among potential responses or processes. Such conflict monitoring can signal the need for top-down cognitive control mechanisms facilitating the maintenance or switching of attentional focus, or selection from competing responses (Badre & Wagner, 2004; Botvinick, Cohen, & Carter, 2004; Kerns et al., 2004; Miller & Cohen, 2001). According to this interpretation, increased ACC activity is followed by increased top-down control. Notably, ACC activity increased during the preparation period, when no obvious response conflict existed. Recent studies suggest a possible reason: ACC may be involved in suppressing irrelevant thoughts (Anderson et al., 2004; Wyland, Kelley, Macrae, Gordon, & Heatherton, 2003), such as daydreams or thoughts related to a preceding event (in this case, the preceding trial). Thus, ACC activity may have allowed participants to attack the next problem with a "clean slate." This explanation assumes that insight processing is more susceptible to internal interference

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[2] We did not contrast insight or noninsight preparation against time-out preparation in Experiment 2 (as we did in Experiment 1), because the contrast would have been confounded by some temporally proximal solutions, which would have been absent in the time-out trials, and which would have affected fMRI signal.

[3] Most prior studies have associated ACC activity with changes in theta-band EEG power (Luu, Tucker, & Makeig, 2004), but some studies have associated it with alpha-band oscillations (Goldman et al., 2002).

