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New approaches to demystifying insight

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After a person has become stuck on a problem, they sometimes achieve a clear and sudden solution through insight – the so-called *Aha!* experience. Because of its distinctive experience, the origins and characteristics of insight have received considerable attention historically in psychological research. However, despite considerable progress in characterizing insight, the underlying mechanisms remain mysterious. We argue that research on insight could be greatly advanced by supplementing traditional insight research, which depends on a few complex problems, with paradigms common in other domains of cognitive science. We describe a large set of mini-insight problems to which multiple methods can be applied, together with subjective reports to identify insight problem-solving. Behavioral priming and neuroimaging methods are providing evidence about what, where, and how neural activity occurs during insight. Such evidence constrains theories of component processes, and will help to demystify insight.

Introduction

Almost everyone has had the '*Aha!*' experience when solving a problem. After working for some time on a vexing problem, the solution comes in a sudden and unexpected flash. Most of these insights are rather minor events, such as a solution to a crossword puzzle. However, there are many anecdotes – indeed, some might say a mythology – about insights involved in the solution of far more complex and important problems, such as Kekule's discovery of the ring structure of benzene [1] and Poincaré's discoveries in mathematics [2].

The scientific understanding of insight has grown sporadically for almost a century. Supplementing traditional research with newer paradigms from the recent advances in neuroimaging would put the field in position to make another leap forward in our understanding of insight. In this article we discuss several limitations in the way insight research is typically done, which present difficulties for using certain paradigms. These limitations include inconsistent efforts to determine whether insight has occurred, the assumption that 'insight problems' produce insight solutions, and the use of small numbers of problems. We offer a novel approach to illustrate what might be gained by attempts to overcome these limitations.

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What is insight?

The term 'insight' is used to designate the clear and sudden understanding of how to solve a problem. Insight is thought to arise when a solver breaks free of unwarranted assumptions, or forms novel, task-related connections between existing concepts or skills.

Most researchers accept insight as *subjectively* different from trial-and-error or algorithmic problem-solving. Despite these subjective differences, a persistent debate surrounds whether insight represents a distinct type of problem-solving involving at least some distinct cognitive mechanisms, or is merely an epiphenomenon based on the same cognitive mechanisms as non-insight solutions [3–5]. The two sides of the debate have been described as the 'Special-Process' and 'Business-as-Usual' views [6].

Most insight researchers subscribe to the 'Special-Process' view, suggesting that insight involves unique processes [7]. For example, representational-change theory proposes that insight occurs when the solver reinterprets or re-represents the problem by relaxing self-imposed constraints and/or decomposes chunked items in the problem, processes not necessary for non-insight solutions [8,9]. However, others subscribe to the 'Business-as-Usual' view arguing that insight and non-insight solutions are attained with precisely the same cognitive mechanisms. For example, progress-monitoring theory proposes that solvers try to minimize the difference between the current state of the problem and the goal state. Insight occurs only when the solver realizes that the distance to the goal is unachievable in the remaining moves and that a new set of moves must be sought. Thus, the solver must select a new move rather than form a new representation of the problem. Insight should only occur when the newly considered move brings the goal within a person's capacity to look ahead from the current state to the goal state [10,11].

Limitations of classical insight research

Has insight occurred?

Examining the literature makes it clear that although different theories of insight exist, there is no clear way to compare their predictions, especially given that they often address different components of the insight process.

There is widespread agreement within both 'Special-Process' and 'Business-as-Usual' camps that insight solutions differ from non-insight solutions in a number of ways:

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(i) solvers experience their solutions as sudden and obviously correct (the *Aha!*)

(ii) prior to producing an insight solution solvers sometimes come to an impasse, no longer progressing towards a solution

(iii) solvers usually cannot report the processing that enables them to overcome an impasse and reach a solution [7,12].

In addition, performance on insight problems correlates with other cognitive abilities that do not correlate with performance on non-insight problems, such as identifying out-of-focus pictures or embedded figures [13].

Despite the agreement regarding how insight and non-insight solutions *typically* differ, there is no consistent set of necessary criteria to show that an individual has experienced insight. Usually the solver is not asked whether she solved a problem with insight – instead insight is assumed because an 'insight' problem was solved.

