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Abstract

Two accounts of insight problem solving dominate the current literature: the 'special-process' theory (e.g., Bowden, Jung-Beeman, Fleck, & Kounios, 2005) which attributes insight to implicit processes of spreading activation that are localised in the right hemisphere, and the 'business-as-usual' theory (e.g., MacGregor, Ormerod, & Chronicle, 2001), which proposes that both insight and non-insight problems draw on the same analytic mechanisms, which are verbally-based and left-hemisphere localised. We report an experiment in which participants tackled complex and simple insight tasks (Compound Remote Associates) whilst engaging in articulatory suppression (AS) or whilst thinking aloud (TA). Accuracy and latency data indicate that insight problem solving is hindered under AS requirements. Since AS should not affect implicit spreading activation this finding is difficult to reconcile with the special-process theory, although it would be predicted by the business-as-usual theory since AS would damage verbally-based problem analysis. The data also indicate that TA has a facilitatory effect on solving complex problems. Again, this seems explicable from the business-as-usual perspective since TA can enhance analytic processing, but is less easily accommodated by the special-process theory, which claims that verbalisation should 'overshadow' insight.

Keywords: Insight problem solving; compound remote associates; concurrent verbalisation; articulatory suppression.

Introduction

'Insight' during problem solving arises when an individual who is stuck on a task and unable to make headway suddenly breaks free of their unhelpful thoughts and is able to find a solution (e.g., Kaplan & Simon, 1990). Such insight problem solving appears to have several key features. First, individuals, having spent time reflecting on the problem, reach a point of *impasse* where they are unable to move forwards to achieve a solution, perhaps because of the continued application of misleading or mistaken assumptions (Dominowski & Dallob, 1995). Second, the insight into the solution seems to emerge suddenly – giving rise to the so-called "Aha!" experience – rather than arising as a result of incremental processes that bring people progressively nearer to the solution (Metcalfe & Weibe, 1987; Smith & Kounios, 1996). Third, problem solvers find it difficult to describe the processes that help them to overcome the impasse, perhaps because of the suddenness with which the solution arrives (e.g., Maier, 1931) or because solution processes are simply non-reportable in nature (e.g., Knoblich, Ohlsson, & Raney, 2001).

The Special-Process Theory of Insight

Although researchers have debated whether these three characterising features of insight problem solving are strictly necessary (e.g., Ohlsson, 1992, disputes the notion that complete solutions suddenly become available), there is no doubt that these features have informed the dominant account of insight problem solving in the literature, the so-called 'special-process' theory (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). The special-process theory embraces the idea that insight and non-insight problems invoke different processing mechanisms. Indeed, the core claim of the special-process theory is that insight is driven by the operation of non-reportable processes that function at an implicit, sub-conscious level in order to change the current, unsuccessful representation of a problem into a new representation that can lead to a solution. In this way the special-process theory builds upon Ohlsson's (1984, 1992) 'representational-change' account of insight, which suggests three ways in which a problem's representation may be changed through implicit processes so as to enable solution success: (1) *elaboration* – where new information about the problem is added to the original representation; (2) *re-encoding* – where the problem is reinterpreted in a different, more successful way; and (3) *constraint relaxation* – where self-imposed constraints are relaxed, allowing progress to be made.

Several sources of evidence support the notion of representational change in insight problem solving. For example, insight problems which embody constraints that are difficult to relax because of prior domain knowledge are very hard to solve (e.g., Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, et al., 2001). Studies have also attempted to clarify whether the thought processes that arise before an insightful solution are conscious or unconscious. Bowden and Jung-Beeman (1998) presented participants with yet-to-be-solved problems requiring a single-word solution. Participants were then presented with either the solution word or an unrelated word. Bowden and Jung-Beeman found that participants read the solution word faster than the unrelated word, suggesting that unconsciously participants already knew the solution word before becoming consciously aware of it (see also Siegler, 2000).

