Attention and Working Memory in Insight Problem-Solving

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Abstract

Individuals differ in their ability to solve insight problems. We suggest that differences in attention switching and working memory skills underlie differences in insight problem solving ability. We consider the results of an experiment that shows that correct performance on a range of insight problems is related to correct performance on measures of attention-switching and working memory storage and processing, but not to measures of selective attention and sustained attention. We discuss the implications of the results for understanding the component processes in insight problem solving.

Keywords: Insight; problem-solving; individual differences; attention; working memory.

Introduction

Suppose you are asked to describe how to throw a ping-pong ball so that it will travel a short distance, come to a dead stop and then reverse itself (Ansburg and Dominowski, 2000). You are not allowed to bounce it off any surface or tie anything to it. Some individuals solve the problem readily. Others never do. Some people suggest putting a back-spin on the ball (which will not work), or throwing it to another person (which violates the requirement for the ball to stop and return by itself). Although the problem initially seems impossible, there is a simple answer. Throw the ball straight up in the air and gravity will cause it to stop for an instant before falling back to earth. Many people assume that the ball must travel forward and back but once they realise it can also go up and down, the solution follows readily (Murray and Byrne, 2005a). Why do individuals differ in their ability to solve insight problems? Our aim in this paper is to consider some of the component skills upon which insight problem solving depends (see also Murray and Byrne, 2005b).

Insight problems usually require some kind of change to the initial interpretation of the problem and its anticipated solution (Weisberg, 1995). For example, in the ping-pong ball problem, a successful solution requires a change from a horizontal trajectory to a vertical one. People must possess some knowledge to solve insight problems, for example, knowledge about the effects of gravity. Insight problems tend to be 'ill-defined', that is there is some ambiguity about what the problem requires, or what form the solution will take. They are often more difficult to solve than they at first appear and sometimes the solution occurs suddenly to the solver in an 'aha' moment (e.g. Duncker, 1945).

One view is that solving insight problems may not require different processes from solving non-insight problems such as mathematics problems (Weisberg & Alba, 1981; review in Mayer, 1995). Another view is that there are key differences between the two sorts of problems (e.g., Metcalfe and Wiebe, 1987). For example, participants can more accurately predict their future success given a second chance at an unsolved non-insight problem compared to an unsolved insight problem. Their ratings of how close they feel to a solution when they work on a non-insight problem exhibit an incremental pattern as they neared a correct solution, but for insight problems it remained uniformly low until a sudden increase just before the solution (Metcalfe and Wiebe, 1987). Many studies have identified empirical differences between insight and non-insight problems (Schooler, Ohlsson and Brooks, 1993; Lavric, Forstmeier and Rippon, 2000; Gilhooly and Murphy, 2004; Jung-Beeman, Bowden, Haberman, Frymiare, Arambel-Liu, Greenblatt, Reber and Kounios, 2004).

Our aim is to consider the component skills required in insight problem-solving. We have suggested that people need to keep in mind several alternative possibilities to solve insight problems (Murray and Byrne, 2005a). Individuals may have difficulty in keeping in mind alternatives because multiple possibilities can exceed their working memory capacity (Byrne, 2005; Johnson-Laird and Byrne, 1991; 2002). They also need to be able to switch their attention between the alternative possibilities to reach a solution. On this account, key component skills required in insight problem solving include attention switching and working memory skills. To test this view, we examined a range of insight and non-insight problems. We measured attention switching, sustained attention, and selective attention, and several aspects of working memory, including working memory storage and working memory storage plus capacity.

Attention and working memory may be crucial for different aspects of successful insight problem solving. Planning a number of moves in advance may be important to solve insight problems such as the well-known nine-dot problem (Chronicle, Ormerod and MacGregor, 2001). Attention may play a role in helping people to decide what elements of a problem to focus on or in helping them to direct the search for relevant information internally and externally. Successful insight problem-solvers are more likely to switch strategies when they realize their current strategy is not working (Davidson, 1995). Some studies have suggested that directing people's attention to a particular element of a problem can improve performance (e.g. Glucksberg and Weisberg, 1966) and people who pay more attention to peripherally presented information make better use of that information in a subsequent task (Ansburg and Hill, 2003).

We measured attention switching skills by using two tasks: the visual elevator task, taken from the Test of Everyday Attention battery (Robertson, Ward, Ridgeway & Nimmo-Smith, 1994) requires participants to count the floors an elevator passes, switching from counting up to counting down. The plus-minus task (Miyake, Friedman, Emerson, Witzki and Howerter, 2000) requires participants to change from adding three to numbers to subtracting three from other numbers. We hypothesized that individuals who correctly solve insight problems will perform well on these measures of attention switching.