Inconsistent efforts to determine whether insight has occurred make it extremely difficult to specify the processes necessary to produce an insight solution. The field would benefit from widespread use of an agreed upon operational definition of insight solutions. To illustrate the difficulty, we need only compare two descriptions of insight processes. Ohlsson [14] suggests that the insight sequence is best described as impasse followed by restructuring. However, is reaching an impasse a necessary component of insight? Does one need to restructure a problem to reach an insight? In progress-monitoring theory it is selecting a different move rather than restructuring the problem that leads to insight [10]. It is possible that both theories are correct and that there are multiple ways in which an insight can be produced. However, without an agreed way to determine whether the solution was an insight we cannot assess the predictions of the competing theories.

Which problems produce insight solutions?

A second limitation on insight research is the common assumption that 'insight problems' are always solved via insight. Researchers agree that the insight experience and the solution of 'insight problems' are not identical, yet traditional methods rely heavily on describing differences in solving attempts and success for these insight and non-insight problems [15].

The solution to a problem can be reached through analytic, if complex, non-insight processes, or with insight processes, or through a combination of both. This point is illustrated by the following problem:

> If you have black socks and brown socks in a drawer, mixed in a ratio of 4 to 5, how many socks will you have to take out to make sure that you have a pair of the same color?

This problem is considered a pure insight problem [16] but can be solved without insight if the solver habitually uses a 'What if…' rather than a mathematical strategy. That is, if the solver asks, '*What if I take out a black sock then a brown sock? I would only need one more sock of either color to have a pair of the same color.*' No insight is required.

Furthermore, insight problems do not represent a homogeneous class of problems. They differ on so many levels that it is easier to find differences than commonalities (e.g. working-memory demands, size of problem space). Often, the problems used in studies of insight have been selected simply because they were used as insight problems in a previous study [16].

Chronicle, MacGregor and Ormerod [11] have identified three approaches to defining insight problems, on the basis of: (i) phenomenological features (e.g. problems for which warmth ratings do not increase until immediately before solution [17]); (ii) the necessity for changes in conceptual knowledge for solutions to be found [6,8]; and (iii) the processes underlying problem-solving [10,18].

The conceptual change and process approaches are useful in developing new problems or assessing whether to use certain existing problems. Phenomenological approaches are best used to determine which problems actually produced insight for each individual solver. Therefore, in addition to using well-defined processes to classify specific problems as insight or non-insight problems, researchers should focus on operational definitions of insight that can be applied independently of the problems themselves.

The use of small numbers of problems

Classic insight problems are often so difficult that only a small percentage of participants manage to produce a solution without some assistance (e.g. a hint) or within a reasonable amount of time (e.g. less than 10 min). The reliance on 'classic' insight problems has led to only a small set of problems being used in any given experiment. Participants might be asked to solve only a single problem while their moves and verbal protocols are recorded and analyzed. Although there is much that can be learned from this approach [19], supplementing it with other methods will clearly benefit the field.

Even when multiple exemplars of a given problem [8] are used, it is rare that participants have been asked to attempt more than 15 problems in an experimental session. Small numbers of problems limit both the reliability of data and the variety of techniques – such as neuroimaging, or reaction-time priming – that can be used. Furthermore, the complexity of typical insight problems can lead to the confounding of variables, which hinders the clear decomposition of the component processes of problem-solving. To take advantage of advances in neuroimaging a larger set of problems must be used.

A new framework for investigating insight

We have developed a framework for investigating insight that deals with the above problems. We were motivated by three factors: (1) To develop a model that specifies the processes that are important for insight and link them to neural networks in the brain. (2) To be able to use techniques, such as visual-hemifield presentation, priming measures, and neuroimaging that can reveal objective correlates of solvers' subjective experiences. (3) To develop problems that require the processes specified by the model for solution and could be used with the techniques mentioned in (2). These problems should also be solvable with or without insight.

To test our model (briefly described below) we developed a set of compound remote associates (CRA) problems that could be used in investigating insight (see Box 1). Others have used similar problems but no existing set was large enough for our needs [20–24].

In three of our experiments participants were provided with a description of insight and non-insight experiences and then reported whether they experienced insight on each individual problem. This procedure avoids the issue of *a priori* definitions of insight problems and takes into account the fact that some people might solve a problem with insight whereas others solve the same problem without insight. Although self-reports are subjective, we have tried to provide clear instructions; the fact that participants show similar and distinct behavioral and neural patterns demonstrates that they are using consistent bases for reporting insight. In addition, comparisons between insight and non-insight are not confounded by potential differences in task stimuli independent of the insight/non-insight distinction (e.g. different sets of problems are likely to differ in difficulty).

