

**The Prepared Mind:
Neural Activity Prior to Problem Presentation
Predicts Subsequent Solution by Sudden Insight**

John Kounios¹, Jennifer L. Frymiare², Edward M. Bowden³,
Jessica I. Fleck¹, Karuna Subramaniam³, Todd B. Parrish³, and Mark Jung-Beeman³

IN PRESS: *Psychological Science*

¹Department of Psychology, Drexel University, MS 626, 245 N. 15th Street, Philadelphia, PA 19102-1192, USA (phone: 215-762-3318; fax: 215-762-7977)

²Department of Psychology, University of Wisconsin-Madison, 1202 West Johnson Street, Madison, WI 53706, USA (phone: 608-262-6989; fax: 608-262-4029)

³Department of Psychology and Cognitive Brain Mapping Group, Northwestern University, 2029 Sheridan Road, Evanston, IL 60208-2710, USA (phone: 847-491-4617; fax: 847-491-7859)

Address editorial correspondence to

John Kounios (john.kounios@gmail.com)

or

Mark Jung-Beeman (mjungbee@northwestern.edu)

Running Title: Neural Preparation for Insight

Word Count: 3990

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 independent of specific problems. 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 subject-reported insight. Specifically, EEG topography and frequency (Experiment 1), and fMRI 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. EEG topography suggests 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 measures of intelligence and creativity (Ansburg & Hill, 2003; Davidson, 1995).

While 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 et al., 1995; Wallas, 1926). Such study is obviously helpful, but probably facilitates problem solving both by insight and by noninsight analytic processing.

We hypothesized another type of preparation, one that does not depend on information related to specific problems, but which biases a person toward processing that facilitates solution by insight. Here, we demonstrate that preparation for solving can be associated with distinct brain states, one biasing toward solution with insight, the other 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 versus 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, to 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 et al., 2005). Instead, 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 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 experiences reflect the sudden conscious availability of a solution rather than some ancillary process. For example, (A) the associated

neural activity does not reflect subjects' affective or surprise reactions following solutions, because the onset of the corresponding sudden burst of neural (gamma-band electroencephalogram) activity in the right anterior superior-temporal gyrus coincides with, rather than follows, the conscious availability of the solution; (B) task-related activity occurs in this 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 examined neural activity as people prepared for each problem, prior to its presentation (therefore 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 et al., 1998; Cooper et al., 2003; Goldman et al., 2002; Laufs et al., 2003; Ray & Cole, 1985; Worden, et al., 2000). The topographic distribution of alpha across the scalp therefore mirrors the spatial distribution of neural activity (Pfurtscheller & Lopes da Silva, 1999). We focus 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

Methods

After giving informed consent, 19 participants attempted to solve 186 problems. On each trial (Figure 1), subjects 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-sec epoch selected as the *preparation interval* of interest. After 1 sec, 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, Bowden & Jung-Beeman, 2003b). They also can be solved either with insight or with noninsight analytic processes (Jung-Beeman et al., 2004; Bowden & Jung-Beeman, 2003a), allowing us to 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 solved the problem, verbalized the solution when prompted, and then, when prompted, pressed one of two buttons to indicate whether 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-sec intertrial 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 (.02 – 100 Hz). Eyeblink artifacts were removed using EMSE 5.0. Trials containing other artifacts were identified by visual inspection and deleted.

EEG segments corresponding to the preparation intervals were extracted and, based on subjects' performance on the following problem, were sorted into three types of preparation, leading to solutions with insight, without insight, or timeouts (when subjects failed to respond within 30 sec). (Error trials were rare and 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-sec time limit. Subjects labeled 56.2% (sd: 8.3) of solutions as insight (average median response time: 7.70 sec, sd: 2.60) and 42.5% (sd: 8.9) as noninsight (7.48 sec, sd: 3.08). Of trials with 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 (*insight preparation* versus *noninsight preparation*). Moreover, visual inspection of power spectra suggested that insight versus noninsight preparation was 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 timeouts (*timeout preparation*), and separately contrasted noninsight preparation against timeout preparation. This also allowed us to assess whether preparation for successful problem solving differed from preparation preceding unsuccessful problem processing. Two repeated-measures analyses of variance (ANOVA) were performed on log-transformed EEG power to examine anterior-posterior and hemispheric differences in two low-alpha sub-bands (the Frequency factor: 8-9 Hz versus 9-10 Hz, determined by visual inspection of the power spectra) for insight, noninsight, and timeout 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 X Trial-Type X 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] sites) in order to assess possible hemispheric effects, yielding a significant Trial-Type X Hemisphere interaction ($F[2,36] = 4.07, p_{\text{rep}} = .93, \varepsilon^2 = .18$).