Recent neuroimaging research has examined claims for insight problem solving differing from other types of problem solving in terms of neurological activity. Bowden and Jung-Beeman (1998) suggest that to solve insight problems the individual has to retrieve associations that are 'indistinctly related' to features of the presented task. They propose that this type of processing occurs in the right hemisphere, which is capable of coarse semantic coding such as the weak activation of alternative problem associations. In contrast, the left hemisphere is specialised for fine semantic coding, which focuses activation on a single problem interpretation. During insight, fine semantic coding can cause misdirection by concentrating attention on irrelevant problem components such that the solver in unable to see past an initial interpretation to find a solution. Bowden and Jung-Beeman (1998) tested this theory by presenting to each visual field either solution words or unrelated words for unsolved insight problems. Results demonstrated a left visual field (right-hemisphere) advantage for solution-words. Other neuroimaging studies support the idea that insight problem solving involves activation localised in the right anterior superior temporal gyrus (Bowden et al., 2005). In addition, EEG recordings have revealed a sudden burst of high frequency (gamma band) neural activity in the same region immediately *preceding* insight solutions. It seems that solvers change the focus of their efforts just before insight, thereby allowing previously non-reportable, right-hemisphere solution-information to emerge into consciousness (Bowden et al., 2005).

The Business-as-Usual Theory of Insight

Notwithstanding the wide range of experimental and cognitive neuroscience evidence supporting the special-process theory of insight, a number of theorists argue for a contrary position. They claim that insight and non-insight problems – whilst clearly differing in terms of key features such as their tendency to induce an impasse state – are still tackled and solved using equivalent cognitive mechanisms (e.g., Weisberg, 2006). Those who adopt what Bowden et al. (2005) refer to as this 'business-as-usual' approach emphasise the role of strategies such as means-ends analysis and hill-climbing (Newell & Simon, 1972) in leading to the step-by-step attainment of insight solutions.

An example of the business-as-usual approach is the 'progress-monitoring theory' developed by MacGregor, Ormerod, and Chronicle (2001; Chronicle, Ormerod, & MacGregor, 2004). This theory proposes that solvers aim to minimise the difference between their current 'problem state' and the 'goal state' regardless of whether a problem is an insight or non-insight task. Accordingly, insight is simply the realisation that a goal state is not achievable with the remaining available moves such that the solver must devise new moves to obtain the solution (perhaps using knowledge acquired during the previous solution attempt) rather than forming a novel *representation* of the problem (as in the representational-change account). According to progress-monitoring theory insight should arise whenever a newly considered move or set of moves allows the solver to look ahead from the current state to the goal state.

Rationale and Aims of the Experiment

As we noted earlier, the evidence supporting the special-process account of insight is compelling. Nevertheless, we also see merit in the arguments of the business-as-usual view. In particular, it seems likely that problem solvers will at least initially try to tackle insight and non-insight tasks using similar strategies since they are not presented to participants pre-labelled as 'insight' or 'non-insight' problems. As such, we acknowledge that notions such as progress monitoring and the application of analytic strategies need to be given serious consideration in any attempt to develop a comprehensive framework for understanding insight. As Bowden et al. (2005) note, it may well be the case that both special-process and business-as-usual theories are correct, and that there are multiple ways in which insight can be produced.

The experiment that we report aimed to inform the debate as to whether insight problem solving relies primarily on unconscious and non-reportable processes (the special-process view) as opposed to conscious and reportable processes (the business-as-usual view). The insight tasks that were used in the experiment were *compound remote associates* or CRA problems that are patterned on items in the Remote Associates Test (RAT) pioneered by Mednick (1962). Each CRA involves presenting participants with three words (e.g., 'apple', 'family', and 'house') and requiring them to produce a solution word that can form a well-known compound word when combined with each of these three items. In this example the solution word 'tree' would form the following, familiar compounds: 'apple-tree', 'family-tree', and 'tree-house'.

Although CRAs are not as complex as classic insight problems, Bowden et al. (2005) argue that they nevertheless exhibit the key features of insight tasks in as much as: (1) participants are often misdirected in their initial efforts at finding a solution such that they encounter an impasse state; (2) participants frequently comment that they arrive at solutions suddenly and have an *Aha!* experience; and (3) participants typically find that they are unable to report how they overcame the impasse in order to generate the correct solution. In addition, CRAs have key advantages over standard insight tasks in that they possess a single unambiguous solution that can be generated in a relatively short timeframe such that many problems can be attempted in an experimental session. Furthermore, CRAs are highly amenable to empirical study using time-based measures of solution latencies that may be highly informative when examining theories of insight. Our experiment capitalised on these advantageous aspects of CRAs and involved obtaining data on both solution latencies and solution frequencies.