Having participants make insight judgments is analogous to participants' recognition judgments in the remember/know memory paradigm, in which after making a recognition judgment about an item, the participant is asked whether she actually remembered the prior occurrence of the item, or she just 'knew' that the item occurred before. The subjective experience is used to classify each recognition judgment [25]. Several neuroimaging and ERP studies have used this paradigm to show different brain activations for 'remember' and 'know' judgments.

Box 1. Compound remote associates problems

We have developed a large set of simple problems [31] named compound remote associates or CRA problems, for research on insight. They are patterned after items in the Remote Associates Test (RAT) developed by Mednick [43].

Example

Each of the three words in (a) and (b) below can form a compound word or two-word phrase with the solution word. The solution word can come before or after any of the problem words.

a. french, car, shoe
b. boot, summer, ground
(solutions appear below)

Although RAT items are not as complex as classic insight problems, they exhibit three properties of insight problems (see main text). Specifically, solvers are often misdirected in their solution efforts, cannot report how they overcame an impasse ('*it just popped into my head*'), and have an *Aha!* experience when they achieve solutions. Moreover, performance on the original RAT reliably correlates with success on classic insight problems ([13], P.I. Dallob and R.L. Dominowski, personal communication). Thus, solving RAT-like problems is likely to depend on at least some of the same component processes involved in solving more complex insight problems.

The CRA problems we have developed have several advantages over classic insight problems: They can be solved in a short time, so that many can be attempted in a single experimental session; They have single-word, unambiguous solutions, which make scoring of responses easier; They are physically compact, so that they can be presented in a small visual space or short time span. These features allow for better control and measurement of timing variables (e.g. measuring the time between presentation and solution, controlling timing of hint presentation, or timing of solution presentation for solution-judgment tasks, etc.) and display variables (e.g. position of the problem and/or solution on the screen). These features permit the use of various paradigms (e.g. priming, solution recognition, hemispheric-difference paradigms, and neuroimaging).

(Solutions: a. horn b. camp)

The neurological model

There have been very few attempts to describe the neural correlates of insight [26,27]. Linking the processes proposed to be important in insight to specific brain regions and/or networks thought to carry out these processes will focus theories of insight and lead to a fuller understanding of whether insight is a distinct type of problem-solving. This has been made possible by the increasing use of neuroimaging, especially event-related designs, to study complex cognition [28–30], and the development of insight problems and paradigms amenable to such methods [31–33].

Our model of insight is based on our belief that the processes involved in problem-solving overlap with processes involved in language comprehension; in both situations one must use general knowledge to fill in information missing from the environmental stimulus, the information must be integrated into a coherent unit, much of this processing is unconscious, and the results of this processing must become available to consciousness for output [34,35]. Our model of insight proposes neural mechanisms for the re-representation of a problem and specifies the brain areas in which they take place.

All problem-solving requires a complex cortical network to encode the problem information, to search memory for other relevant information, evaluate this information, apply operators, and so forth. We propose that insight involves a set of problem-solving processes, which largely overlaps with the set of non-insight processes, but with some processes particularly emphasized in, or perhaps unique to, insight. We propose that insight occurs during a confluence of events:

(i) Initial processing of the problem produces strong activation of information that is not related to solution [36], and *weak activation* of information that is critical for solution (so weak that it is unconscious or unavailable for output);

(ii) Processing that leads to solution involves *integration* of problem elements across relations or interpretations that are non-dominant for the individual or contextually non-biased. This integration allows weakly activated concepts or elements to reinforce each other, strengthen, and eventually emerge into consciousness;

(iii) The solver must *switch* the focus of processing to the unconscious activation and select it for consciousness and output. [37]

We have proposed that weak semantic activation of alternative interpretations is more likely to occur in the right hemisphere (RH), whereas semantic activation of the dominant interpretation is more likely to occur in the left hemisphere (LH) [34,38]. According to this framework, the LH uses relatively fine semantic coding, such that when people encounter words, the LH strongly activates a small 'semantic field' of information closely related to the contextually biased interpretation. Although normally effective, this activation pattern makes the LH vulnerable to misdirecting features of insight problems. By contrast, the RH engages in relatively coarse semantic coding, and is therefore more likely to maintain diffuse activation of alternative meanings, distant associations and solution-relevant concepts (as well as misdirected and solution-irrelevant information) [39]. Initially, solvers may be unable to take advantage of weak solution activation – more likely to occur in the RH – because it is weak, and might be blocked or overshadowed by stronger, more focused, but misdirected, activation – likely to be stronger in the LH.