In order to specify the topographic differences driving the interactions in the omnibus ANOVAs, the statistical parametric maps shown in Figure 2 were computed 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 ANOVA¹. Contrasted with timeout preparation, insight preparation was associated with greater neural activity (i.e., less alpha power) peaking over mid-frontal cortex (from 9-10 Hz, shown in Figure 2, top right) and left anterior-temporal cortex (8-9 Hz and 9-10 Hz, Figure 2, top row.). In contrast, noninsight preparation, compared to timeouts, was associated with greater neural activity (decreased 8-9 Hz alpha, Figure 2, bottom left) peaking over occipital cortex.

Notably, no effects of contrasting successful versus unsuccessful (i.e., timeout) preparation were common to insight and noninsight preparation. This suggests that subjects did not fail to prepare on some trials (e.g., by not attending); rather, they failed because they could not solve that particular problem (quickly enough). They likely engaged in relatively more insight processing on some

unsuccessful trials and relatively more noninsight processing on others, though we have no way of sorting those trials.

These observations were further explored by a set of more focused analyses. An ANOVA examined power values for insight (9-10 Hz) and noninsight (8-9 Hz) trials (the Insight factor) 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 X Anterior-Posterior interaction ($F[1,18] = 8.46$, $p_{\text{rep}} = .97$, $\varepsilon^2 = .32$). There were also marginally significant Insight X Hemisphere ($F[1,18] = 4.04$, $p_{\text{rep}} = .91$, $\varepsilon^2 = .18$) and Insight X Anterior-Posterior X Hemisphere ($F[1,18] = 3.04$, $p_{\text{rep}} = .88$, $\varepsilon^2 = .14$) interactions. To specify the topographic differences underlying these interactions, a statistical parametric map was computed as a follow-up test (Figure 3). 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 mid-frontal cortex and greater activity associated with noninsight preparation over a broad region of posterior cortex (Figure 3, bottom row). In the 9-10 Hz frequency band, there was greater neural activity associated with insight than for noninsight preparation, peaking at electrodes over left temporal, right temporal, right inferior-frontal, and bilateral somatosensory cortex (Figure 3, top row). (The latter 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 the experimental session, due to 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 F 's < 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 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.

Methods

After informed consent, 25 subjects attempted to solve, within 15 sec, 135 compound remote associate problems during fMRI scanning. Five subjects were replaced: four showed excessive movement or poor MRI signal, and one responded “noninsight” on only two trials. The paradigm described above was slightly modified 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 sec, randomly chosen) that followed the insight judgment (after a solved problem) or the timeout event (after an unsolved problem). No button-press was required, 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-Tesla 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 (TR = 2 sec for 38 slices, 3 mm thick, TE = 20 msec, matrix-size 64x64 in 220-mm field of view). Each of 5 runs began with an 8-sec saturation period, then participants solved problems for up to 10 min, 20 sec (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 linear model analysis (Ward, <http://afni.nimh.nih.gov/afni>) that extracted average estimated responses 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 sec following the onset). Insight-preparation versus noninsight-preparation difference-scores from each participant were combined in a second-stage random-effects analysis to identify differences consistent across participants. The significance threshold combined cluster-size and t -values for each voxel within a cluster (1000 mm³ in volume in which each voxel was reliably different across participants, [$t(24) = [3.374]$, $p < 0.0025$, uncorrected]). This combination threshold yields very low false-positive rates in simulations. Importantly, the results essentially replicate those observed with EEG in Experiment 1.