In an attempt to inform the special-process versus business-as-usual debate we set up an experiment involving three within-participants conditions. The first was a control condition where participants worked silently on the target insight problems to provide a baseline measure of performance. The second condition required participants to engage in a concurrent 'articulatory suppression' (AS) task (i.e., repeating aloud a short number sequence). The third condition involved a concurrent 'thinking aloud' (TA) requirement, whereby participants verbalised all thoughts passing through their minds. We also included a second within-participants factor which entailed a problem-complexity manipulation (i.e., half the presented problems were relatively complex and half were relatively easy) since it is possible that only the more challenging problems (i.e., ones that have a greater likelihood of inducing an impasse state) would provide informative data relevant to understanding the processes underpinning insight.

What might the two opposing insight theories predict in relation to the secondary-task manipulation? First, we examine predictions for the business-as-usual theory. In the AS condition the repetition of a number sequence will draw on the same phonological working-memory resources necessary for fluent verbal analysis and active maintenance of problem elements. This competition for verbal working-memory resources should disrupt insight problem solving, leading to longer decision latencies and potentially lower success rates compared with the control condition. Such disruption should be especially marked on the more complex CRAs, which would require a broader search of the problem space to find a correct word associate as well as maintenance of information about multiple failed solution attempts so as to avoid their repetition. In the TA condition the requirement to provide a concurrent account of thinking should be minimally disruptive according to the business-as-usual account since people are simply reporting verbally-based information codes that would normally be heeded during the solving of CRA problems (cf. Ericsson & Simon, 1993). It is even possible that thinking aloud could have a beneficial effect on solution latencies and frequencies since there is evidence that verbalisation can help solvers maintain a focus on task goals and strategies (Chi, 2000).

Next we examine the predictions of the special-process theory and show that they are essentially the converse of those derived from the business-as-usual theory. In the AS condition, the requirement to articulate a well-known number sequence should not adversely affect the implicit, non-reportable processes of spreading activation that are assumed to arise in the right hemisphere in order to achieve task success. As such, solution latencies and frequencies should not be hindered to any significant degree in the AS condition. Indeed, it is possible that AS may serve to dampen down the fine semantic coding activity of the verbally-oriented left hemisphere, thereby making it easier for the products of gross semantic coding in the right-hemisphere to shine through into consciousness, thereby speeding up solutions and improving accuracy.

The TA condition is also intriguing from the special-process perspective. In particular, previous research has found that thinking aloud during insight problem solving can hinder successful performance, giving rise to a so-called 'verbal overshadowing' effect (Schooler, Ohlsson, & Brooks, 1993). Verbal overshadowing of insight has been claimed to arise because verbalisation directs attention toward aspects of the problem that can easily be verbalised, but which are inappropriate for finding solutions (Fleck & Weisberg, 2004). At the same time, the implicit, non-verbalisable processes that promote insightful solutions are neglected owing to the predominant need to maintain an ongoing verbal report (Schooler et al., 1993). In sum, the special-process theory predicts that TA verbalisation should increase solution latencies and potentially reduce solution frequencies. Such effects should be more marked on harder CRAs (which are more likely to be associated with impasses) than easier CRAs, which may be solved without an impasse state being reached.

Method

Participants

An opportunity sample of 30 participants was recruited on a volunteer basis from undergraduate students at Lancaster University (15 males, 15 females; mean age = 34 years; SD = 11.16 years). All participants were right handed and spoke English as their first language.