The model assumes that all thinking involves complementary right (RH) and left hemisphere (LH) processes. That is, each hemisphere performs its own computations on input but, because information can be shared between the hemispheres, these processes are not strictly isolated from each other, and each contributes differentially to any complex behavior. We believe that RH processing plays an important role in creative thinking generally and in insight specifically.

Testing the model

Our model proposes differences in the processing performed by each hemisphere. To test this, we started by using visual-hemifield presentation and a priming paradigm (or speed-of-solution decision) for examining what each hemisphere 'knew' about the solution. We are now using neuroimaging techniques to link the proposed processes to their underlying neural networks.

Behavioral findings using the framework

The model predicts that activation of alternative meanings and more distant associations would persist in the RH whereas any misdirected activation would subside. We tested this prediction in a series of experiments. After trying to solve our compound remote associates (CRA) problems, participants read aloud solution or unrelated target words presented to the left visual field/Right Hemisphere (lvf-RH) or right visual field/Left Hemisphere (rvf-LH). (The optic nerves carry input from one visual hemifield to the contralateral hemisphere). Participants showed greater priming (i.e. faster responses to solution target words than to unrelated target words) for solution words presented to the lvf-RH than to the rvf-LH. In a second experiment participants showed a similar lvf-RH advantage for recognizing solutions to unsolved problems. These results demonstrate that in a problem-solving context, solution-relevant information is unconsciously activated before solving the problem, and that such activation is stronger in the RH than in the LH. Our suggestion is that this activation is useful for recognizing, and perhaps producing, solutions to insight problems [32].

We next examined the time course of hemispheric differences in activation of solutions to insight-like problems, by probing for solution-related activation after four different durations of solving effort (from 1 s to 15 s). For unsolved problems, solution activation existed

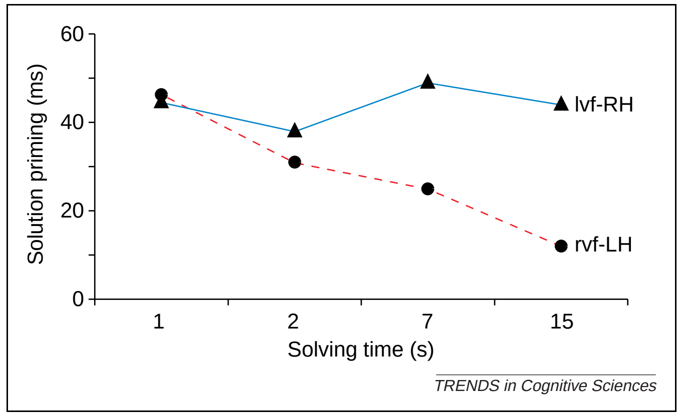

Figure 1. Solution priming effect (i.e. participants read aloud solution words faster than unrelated words) for target words presented to the right visual field-Left Hemisphere (rvf-LH) or to the left visual field-Right Hemisphere (lvf-RH), after 1, 2, 7, or 15 s of solving effort. Participants showed greater solution priming for lvf-RH targets than for rvf-LH targets at all times except 1 s. (Reprinted from [40]. Copyright 2000 Psychonomic Society, Inc.)

initially in both hemispheres, but was maintained only in the RH [40] (Figure 1). Moreover, we demonstrated that the presence and laterality of solution activation is linked to the *Aha!* experience. Following unsolved problems, the participants showed greater priming for solutions that they recognized with insight, according to their own subjective ratings. This association was stronger for solutions presented to the lvf-RH than for those presented to the rvf-LH. These results tie in with the subjective experience of insight to an objective measure – semantic priming – and suggest that people have an *Aha!* experience in part because they already had semantic activation that could lead them to recognize the solution quickly [33].

Neuroimaging findings

These behavioral studies indicated distinct patterns of cognitive processing and hemispheric involvement for recognizing solutions with and without insight. Two neuroimaging experiments were then conducted in which participants solved CRA problems with or without insight [41]. We observed two objective neural correlates of insight. fMRI results revealed an increased signal in the right anterior superior temporal gyrus for insight relative to non-insight solutions (Figure 2). This effect probably does not reflect merely emotional responses to insight solutions, because the same area showed an increased signal during initial solving efforts. Additionally, scalp EEG recordings revealed a sudden burst of high-frequency (gamma-band) neural activity in the same region just before insight, but not non-insight, solutions.