We also measured selective attention and sustained attention. We measured selective attention by using the map search test, from the Test of Everyday Attention battery (Robertson et al, 1994) which requires participants to find all the symbols for a restaurant on a detailed area map, within a time limit. The participant has to ignore other symbols as well as distracting information such as place names and topographical information. We measured sustained attention, by using the Sustained Attention Response Task (Robertson, Manly, Andrade, Baddeley and Yiend, 1997), which measures how successful people are at inhibiting an automatic response when a target appears. A series of numbers are presented very quickly and the participant must press a button when each number appears except when that number is three, and instead they must refrain from responding. We hypothesized that individuals who correctly solve insight problems would not perform well on these measures of selective and sustained attention (see Murray and Byrne, 2005b for details).

We measured working memory storage capacity by using the digit span task which requires participants to memorize a sequence of numbers. We measured working memory storage plus processing capacity by using the sentence span task which requires participants to process information in a sentence as well as memorizing the last word of that sentence. We hypothesized that individuals who correctly solve insight problems would perform well on these measures of working memory storage and processing capacity. To ensure a clear measure of the role of working memory during the problem-solving process, we asked participants to work on solving each problem without recourse to any memory aids such as pen-and-paper.

We examined attention and working memory for both insight and non-insight problems and we consider the results for insight problems here (see Murray and Byrne, 2005b).

Method

There were 33 participants who were undergraduates from Trinity College, University of Dublin and they were paid 10 euro for one hour. They received eight insight problems that required a single insight to reach solution, half of them were action problems, such as the ping-pong problem described earlier, and other half were 'conundrum' problems (e.g., how can a man marry twenty women in one town without breaking any law? The man did not divorce and all the women are still alive). We also gave them four well-defined, non-insight problems, such as an algebra problem (for details of the problems see Murray and Byrne, 2005b).

Participants also received four attention tasks and two working memory task as follows:

Attention switching: visual elevator The task measures the ability to switch attention from counting upwards to counting downwards. Participants must follow the journey of an elevator, as represented on a test card, by counting the floors as it goes up and down. There were two practice trials followed by ten timed test trials. The dependent measures were an accuracy measure of how often the participant ends on the correct floor after a trial and a time measure based on the total time taken for correct trials divided by the number of switches in counting direction needed in those trials. This measure gives an indication of how long it took the participant to switch between counting strategies. Both measures were then transformed to scale scores according to the participant's age as described in the test manual for the Test of Everyday Attention Battery (Robertson et al, 1994).

Attention switching: plus-minus The task measures switching between the strategies of addition and subtraction (Miyake et al, 2000). Participants were given a sheet of paper with three columns of 30 numbers each. The numbers used were all the two digit numbers, with each number from 10 to 99 used once only, and randomly mixed to form the three columns. In the first column, participants added the number three to each number in the column and wrote the answer in the space next to it; in the second column, they subtracted and in the third column they alternated between addition and subtraction. The dependent measures were the time cost of switching by subtracting the mean time of the first two columns from the time on the third column, and an accuracy measure based on the errors each participant made. Where a mistake in the plus-minus alteration occurred, this switching error was counted as one error rather than counting each number that was incorrect as a direct result of the incorrect switch.

Selective attention: map search Participants are asked to find all the knife-and-fork symbols on a detailed map of Philadelphia. They have two minutes to circle as many as they can (maximun 80). The task aims to measure how distracted participants are by the other information on the map, such as other symbols and place names, by how many symbols they can find in the time limit. The dependent measure is how many symbols are found within the time limit, which is then scaled according to the participant's age as prescribed in the test manual (from the Test of Everyday Attention Battery, Robertson et al, 1994).

Sustained Attention Response Task This computer-based task requires participants to make a response (press the spacebar) every time they see a number, except when that number is three in which case they have to withhold the response. We wrote a random sustained attention response task program in Superlab (based on the details given in Robertson et al, 1997). A total of 225 single digits were presented, 25 of which were the target number three. Each number was presented for 250msec followed by a 900msec mask. Participants were told that they could still respond while the mask was on the screen if they had not had time to respond to the number. Before commencing the test trial each participant did a practice trial consisting of eighteen digits, two of which were targets. The dependent measure was the number of targets to which the participants responded when they should have withheld a response.

Working memory: digit span This task is taken from the WAIS-R (Weschler, 1981) and measures the storage capacity of working memory. Participants were asked to recall ever-increasing strings of digits read out by the experimenter. The participants had to recall each string of a given length in a forward direction for two trials. The experimenter read out a practice three-digit sequence before starting. The forward sequence started with three single digits up to a maximum of nine digits with two trials of each length. When all forward trials were completed, participants attempted to recall strings of numbers in reverse. The backward sequence was similar to the forward sequence but started with two digits up to a maximum of eight. Participants were given one point for each string correctly recalled. The procedure used was that described by the WAIS-R Manual and testing was halted if a participant made an error in two consecutive trials of the same length. The dependent measure was the number of correctly recalled strings with a maximum possible score of 28. This score was then scaled according to the age of the participant in keeping with the procedure advised in the WAIS-R manual.