Signal acquisition and initial data analyses are described in detail elsewhere (Virtue et al., 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-sec time limit, and labeled 55.8% (sd: 13.9; median RT: 5.84 sec, sd: 1.24) of solutions as insight, and 43.4% (sd: 13.6; median RT: 7.81 sec, sd: 1.79) as noninsight. Of all responses, 6.6% (sd: 5.4) were errors.

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," most strongly in anterior-cingulate cortex (ACC). Small regions within posterior-cingulate cortex (PCC) and bilateral posterior middle/superior-temporal gyri (M/STG) also showed slightly increasing or sustained activity during preparation.

Of greater interest, signal change during the preparation interval varied systematically according to whether the subsequent problem was solved with insight versus noninsight (Figure 4, Table 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 sub-region 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 mm³ at $p < .01$, 1344 mm³ at $p < .05$) showing stronger signal for noninsight than insight preparation was in the left middle-occipital gyrus (Table 1).

General Discussion

Effects on EEG topographies, peak low-alpha frequencies, and fMRI signal all demonstrate that different neuronal populations are active prior to the presentation of problems subsequently solved with insight versus 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.

While 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 insight preparation effects observed with EEG².

We begin with the ACC region identified in fMRI, which is the likely source of the insight-related mid-frontal activity observed with EEG³. This region showed the most robust fMRI pattern of increasing activity 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 selecting from competing responses (Badre & Wagner, 2004; Botvinick et al., 2004; Kerns et al., 2004; Miller & Cohen, 2001). According to this model, increased ACC activity is followed by increased top-down control. Notably, ACC activity increased during the preparation period, when no obvious response conflict exists. Recent studies suggest a possible reason: ACC may be involved in suppressing irrelevant thoughts (Anderson et al., 2004; Wyland et al., 2003), such as daydreams or thoughts related to the preceding trial, thus allowing solvers to attack the next problem with a “clean slate.” This explanation assumes that insight processing is more susceptible to internal interference than is noninsight processing (Schooler et al., 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 cognitive control mechanisms are modulating activity in brain areas related to semantic processing. Greater neural activity was observed for insight than for noninsight preparation in bilateral temporal cortex (left more than right, in both experiments). We propose that this temporal-lobe activity reflects readiness to engage semantic activation, particularly guided by top-down processes such as those associated with 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 activation indicates that subjects are 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) in which solvers initially focus on prepotent associations, possibly reaching impasse if this does not lead to 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. In contrast, this shift of attention may be less likely to occur when people use a less controlled mode of processing based on passive evidence accrual.

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 .3 sec before insight (compared to 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). It was proposed that this right anterior temporal activity reflects 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 two cortical regions: (1) posterior temporal regions, hypothesized to reflect readiness to initially pursue prepotent associations; (2) ACC, 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, the 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 EEG. It's possible that an effect was present in this deep area, but was cancelled 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 fMRI. It is possible that this effect was stronger in the EEG experiment because the preparation period was more active and predictable, with subjects pressing a button to indicate readiness in the EEG, 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 prior to even seeing a problem influences whether the person will solve that problem with insight or noninsight processing. Insight preparation could be characterized as being prepared to strongly activate prepotent candidate solutions while also being prepared to switch attention to nonprepotent candidates, thereby enabling a person to retrieve 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 interfering with insight in order to optimize performance for different types of problems and contexts. From this, we may learn to lessen the impact of chance on efforts to reach insightful solutions, a goal that Pasteur would likely have endorsed.

Acknowledgments

NIDCD grants DC-04818 (to JK) and DC-04052 (to MJ-B) supported this research. We thank D. Stephen Lindsay, James Cutting, and an anonymous reviewer for helpful comments.

Notes

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.
2. We did not contrast fMRI signal for insight or noninsight preparation against timeout preparation (as in the EEG experiment), because the contrast would be confounded by some temporally proximal solutions, which are absent in the timeout trials, and which would affect fMRI signal.
3. Most prior studies have associated ACC activity with changes in theta-band EEG power (Luu et al., 2004), but some studies have associated it with alpha-band oscillations (Goldman et al., 2002).

