Executive functions in insight *versus* non-insight problem solving: an individual differences approach.

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ABSTRACT

This study investigated the roles of the executive functions of inhibition and switching and of verbal and visuo-spatial working memory capacities in insight and non-insight tasks. Eighteen insight tasks, 10 non-insight tasks and measures of individual differences in working memory capacities, switching and inhibition were administered to 120 participants. Performance on insight problems was not linked with executive functions of inhibition or switching but was linked positively to measures of verbal and visuo-spatial working memory capacities. Non-insight task performance was positively linked to the executive function of switching (but not to inhibition) and to verbal and visuo-spatial working memory capacities. These patterns regarding executive functions were maintained when the insight and non-insight composites were split into verbal and spatial insight and non-insight composite scores. The results are discussed in relation to dual processing accounts of thinking.

INTRODUCTION

Problem solving is a major cognitive function and is essential to achieving goals when no pre-learned solution can be retrieved from memory. Progress has been made in understanding how people solve well-defined problems (such as Tower of Hanoi tasks) in which the starting state, the goal to be reached and the possible actions are presented clearly and unambiguously (Egan & Greeno, 1974). Such well defined problems can be solved by heuristically guided search within the original representation. However, less progress has been made in understanding how solvers tackle tasks that induce misleading problem representations within which solution is impossible and so require re-structuring of the initial representation for solution to occur (Ohlsson, 1992; Weisberg, 1995). Such tasks are generally known as "insight" problems and a typical example of this type of problem is the *Matchsticks problem*: "Given six matches, make four equilateral triangles, with one complete match making up the side of each triangle." Participants generally form an over-restricted representation of the goal and confine their attempts to two-dimensional arrangements. The problem solution cannot be achieved unless the matches are used in three dimensions to form a triangular based pyramid. The Matchstick problem is thus an example of an "Insight" problem since within the typically derived initial problem representation, the goal cannot be reached and a re-structured goal representation, in which matches may be used in three dimensions, is required for solution. In non-insight problems, by contrast, the goal can be reached by search within the initial representation. The Tower of Hanoi task is an example of a "Non-Insight" problem in which the initial representation is adequate to allow solution through sequential search processes.

Explaining how re-structuring occurs is still a major challenge for cognitive theory despite a long history of research from the Gestalt psychologists (e.g., Duncker, 1945) to more recent information-processing approaches (e.g., Ash & Wiley, 2006; Chronicle, MacGregor &

Ormerod, 2004; Gilhooly & Murphy, 2005). Two broad approaches to explaining re-structuring are currently competing. One approach is generally labelled "business as usual" and posits that re-structuring takes place through small incremental and reportable steps that change the initial representation following failures to solve (Fleck & Weisberg, 2004; Weisberg, 2006). The second approach may be labelled "special process" and proposes that re-structuring involves un-reportable processes that operate unconsciously (such as, spreading activation) to change problem representations and lead to phenomenologically sudden solutions (e.g., Schooler, Ohlsson & Brooks, 1993; Ollinger, Jones & Knoblich, 2006). The view that at least some distinct processes are involved in insight as against non-insight problem solving has been supported by a number of studies which we will now briefly outline.

Previous approaches contrasting insight v. non-insight tasks

Metcalfe and Wiebe (1987) found that feeling of warmth judgements regarding imminence of solution behaved differently for insight as against non-insight tasks. In the case of non-insight problems, feelings of warmth predicted closeness to solution but with insight problems, feelings of warmth were unrelated to closeness to solution, suggesting that unconscious implicit processes underlay insight solutions as against non-insight solutions.

Schooler, Ohlsson and Brooks (1993) also found a separation between insight and non-insight problems in that concurrent thinking aloud verbalisation interfered with insight problem solving but not with the non-insight problem solving. This result was interpreted as indicating that insight problems normally involved unconscious non-verbal processes which were over-shadowed by concurrent verbalisation. However, this result has proven difficult to replicate (Fleck & Weisberg, 2004) and may reflect a confounding of spatial and insight factors in the problems used in Schooler *et al*.'s (1993) studies rather than a verbal overshadowing effect for insight problems in general (Gilhooly, Fioratou & Henretty, 2009).

Recent neuroscience studies have also addressed the question of differences in underlying processes between insight and non-insight problem solving using Compound Remote Associates (CRA) items. In these tasks, participants are presented with 3 problem words (*e.g*., *pine, crab, sauce*) and attempt to produce a single solution word (*e.g*., *apple*) that can form a familiar combination with each of the three problem words (*e.g*., *pineapple*, *crab apple, apple sauce*). Bowden and Jung-Beeman (2003) found that when “Insight” was explained to the participants as “a sudden “Aha” experience coupled with a certainty that the solution was right” then participants sometimes reported solving CRA problems “with insight” and sometimes reported solutions “without insight”. In solving CRA items it would seem that solution occurs sometimes through a reportable sequential search procedure of testing possible associates of each word (a “business as usual” process that does not lead to an insight experience as defined by the Bowden and Jung-Beeman, 2003) and sometimes through unconscious and un-reportable processes (leading to an experience of “insight” as defined by Bowden and Jung-Beeman, 2003). Self reported insight solutions were associated with primes sent to the right hemisphere but not with left-hemisphere primes.