Materials

Seventy-two compound remote associate (CRA) problems were derived from the set of 144 developed by Bowden and Jung-Beeman (2003). Using their normative solution-time data we classed 36 problems as 'easy' (mean solution latencies < 15 s) and 36 as 'difficult' (mean solution latencies > 15 s). Pilot testing of these CRAs revealed that a few words were unfamiliar to participants owing to the use of American vocabulary. To overcome this, American words were exchanged for the English equivalents (e.g., 'garbage' was replaced with 'rubbish'). Twelve easy and 12 difficult problems were allocated to each of the three experimental conditions on a random basis. During the experiment these problem sets were systematically rotated across conditions so as to feature in each condition an equal number of times. Problem-presentation order was independently randomised for all participants. Five CRAs of mixed difficulty were also selected from Bowden and Jung-Beeman (2003) as practice items. All CRAs were displayed sequentially on a laptop PC and response latencies were measured contingent on the participant pressing a space bar prior to registering their solution.

Design

This experiment employed a 3 x 2 repeated-measures design. The first factor was secondary-task condition with three levels: control, articulatory suppression (AS), and think aloud (TA). The second factor was problem complexity with two levels: easy versus difficult. The control condition required participants to solve the CRAs silently without the imposition of a secondary task. The AS condition required the continuous repetition of the sequence '1-2-3-4-5-6' at a rate of 1 number per second, concurrent with problem solving. The TA condition required participants to verbalise all thoughts, including tactics they were employing, details of presented words they were focusing on and information on words they were considering as candidate solutions. Complete counterbalancing of the secondary-task conditions was carried out to control for order effects. The dependent variables were response latencies (in seconds) and total accuracy scores for complex and easy problems.

Procedure

Participants were given instructions that provided an overview of the experimental conditions and task requirements, including the importance of responding as quickly and as accurately as possible (Note: If 30 s elapsed during a trial then the problem was replaced with a blank screen and the participant's latency was scored as 30s for that trial). The five practice problems were administered before testing began so that participants could gain familiarity with the experimental procedure. None of the practice trials involved a secondary task. All trials began with a central fixation cross presented on the screen, followed by the three words of the CRA problem presented simultaneously in a horizontal orientation, followed by the appearance of a blank screen either after 30 s or after participants had pressed the space bar to register their solution. Response latencies were measured from problem presentation to the point where the participant pressed the space bar or when the trial timed out. After the solution had been registered the participant pressed the space bar again to initiate the next trial. If the participant could not produce a solution they were instructed to move on to the next trial. Participants in the control condition were required to solve the problems without any secondary task. Participants in the AS condition had to generate a solution whilst simultaneously repeating the well-leaned number sequence. Those in the TA condition had to provide a concurrent verbal report of their problem solving behaviour. If participants stopped verbalising (TA condition) or articulating (AS condition) they were prompted to continue after a couple of seconds.

Results

Solution Accuracy

Mean accuracy data (Table 1) were examined using a 2 x 3 repeated-measures ANOVA. This revealed a significant main effect of secondary-task condition, $F(2, 58) = 31.85$ $MSE = 1.84$, $p < .001$, $\eta_p^2 = 0.52$, with accuracy being greater in the control and TA conditions relative to the AS condition. There was also a significant main effect of problem complexity, $F(1, 29) = 6.37$, $MSE = 1.93$, $p = .017$, $\eta_p^2 = 0.18$, with accuracy being greater with the easier problems than with the complex problems. Finally, there was a reliable condition by complexity interaction, $F(2, 58) = 20.97$, $MSE = 1.70$, $p < .001$, $\eta_p^2 = 0.42$.

Table 1: Mean accuracy data (maximum score per condition = 12; SDs in parentheses).

	Secondary-Task Condition		
	Control	TA	AS
Easy	10.33 (1.33)	8.73 (1.48)	8.13 (1.66)
Complex	8.37 (1.81)	9.97 (1.10)	7.00 (2.02)

We explored this interaction using simple main effects analyses. The simple main effect of secondary-task condition on the easy problems was significant, $F(2, 58) = 17.57$, $p <.001$. Bonferroni tests ($\alpha = .05$) revealed that accuracy was significantly greater in the control condition (10.33) than in the TA condition (8.73) and AS condition (8.13). These results indicate that secondary-task requirements were disruptive to solution success with the easy problems. The simple main effect of secondary-task condition on complex problems was also significant, $F(2, 58) = 34.14$, $p < .001$. This time Bonferroni tests indicated a different pattern of results, with accuracy in the TA condition (9.97) and control condition (8.37) being significantly greater than in the AS condition (7.00), and with accuracy in the TA condition also being greater than in the control condition. Thinking aloud thus enhances performance with complex problems, but hinders performance with easy problems; the AS requirement hinders performance with both easy and complex problems.