References

- Ansburg, P.I., & Hill, K. (2003). Creative and analytic thinkers differ in their use of attentional resources. *Personality and Individual Differences*, *34*, 1141-1152.
- Anderson, M.C., Ochsner, K.N., Kuhl, B., Cooper, J., Robertson, E., Gabrieli, S.W., Glover, G.H., & Gabrieli, J.D.E. (2004). Neural systems underlying the suppression of unwanted memories. *Science*, *303*, 232-235.
- Badre, D., & Wagner, A.D. (2004). Selection, integration, and conflict monitoring; assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron*, *41*, 473-487.
- Beeman, M., Friedman, R.B., Grafman, J., Perez, E., Diamond, S., & Lindsay, M.B. (1994). Summation priming and coarse semantic coding in the right hemisphere. *Journal of Cognitive Neuroscience*, *6*, 26-45.
- Beeman, M.J. & Bowden, E.M. (2000). The right hemisphere maintains solution-related activation for yet-to-be solved insight problems. *Memory & Cognition*, *28*, 1231-1241.
- Botvinick, M.M., Cohen, J.D., & Carter, C.S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in Cognitive Sciences*, *8*, 539-546.
- Bowden, E.M., & Beeman, M.J. (1998). Getting the right idea: Semantic activation in the right hemisphere may help solve insight problems. *Psychological Science*, *9*, 435-440.
- Bowden, E.M., & Jung-Beeman, M. (2003a). Aha! Insight experience correlates with solution activation in the right hemisphere. *Psychonomic Bulletin & Review*, *10*, 730-737.
- Bowden, E.M., & Jung-Beeman, M. (2003b). Normative data for 144 compound remote associate problems. *Behavior Research Methods, Instruments, & Computers*, *35*, 634-639.
- Bowden, E.M., Jung-Beeman, M., Fleck, J., & Kounios, J. (2005). New approaches to demystifying insight. *Trends in Cognitive Sciences*, *9*, 322-328.

- Cook, I.A., O'Hara, R., Uijtdehaage, S.H., Mandelkern, M., & Leuchter, A.F. (1998). Assessing the accuracy of topographic EEG mapping for determining local brain function. *Electroencephalography and Clinical Neurophysiology* 107, 408-414.
- Cooper, N.R., Croft, R.J., Dominey, S.J.J, Burgess, A.P., & Gruzelier, J.H. (2003). Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *International Journal of Psychophysiology*, 47, 65-74.
- Davidson, J.E. (1995). The suddenness of insight. In: R.J. Sternberg & J.E. Davidson (Eds.), *The nature of insight* (pp. 125-155). Cambridge, MA: MIT Press.
- Dien, J., & Santuzzi, A.M. (2005). Application of repeated measures ANOVA to high-density ERP datasets: A review and tutorial. In T.C. Handy (Ed.), *Event-related potentials: A methods handbook* (pp. 57-82). Cambridge, MA: MIT Press.
- Faust, M., & Lavidor, M. (2003). Semantically convergent and semantically divergent priming in the cerebral hemispheres: lexical decision and semantic judgment. *Cognitive Brain Research*, 17, 585-597.
- Gevins, A., Smith, M.E. (2000). Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style. *Cerebral Cortex*, 10, 829-839.
- Goldman, R.I., Stern, J.M., Engel, J., Cohen, M.S. (2002). Simultaneous EEG and fMRI of the alpha rhythm. *NeuroReport* 13, 2487-2492.
- Hutsler, J., & Galuske, A.W. (2003). Hemispheric asymmetries in cerebral cortical networks. *Trends in Neurosciences*, 26, 429-435.
- Jung-Beeman, M. (In press). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Sciences*, November 2005.
- Jung-Beeman, M., Bowden, E.M., Haberman, J., Frymiare, J.L., Arambel-Liu, S., Greenblatt, R., Reber, P.J., & Kounios, J. (2004). Neural activity when people solve verbal problems with insight. *Public Library of Science Biology*, 2, E97.
- Kerns, J.G., Cohen, J.D., MacDonald, A.W. 3rd, Cho, R.Y., Stenger, V.A., & Carter, C.S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*, 303, 1023-1026.
- Kvavilashvili, L., & Mandler, G. (2004). Out of one's mind: a study of involuntary semantic memories. *Cognitive Psychology*, 48, 47-94.
- Laufs, H., Krakow, K., Sterzer, P., Eger, E., Beyerle, A., & Salek-Haddadi, A. (2003). Electroencephalographic signatures of attentional and cognitive default modes in spontaneous brain activity fluctuations at rest. *Proceedings of the National Academy of Sciences USA*, 100, 11053-11058.
- Luu, P., Tucker, D.M., & Makeig, S. (2004). Frontal midline theta and the error-related negativity: neurophysiological mechanisms of action regulation. *Clinical Neurophysiology*, 115, 1821-1835.
- Mayer, R.E. (1995). The search for insight: Grappling with Gestalt psychology's unanswered questions. In R.J. Sternberg & J.E. Davidson (Eds.), *The nature of insight* (pp. 3-32). Cambridge, MA: MIT Press.
- Metcalf, J., & Wiebe, D. (1987). Intuition in insight and noninsight problem solving. *Memory & Cognition*, 15, 238-246.