A second EEG finding was that, about 1.5 s before insight solutions, there was a sudden increase in power in the alpha-band frequency, suggesting a decrease in neural activity, over right visual cortex (Figure 3). These effects are not attributable to emotional responses, because the neural activity preceded the solutions. We concluded that solvers abruptly change the focus of their solving efforts just before insight solutions, allowing solution information that linked the various problem elements to emerge suddenly into consciousness.

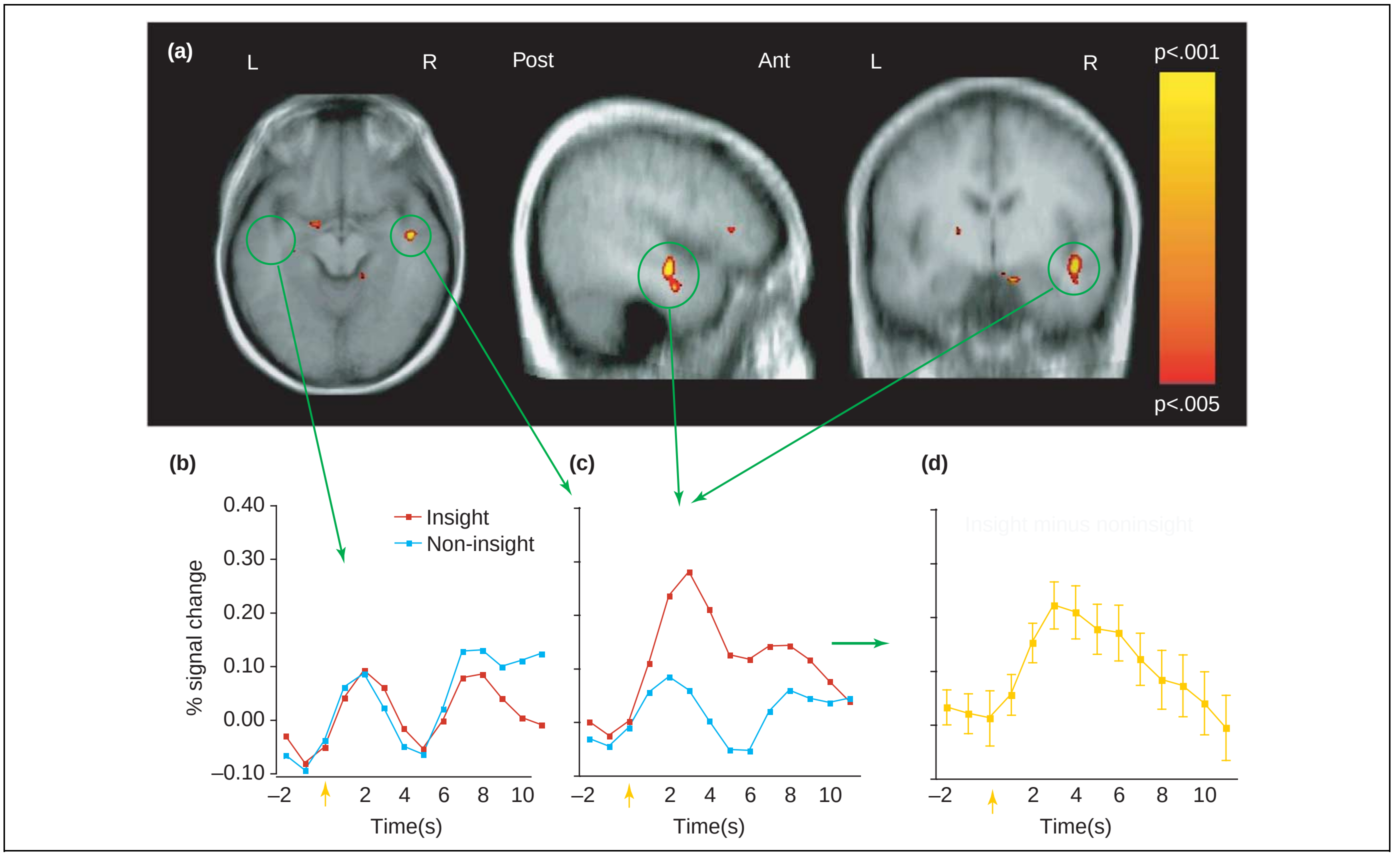

Figure 2. fMRI activation for insight versus non-insight problem-solving in the right-hemisphere anterior superior temporal gyrus (RH-aSTG) **(a)** Voxels showing greater fMRI signal for insight compared with non-insight solutions, overlaid on the averaged normalized structural image of all subjects. The active area has a volume of 531 mm3 (peak t=4.89 at x,y,z coordinates 44, 9, 9 in Talairach space). **(b,c)** Group average signal change following the solution event, for insight (red plot) and non-insight (blue plot) solutions (yellow arrow indicates button press): **(b)** over entire LH-aSTG region; **(c)** over entire RH-aSTG region. **(d)** Insight-solution signal change minus non-insight-solution signal change, in RH-aSTG (error bars show the standard error of the mean of the difference at each time point). (Reprinted from [41]).