The simple main effects analyses conducted to examine the effect of problem complexity at each level of secondary-task condition confirmed this interpretation of the interaction. The simple main effect of problem complexity for the control condition was as expected: complex problems showed less accurate performance (8.37) than easy problems (10.33), $F(1, 29) = 22.66$, $p < .001$. The simple main effect of problem complexity for the TA condition was significant, $F(1, 29) = 12.80$, $p = .001$, with complex problems actually being more accurate (9.97) than easy problems (8.73). Finally, the simple main effect of problem complexity for the AS condition was significant, $F(1, 29) = 11.24$, $p = .002$, with easy problems being more accurate (8.13) than complex problems (7.00).

Solution Latencies

Incorrect or non-existent responses were scored as taking the maximum permissible time (30 s). Solution latencies for all conditions (Table 2) approximated a normal distribution (no skew values exceeded +/-1.5), therefore natural time data were subjected to a 2 x 3 repeated-measures ANOVA. This revealed a significant main effect of secondary-task condition, $F(2, 58) = 75.53$, $MSE = 7.81$, $p < .001$, $\eta_p^2 = 0.72$, with responses being fastest in the control and TA conditions and slowest in the AS condition. There was a significant main effect of problem complexity, $F(1, 29) = 11.98$, $MSE = 6.69$, $p = .002$, $\eta_p^2 = 0.29$, with easy problems being solved faster than complex problems. There was also a reliable condition by complexity interaction, $F(2, 58) = 38.13$, $MSE = 5.02$, $p < .001$, $\eta_p^2 = 0.57$.

Table 2: Mean solution latencies in seconds (with SDs in parentheses).

	Secondary-Task Condition		
	Control	TA	AS
Easy	12.74 (3.14)	15.56 (3.05)	18.30 (2.79)
Complex	16.48 (3.19)	12.79 (3.43)	21.32 (2.49)

Simple main effects analyses were conducted to unpack the interaction. The simple main effect of secondary-task condition on the easy problems was significant, $F(2, 58) = 37.42$, $p < .001$. Bonferroni tests ($\alpha = .05$) indicated that the control condition (12.74) had reliably faster latencies than the TA condition (15.56) and the AS condition (18.30), and that the latencies in the TA condition were also faster than the AS condition. The simple main effect of secondary-task condition on the complex problems was also significant, $F(2, 58) = 82.75$, $p < .001$, but this time Bonferroni tests revealed that latencies in the TA condition were significantly faster (12.79) than in the control condition (16.48) and AS condition (21.32). In addition, latencies in the control condition were significantly faster than in the AS condition. In summary, these analyses parallel and extend what was observed with the accuracy data. First, the TA requirement does not disrupt performance with the complex problems, and, in fact, enhances the speed of responding relative to the other conditions. Second, the TA requirement impacts negatively on response latencies for the easy problems. Third, the slowest responding in all conditions is associated with the AS requirement.

The final simple main effects analyses examined the influence of problem complexity at each level of secondary-task condition and confirmed the previous interpretation of the interaction. The simple main effect of problem complexity for the control condition was as predicted, with complex problems showing longer latencies (16.48) than easy problems (12.74), $F(1, 29) = 34.82$, $p < .001$. The simple main effect of problem complexity for the TA condition was significant, $F(1, 29) = 18.24$, $p < .001$, with easy problems (15.56) actually taking longer to solve than complex problems (12.79). The simple main effect of problem complexity for the AS condition was significant, $F(1, 29) = 31.52$, $p < .001$, with complex problems (21.32) taking longer to solve than easy problems (18.30).