- Miller, E.K., & Cohen, J.D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, 24, 167-202.
- Pfurtscheller, G., & Lopes da Silva, F.H. (1999). *Handbook of electroencephalography and clinical neurophysiology, revised series, volume 6: Event-related desynchronization*. Amsterdam: Elsevier.
- Ray, W.J., & Cole, H.W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science*, 228, 750-752.
- Schooler, J.W., Ohlsson, S., & Brooks, K. (1993). Thoughts beyond words: When language overshadows insight. *Journal of Experimental Psychology: General*, 122, 166-183.
- Seifert, C.M., Meyer, D.E., Davidson, N., Patalano, A.L., & Yaniv, I. (1995). Demystification of cognitive insight: Opportunistic assimilation and the prepared-mind perspective. In R.J. Sternberg & J.E. Davidson (Eds.), *The nature of insight* (pp. 65-124). Cambridge, MA: MIT Press.
- Shaw, J.C. (2003). *The brain's alpha rhythms and the mind*. Amsterdam: Elsevier.
- Small, D.M., Gitelman, D.R., Gregory, M.D., Nobre, A.C., Parrish, T.B., & Mesulam, M-M. (2003). The posterior cingulate and medial prefrontal cortex mediate the anticipatory allocation of spatial attention. *NeuroImage*, 18, 633-641.
- Smith, R.W., & Kounios, J. (1996). Sudden insight: all or none processing revealed by speed-accuracy decomposition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22, 1443-1462.
- Sternberg, R., & Davidson, J.E. (1995). *The nature of insight*. Cambridge, MA: MIT Press.
- Virtue, S., Haberman, J., Clancy, Z., Parrish, T., & Jung-Beeman, M. (In press). Neural activity during inference generation. *Cognitive Brain Research*.
- Wallas, G. (1926). *The art of thought*. New York: Harcourt Brace Jovanovich.
- Weisberg, R.W. (1995). Prolegomena to theories of insight in problem solving: A taxonomy of problems. In R.J. Sternberg & J.E. Davidson (Eds.), *The nature of insight* (pp. 157-196). Cambridge, MA: MIT Press.
- Worden, M.S., Foxe, J.J., Wang, N., & Simpson, G.V. (2000). Anticipatory biasing of visuospatial attention indexed by retinotopically specific alpha-band electroencephalography increases over occipital cortex. *Journal of Neuroscience*, 20, RC63.
- Wyland, C.L., Kelley, W.M., Macrae, C.N., Gordon, H.L., & Heatherton, T.F. (2003). Neural correlates of thought suppression. *Neuropsychologia*, 41, 1863-1867.