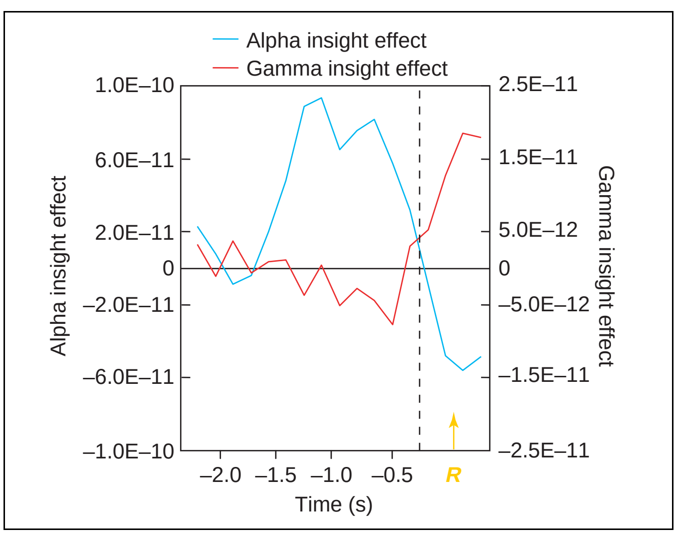

Figure 3. The time course of the EEG insight effect. Alpha power (9.8 Hz at right parietal-occipital electrode PO8) and gamma power (39 Hz at right temporal electrode T8) for the insight effect (i.e. correct insight solutions minus correct non-insight solutions, measured in units of volts^2). The left *y*-axis shows the magnitude of the alpha insight effect (blue line); the right *y*-axis the gamma insight effect (red line). The *x*-axis represents time (in seconds). The yellow arrow and R (at 0.0 s) signify the time of the button-press response. Note the transient enhancement of alpha on insight trials (relative to non-insight trials) before the gamma burst. (Reprinted from [41]).

Summary

'Insight' occurs when someone solves a problem or discovers a solution path, by a sudden breakthrough. It has proven difficult to determine precisely the mechanisms underlying insight, partly owing to limitations of traditional insight research.

Where some aspects of cognition involve mostly continuous processing, with insight at least some information is transmitted from one stage to another (or to output) in a discrete manner [18,42]. As such, insight is similar to a large domain of cognition including perception and language processing (e.g. metaphors, garden-path sentences, jokes, etc.).

Although all problem-solving relies on a largely shared cortical network, our research suggests that the sudden flash of insight occurs when solvers engage distinct neural and cognitive processes that allow them to see connections that previously eluded them. It would not have been possible to carry out these experiments using classic insight and non-insight problems. We therefore developed a model task using a large set of problems, each of which could be solved in a short time and with or without insight, and which could be used in priming, visual-hemifield, and neuroimaging paradigms. We also used participants' reports of insight to classify solutions rather than categorizing the problems *a priori*.

Box 2. Questions for future research

- Will our findings transfer to other types of problems, such as problems in the visual domain?
- Is the right superior temporal gyrus the 'insight area' of the brain? This is probably too simplistic, but what other areas of the brain are likely to be important for insight?
- What can be learned by investigating the relations between individual differences in attention, mood, and so forth, and the probability of insight occurring?
- Is the '*Aha!*' of self-discovery qualitatively different from the '*U-Duh!*' of having the solution presented to one?

We are not advocating the abandonment of classic insight problems, nor are we suggesting that CRA-like problems be used for all insight research. We are advocating that the standard techniques and problems used for insight research be supplemented with other techniques and problems, our model task being one example.

Likewise, we advocate the use of solvers' judgments of insight along with attempts to link them to objective indications of insight. Of course overt subjective measures are always vulnerable to demand characteristics; however, they have been used to great benefit in psychophysics and memory research [25] and we believe they will continue to be valuable in insight research.

A better understanding of the brain bases of insight will help constrain theories about the processes involved – thus helping to demystify insight (see also Box 2). Supplementing traditional research with newer paradigms would put researchers in position to make another leap forward in our understanding of insight.

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