General Discussion

The experiment was undertaken in an attempt to inform the ongoing debate as to whether insight problem solving relies primarily on implicit, unconscious and non-reportable processes (the special-process view; e.g., Bowden et al., 2005) as opposed to explicit, conscious and reportable processes (the business-as-usual view; e.g., MacGregor et al., 2001). We used a mix of complex and easy compound remote associate tasks (CRAs) as our target insight problems and manipulated the presence of a concurrent secondary task: thinking aloud (TA) versus articulatory suppression (AS) versus control. We predicted that the resulting patterns of impaired and facilitated problem-solving performance arising from this secondary-task manipulation would provide novel evidence to help arbitrate between competing theories. Although our findings were more subtle than we had anticipated, we argue below that they seem broadly supportive of the business-as-usual theory, and appear to be less readily explicable from the special-process perspective.

We begin by assessing the results for the complex CRAs, since our findings here concur very neatly with the predictions that we derived from the business-as-usual theory of insight. This theory would predict that the AS requirement should hinder performance, since competition between these verbally-based tasks for limited verbal working-memory resources should disrupt the application of conscious, analytic processes when tackling the CRAs. Our findings showed that problem solving for the complex CRAs was reliably slower and less accurate in the AS condition than in all other conditions, as predicted. The special-process theory has difficulty explaining these findings since the AS requirement should have little impact on the operation of unconscious, non-reportable processes based around spreading activation of implicit associations.

In terms of the impact of the TA requirement on complex problems, the business-as-usual theory would predict either no detrimental affect on performance since people are simply articulating the verbal codes that they are heeding anyway, or perhaps some benefit to performance since thinking aloud may help metacognitive strategies and the maintenance of a clear task focus (Chi, 2000). The evidence supports the notion of a facilitation effect, since problem solving was both significantly faster and more accurate in the TA condition than in all other conditions. A further, striking observation was that under TA requirements problem solving was, in fact, faster and more accurate for the complex problems than for the easy problems. The special-process theory would have considerable difficulty accommodating the facilitatory impact of thinking aloud on insight problem solving. This is because special-process theorists embrace the idea that concurrent verbal reporting should 'overshadow' insight by focusing attention on ineffective reportable processes to the determinant of effective, non-reportable processes (Schooler et al., 1993).

Turning to the easy CRAs the results indicated that solution speed and accuracy were disrupted under both AS and TA requirements. These findings can again be accommodated by the business-as-usual theory as follows: The easy problems are straightforward (i.e., control performance was highly accurate and fast) such that they are far less likely than the complex problems to induce a state of impasse. Since these problems would normally be solved easily then *any* form of secondary-task imposition – whether AS or TA - will have a detrimental affect, slowing performance and disrupting solution accuracy. In effect, silent working would be the optimal way to solve these easy problems as quickly and effectively as possible. We acknowledge that this explanation is post hoc, but it does seem to have merit, with the essential point being that the easy CRAs that we used may not, in fact, be insight problems at all, just straightforward cued-recognition tasks that are sensitive to any competing attentional demands. As for the special-process theory, then the worse performance under TA requirement with the easy CRAs could be taken as evidence for verbal overshadowing, but it remains very odd that verbal overshadowing was reversed with the complex problems. In addition, the performance disruption caused by AS on the easy CRAs does not seem to be interpretable from this perspective.

Finally, we recognise that the evidence for thinking aloud facilitating insight with complex CRAs seems difficult to reconcile with findings in the literature indicating a strong verbal-overshadowing effect on insight tasks (e.g., Schooler et al., 1993). One possibility is that tasks that succumb to verbal overshadowing are quite different to the verbally-based CRAs used in the present case. For example, Schooler et al.'s study used primarily *visuo-spatial* insight problems that did not involve verbal components. Maybe insightful solutions to such visuo-spatial tasks do indeed require the application of non-reportable processes localised in the right hemisphere that are sensitive to overshadowing through concurrent TA verbalisation. We have recently explored this issue (Ball, Cook, Gilhooly, & Gundry, 2009) and have found good support for special-process predictions: TA hindered insight on the visuo-spatial problems that we used (as per the verbal-overshadowing hypothesis), whereas AS significantly improved insight. This evidence supports Bowden et al.'s (2005) proposal that the special-process and business-as-usual accounts may both have a role to play in explaining insight. We suggest that one theory may be better able to accommodate processing phenomena seen with verbal problems, whilst the other theory may more readily explain findings associated with visuo-spatial problems.

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