Gyrus/Structure	Brodmann Areas	Volume	Center coordinates			Mean % sig	Max % sig	Mean t	Max t	Effect size <i>d</i>
			X	Y	Z					
Insight preparation > Noninsight preparation										
Left Posterior Mid. & Sup. Temporal Gyri	39,37, 22	2031	-49	-62	15	0.06	0.08	3.6	4.7	.98
Anterior Cingulate	32,24	1922	-4	41	8	0.08	0.10	3.8	4.8	.94
Posterior Cingulate	31	1594	-3	-47	32	0.08	0.11	4.0	5.6	.96
Right Posterior Mid. & Sup. Temporal Gyri	37,39, 22	1266	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 (no significant clusters)										
* <i>Left Middle & Inf Occipital Gyrus</i>	18	375	-30	-98	2	-0.09	-0.12	-3.1	-3.7	

Table 1. Brain areas showing stronger fMRI signal for insight preparation than for noninsight preparation. We used a strict threshold of cluster size 1000 mm³ in which all voxels show a consistent effect across subjects ($t(24)=3.374, p<.0025$). All clusters down to 300mm³, which could reflect true activation but are below our strict threshold, are listed. For each cluster listed, we report signal difference between the contrasted conditions as a percent of average signal within the cluster, the average and maximum t score for all voxels within the cluster. For significant clusters, we include the cluster-wise effect size *d*. *No clusters showed a reverse difference at strict threshold, so we list above the largest area at a lower threshold (375 mm³ at $t(24)=2.795, p<.01$).

Figure Legends

Figure 1. Timeline of events on a trial. A “Ready” message was displayed on a monitor and the subject made a bimanual button-press (“S”) when prepared to start the trial and view the 3 words constituting a problem. The problem was displayed after a 1-sec visual fixation mark. The subject responded again (“R”) as soon as he or she has 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 EEG results for the bracketed preparatory interval consisting of the 2 sec prior to the display of the problem.

Figure 2. Alpha EEG topography during the 2-sec preparatory interval before problems subsequently solved with insight (I) versus noninsight (NI) processing. Plotted values are *t*-scores of electrode-by-electrode comparisons. (A) The left column shows maps for comparisons in the 8-9 Hz frequency band; the right column shows maps for comparisons in the 9-10 Hz band. Red and orange regions show electrode sites at which insight or noninsight preparation periods exhibit less alpha power (i.e., more neural activity) compared to time-out (TO) trials, with the middle 66% of the color scale grayed out. (B) These maps show comparisons between insight preparation at peak power (9-10 Hz) and noninsight preparation at peak power (8-9 Hz). Orange and yellow regions show electrode sites at which insight preparation exhibits less alpha power compared to noninsight preparation. Blue regions show electrode sites at which noninsight preparation exhibits less alpha power compared to insight preparation. The middle 33% of the color scale was grayed out.

Figure 3. Structural image averaged across all 25 subjects, showing all voxels with stronger fMRI signal [$t(24)=3.375$, $p<.0025$, uncorrected] for preparation periods that led to insight solutions than for preparation leading to noninsight solutions. Brain images show (left to right) axial, sagittal, and coronal images (with left hemisphere on left of axial and coronal images) centered on clusters (circled) of significant size, i.e., larger than 1000 mm^3 (no clusters of significant size showed the reverse pattern). For each region, graphs on right show average fMRI signal change (in percent signal) induced by the preparation period, which lasted from 2 to 8 sec, as indicated by bottom range. The blue line shows signal related for insight (I) preparation, pink shows signal related to noninsight (NI) preparation (both with SE bars), and the green line shows the subtraction (I-NI). Analyses identifying significant voxels tested the contrast within the 4 TRs highlighted in the yellow shaded region (i.e., TR ending at 6 sec through TR ending at 12 sec), which corresponds to the expected peak signal for the preparation period. (For comparison, the preceding button press elicited peak signal in motor cortex at 4 sec in these graphs). The four clusters illustrated in brain images and for which signal is graphed are: (A) left posterior M/STG, (B) anterior cingulate cortex, (C) posterior cingulate cortex, (D) right posterior M/STG.