Working memory: sentence span This task was used to measure the capacity of working memory when both processing and storage of information was required (Sub, Oberauer, Wittman, Wilhelm and Schulze, 2002). Participants were asked to rate a series of sentences as true or false and, in addition, to remember the last word of each sentence within a block. The task was presented on a computer using a Superlab program. All sentences were easily true or false and no longer than seven words. The last word of each sentence was always a singular noun between one and three syllables in length. The sentences took the form “The letter k is a vowel” to which the participant responded by pressing a key to indicate if the sentence was true or false. Each sentence was displayed for three seconds and if no true/false response had been given within that time a prompt appeared for one second, giving participants four seconds in total to read the sentence and indicate true or false. Participants started with a practice trial of two sentences and after that attempted two blocks of three sentences eventually increasing to two blocks of six sentences. At the end of each block, participants had to recall the last word of each sentence in that block, in order. Before each trial participants were told how many sentences would be in the following block. As with the digit span, testing was halted if participants made errors in two consecutive trials of the same length. The dependent measure was the total number of words recalled correctly up to a maximum of 36.

During the experiment participants were first presented with the insight and non-insight problems one at a time and were not allowed to write while attempting to solve the problems. Participants were tested individually and said aloud their answers to the experimenter when they were ready, within a two minute time limit. Scores on the twelve problems were compared with performance on the four measures of attention and two measures of working memory. All participants started with the insight problems, the order of which was randomized for each participant. The other tasks were then given in the following order: non-insight problems (in random order), visual elevator, digit span, map search, plus-minus task, sentence span, sustained attention response task.

Results

The mean proportion of insight problems that participants solved correctly was .52. (SD = .28). The mean scores of the attention and working measures are summarized in Table 1. The results corroborated our predictions.

Table 1: Mean scores, standard deviations and correlation values for insight problems with attention and working memory tasks

	Mean	SD	r
Attention switching			
Visual elevator	11.39	2.66	0.515**
Plus-minus	1.56	2.11	-0.511**
Selective attention			
Map search	12.64	3.3	0.23
Sustained Attention			
Response Task	6.58	4.67	-0.079
Working memory			
Digit span	18.29	10.24	0.390*
Sentence span	12.58	3.33	0.511**

Key: * p < .05, one-tailed; ** p < .01, one-tailed

Insight problem solving and attention switching

Individuals who are good at solving insight problems are also good at switching attention. Correct performance on the insight problems was associated with correct performance on the visual elevator task ($r = .515$, $p < .01$). [1] Correct

[1] All correlations are Pearson’s r, n = 33, one-tailed unless otherwise stated.

performance on the insight problems was associated with correct performance on the plus-minus problems ($r = -.511$, $n = 32$, $p < .001$).

Insight problem solving and selective and sustained attention

Individuals who are good at solving insight problems are not necessarily good at tasks requiring selective or sustained attention. Correct performance on the insight problems was not related to correct performance on the selective attention map search task ($r = .023$, $p = .449$). Correct performance on the insight problems was not related to correct performance on the sustained attention response task ($r = -.079$, $n = 31$[2], $p = .336$), as Table 1 shows.

Regression Analysis

We also analyzed insight problem score as the dependent variable in a regression analysis with all the attention and working memory measures. From a stepwise regression, the most efficient model that emerged accounted for nearly 72% of the variance in insight problem score. The predictor variables were: greater accuracy on the plus-minus task ($\beta = -.439$, $p < .01$), greater capacity on the digit span task ($\beta = .498$, $p < .01$), greater accuracy on the visual elevator task ($\beta = .420$, $p < .01$) and more time taken to switch on the plus-minus task ($\beta = .248$, $p < .05$). The adjusted R square was .717 and the model was significant ($F[4,23] = 18.067$, $p < .01$).

Discussion

Individuals who are good at solving insight problems are also good at working memory storage and processing, as measured by the digit span and sentence span tasks. Solving insight problems may require individuals to keep in mind several alternative possibilities (Murray and Byrne, 2005a, 2005b). Multiple possibilities may exceed working memory capacity (Johnson-Laird and Byrne, 2002). Consistent with this account individuals who are better at storing and processing information in working memory are better at solving insight problems. Individuals who are good at solving insight problems are also good at switching attention, as measured by accuracy in the visual elevator and plus-minus tasks. Solving insight problems may require individuals to switch their attention between the alternative possibilities they have in mind in order to reach a conclusion. Consistent with this account, individuals who are better at switching attention are also better at solving insight problems. Individuals who are good at solving insight problems are not necessarily good at focusing their attention or sustaining their attention, as measured by the selective attention map search task, and the Sustained Attention Response Task. The results have implications for theories of insight problem solving. The results suggest that there may not be a single 'insight skill' but that the ability to solve insight problems may rely on a combination of specific executive functions.

[2] Scores for two participants on this measure were lost as a result of a technical error.

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