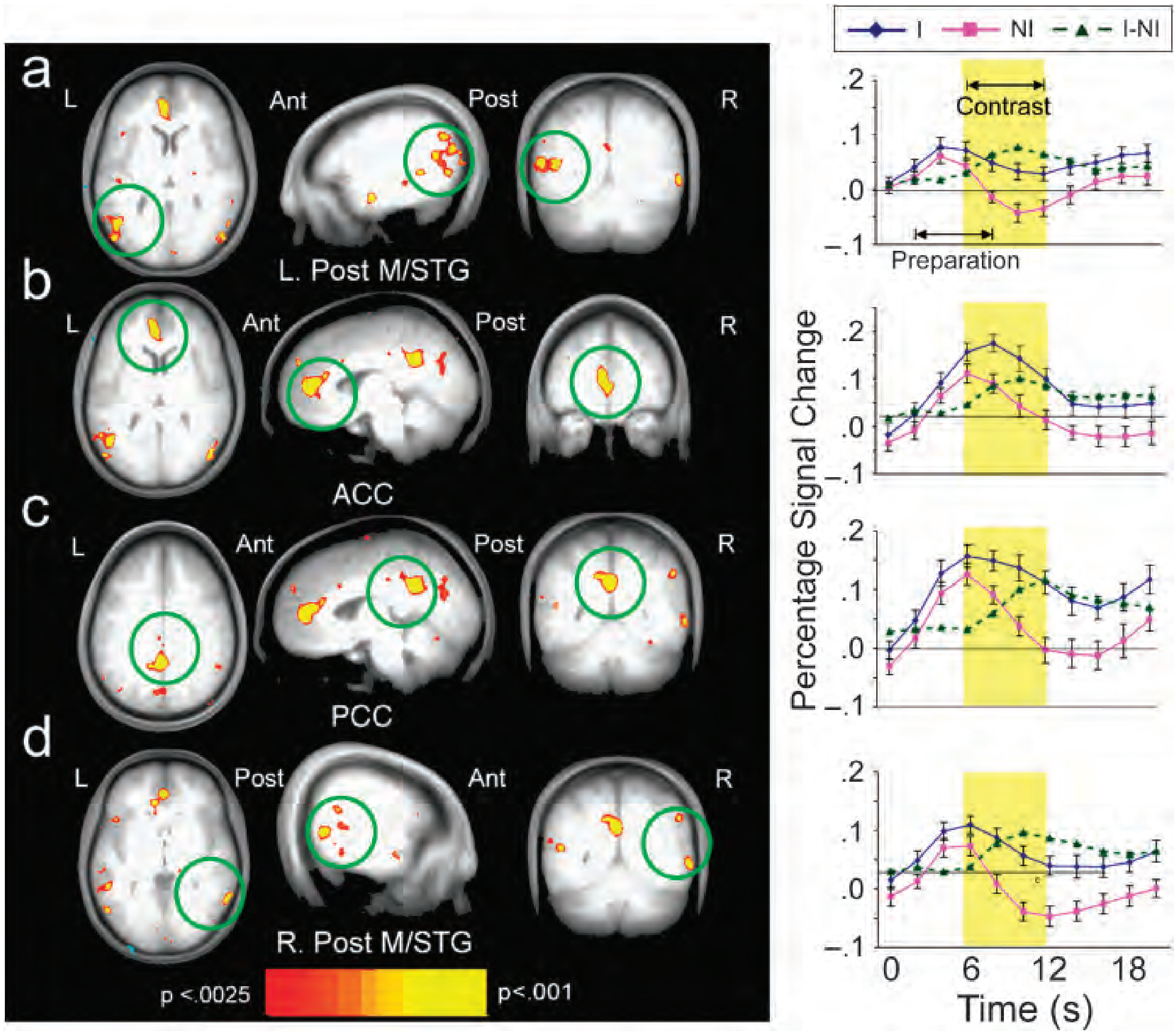

Fig. 3. Results from Experiment 2: structural images averaged across all 25 subjects, showing all voxels with stronger functional magnetic resonance imaging (fMRI) signal, $t(24) = 3.375$, $p < .0025$, uncorrected, for preparation periods that led to insight solutions than for preparation periods that led to noninsight solutions. Each row shows (left to right) axial, sagittal, and coronal images (with the left hemisphere on the left of axial and coronal images) centered on clusters (circled) of significant size (i.e., larger than 1,000 mm^3; no clusters of significant size showed the reverse pattern). For each circled region, the graph on the right shows the average percentage signal change during the shaded 6- to 12-s interval associated with neural activity during the 2- to 8-s preparatory interval (the offset between these intervals being due to the lag of the hemodynamic response). The blue line shows signal related to insight (I) preparation, the pink line shows signal related to noninsight (NI) preparation (both with standard error bars), and the green line shows the subtraction ($I - NI$). Analyses identifying significant voxels tested the contrast within the four TRs (times to repetition) highlighted in the yellow shaded region (i.e., TR ending at 6 s through TR ending at 12 s), which corresponds to the expected peak signal for the preparation period. (The preceding button press elicited peak signal in motor cortex at 4 s in these graphs.) Results are shown for four clusters: (a) left posterior middle/superior temporal gyri (L. Post M/STG), (b) anterior cingulate cortex (ACC), (c) posterior cingulate cortex (PCC), and (d) right posterior middle/superior temporal gyri (R. Post M/STG). Ant = anterior; Post = posterior; L = left; R = right.

than is noninsight processing (Schooler, Ohlsson, & Brooks, 1993), thereby necessitating greater suppression of extraneous thoughts.

Thus, in the context of problem solving, the activity observed in ACC prior to insight may reflect increased readiness to monitor for competing responses, and to apply cognitive control mechanisms as needed to (a) suppress extraneous thoughts, (b) initially select prepotent solution spaces or strategies, and, if these prove ineffective, (c) subsequently shift attention to a nonprepotent solution or strategy. Such shifts are characteristic of insight.

We speculate that during insight preparation, cognitive control mechanisms were modulating activity in brain areas related to semantic processing. Greater neural activity was observed for insight than for noninsight preparation in bilateral temporal cortex (with this activity being more extensive on the left than on the right, in both experiments). We propose that this temporal-lobe activity reflects preparation for semantic activation and

TABLE 1

Brain Areas Showing Significantly Different Functional Magnetic Resonance Imaging Signal for Insight Preparation Versus Noninsight Preparation

Gyrus or structure	Brodmann Area	Volume (mm^3)	Center coordinates x	y	z	Signal change (%) Mean	Max	Mean t	Max t	Effect size (d)
Insight preparation > noninsight preparation										
Left posterior M/STG	39, 37, 22	2,031	−49	−62	15	0.06	0.08	3.6	4.7	0.98
Anterior cingulate	32, 24	1,922	−4	41	8	0.08	0.10	3.8	4.8	0.94
Posterior cingulate	31	1,594	−3	−47	32	0.08	0.11	4.0	5.6	0.96
Right posterior M/STG	37, 39, 22	1,266	52	−62	9	0.07	0.10	3.7	4.8	1.00
Left amygdala	—	438	−25	−7	−9	0.07	0.10	3.8	4.6	—
Left middle temporal gyrus	21	438	−62	−32	−6	0.07	0.10	3.7	4.6	—
Noninsight preparation > insight preparation[a]										
Left middle and inferior occipital gyrus	18	375	−30	−98	2	−0.09	−0.12	−3.1	−3.7	—

Note. We used a strict threshold for significance, requiring a cluster size of 1,000 mm^3 and requiring that all voxels show a consistent effect across subjects, $t(24) = 3.374$, $p < .0025$. For thoroughness, all clusters down to 300 mm^3 are listed. For each cluster listed, we report the signal difference between insight and noninsight preparation as a percentage of the average signal within the cluster, as well as the average and maximum t score for all voxels within the cluster. For significant clusters, we include the cluster-wise effect size, d. M/STG = middle and superior temporal gyri.

[a] No clusters showed significantly greater signal for noninsight preparation than for insight preparation, so we list the largest area at a lower threshold, 375 mm^3 at $t(24) = 2.795$, $p < .01$.

results from top-down processes such as those associated with the ACC. Within a theoretical framework of bilateral semantic processing (Jung-Beeman, 2005; also Faust & Lavidor, 2003) partly based on cytoarchitectonic studies (Hutsler & Galuske, 2003), the bilateral (or slightly leftward) distribution of this activity indicates that subjects were prepared to retrieve both prepotent associations (predominantly in the left posterior M/STG) and weaker associations (in the right posterior M/STG).

This hypothesis is also consistent with a recently proposed model of the neural basis of insight in verbal problem solving (Bowden et al., 2005; Jung-Beeman et al., 2004) according to which solvers initially focus on prepotent associations, possibly reaching an impasse if this does not lead to a solution. However, solvers may maintain weak activation for the solution (Beeman & Bowden, 2000) due to coarser semantic coding in the right hemisphere (Bowden & Beeman, 1998; Bowden & Jung-Beeman, 2003a). Solvers may overcome impasse by switching attention to this weakly activated representation, suddenly increasing its strength. This shift of attention to a nonprepotent solution (or solving process) involves cognitive control mechanisms such as those associated with the ACC. This shift of attention may be less likely to occur when people use a less controlled mode of processing based on passive accrual of evidence.

This interpretation is consistent with a sudden increase in high-frequency EEG power (i.e., gamma-band oscillations peaking at 40 Hz) observed to occur about 0.3 s before insight (compared with noninsight) solutions (Jung-Beeman et al., 2004). This burst of gamma-band activity was focused at right anterior superior-temporal electrodes and corresponded to activity detected by fMRI in the underlying cortex (with no significant insight effect in the left anterior temporal lobe). This right anterior temporal activity may reflect the sudden emergence into consciousness of the correct solution (Jung-Beeman et al., 2004).

The current results extend this prior work by demonstrating that this insight response is the culmination of mechanisms that begin even before a problem is presented. Insight preparation modulates processing and biases toward insight solutions by increasing readiness in (a) left posterior temporal cortex, whose activation is hypothesized to reflect readiness to initially pursue prepotent associations, and (b) ACC, whose activation is hypothesized to reflect cognitive control mechanisms that facilitate initially attending to prepotent associations, then discretely shifting attention to nonprepotent associations—which may include solution-related information activated in the right anterior temporal region.

One additional area, PCC, showed stronger fMRI signal for insight than for noninsight preparation, perhaps reflecting attentional differences (Small et al., 2003). No corresponding effect was evident in the EEG data. It is possible, however, that an effect was present in this deep area, but was canceled out by the opposite effect measured over posterior cortex, which was likely generated in more superficial brain areas. Specifically, EEG revealed greater occipital-parietal activity during noninsight than during insight preparation; there was a similar, though not significant, effect in the fMRI results. It is possible that this effect was stronger in the EEG experiment because the preparation period was more active and predictable; subjects pressed a button to indicate readiness in the EEG experiment, but not in the fMRI experiment. This posterior cortical activity during noninsight preparation may suggest readiness to pursue a less controlled, bottom-up mode of processing, for example, by increasing visual attention just before the problem is displayed.

CONCLUSIONS

The present study demonstrates that a person's preparatory brain state even prior to seeing a problem influences whether the person will solve that problem with insight or noninsight processing. Insight preparation could be characterized as preparing to strongly activate prepotent candidate solutions while also preparing to switch attention to nonprepotent candidates, thereby enabling retrieval of weakly activated solutions characterized by remote associations among problem elements. In contrast, noninsight preparation could be characterized as external attentional focus on the source of the imminent problem. The fact that subjects use both of these forms of preparation suggests either that they spontaneously alternate strategies or that one form of preparation, presumably insight preparation with its top-down component, is perhaps too cognitively demanding to use for every problem in a series.

Future studies will further specify these preparation-related brain states and their determinants. Ideally, this line of research could lead to the development of techniques for facilitating or suppressing insight in order to optimize performance for different types of problems and contexts. In sum, this work may show how to lessen the impact of chance on efforts to reach insightful solutions, a goal that Pasteur would likely have endorsed.

Acknowledgments—Grants DC-04818 (to J.K.) and DC-04052 (to M.J.-B.) from the National Institutes of Deafness and Other Communication Disorders supported this research. We thank D. Stephen Lindsay, James Cutting, and an anonymous reviewer for helpful comments.

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(RECEIVED 8/1/05; REVISION ACCEPTED 11/29/05;
FINAL MATERIALS RECEIVED 2/1/06)