Jung-Beeman, Bowden, Haberman *et al*. (2004) reported functional magnetic resonance imaging (FMRI) and electroencephalogram (EEG) studies using CRAs and self reports of insight or non-insight based solutions. It was found that self-reported insight solutions were associated with increased activity in the right anterior superior temporal gyrus as compared to non-insight solutions. The same brain area showed increased EEG activity beginning shortly before insight solutions were reported compared to when non-insight solutions were reported. This work suggests that there are differences in underlying neural activity between solving CRA problems with and without self-reported insight experiences.

Further empirical support for the division of problems as insight v. non-insight was obtained in a study by Gilhooly and Murphy (2005) that reported a cluster analysis of problem solving scores for 24 insight and 10 non-insight tasks. Results based on the correlations of performance over problems indicated that insight problems did tend to cluster with other insight problems and similarly non-insight problems tended to cluster with other non-insight problems.

Dual processing approaches and insight problem solving

Recently, *dual processing* approaches to thinking, which have strong relevance for the nature of insight problem solving processes, have been developed by Sloman (1996), Stanovich and West (2000), Kahneman (2003), Evans (2003, 2005, 2008) and others. These approaches have typically divided processes into two groups associated with two distinct processing systems, frequently labelled System 1 and 2. Generally, System 1 is seen as relatively old in evolutionary terms and very similar between humans and other animals, automatic, implicit, not constrained by working memory limitations and as generating fast, intuitive responses. System 2, on the other hand, is seen as evolutionarily new and as special to humans. This system underlies abstract reasoning and hypothetical thinking, operates relatively slowly and sequentially, is limited by working memory capacity, and is correlated with general fluid intelligence. Evans (2008) has pointed out that the processes put together as deriving from "System 1" are somewhat heterogeneous and include for example, encapsulated processes for perception, as well as reflexive responses and acquired but automated processes. Evans (2008) argued that it would be more fruitful to conceptualise two Types of processes as against two systems. Type 1 processes are fast, automatic and unconscious while Type 2 processes are seen as slow, effortful and conscious (Samuels, 2009). Type 2 processes are impaired by dual task activity, Type 1 processes are not. Such interference by dual tasks is an indicator of the involvement of working memory as conceptualised by Baddeley (2000, 2003, 2007). The concepts of Type 2 processes and working memory are closely interrelated and evidence for working memory involvement in a given task can be taken as an indication of Type 2 processes being involved in the same task. A number of dual task and individual difference studies have implicated working memory and hence Type 2 processes, in a range of non-insight tasks such as Tower of London problems (Gilhooly *et al*., 2002, 1999; Phillips *et al*., 1999) and syllogisms (Gilhooly *et al*., 1993; 1999).

Approaches to insight which regard re-structuring as requiring explicit, executively demanding processes would predict that Type 2 processes would be clearly implicated in insight problem solving. For example, Kaplan and Simon (1990) proposed that insight resulted from explicit search at the level of problem representations and so implicate executively loading Type 2 processes. In contrast, the original Gestalt analyses of insight (Humphreys, 1951; Kohler, 1969) proposed automatic processes which resolved "stresses" inherent in misleading representations and so led to useful representations free from internal stresses. For example, Maier (1931, p. 193) stated that: "The perception of the solution of a problem is like the perceiving of a hidden figure in a puzzle picture. In both cases (a) the perception is sudden, (b) there is no conscious intermediate stage; and (c) the relationships of the elements in the final perceptions are different from those which preceded, i.e., changes of meaning are involved." Ohlsson (1992) and Schooler *et al*. (1993) argued that insight solutions result from automatic, implicit, non-executive processes such as spreading activation. Also, Jung-Beeman *et al*. (2004) proposed that insight "…involves seeing a problem in a new light, often without awareness of how that new light was switched on." (p.14). These views stressing the role of automatic, unconscious, implicit processes in insight problem solving suggest that Type 2 processes would not be as heavily implicated in insight problem solving as in non-insight problem solving. However, although the role of Type 2 processes in non-insight tasks has been extensively documented through individual difference and dual task studies of working memory involvement, the role of Type 2 processes in insight tasks has not been extensively examined until recently.

Previous results regarding insight and executive loading

Gilhooly and Murphy (2005) found a relationship between insight problem solving and the Figural Fluency task (Phillips, 1997). In this task a page is filled with boxes containing five dots in a pentagonal shape; participants design a different figure in each box by joining two or more dots with straight lines and are asked to complete as many figures as possible in a one minute period. The Figural Fluency task is generally regarded as an executively loading task which involves inhibition of dominant responses and switching of bases of responses. Thus, Gilhooly and Murphy's result supported the possible involvement of the Type 2 processes of switching and inhibition in insight problem solving. Similarly, Murray and Byrne (2005), in a study using 8 insight tasks, reported correlations between insight problem solving and measures of attentional switching and of working memory storage capacity. However, this study did not include a contrasting set of non-insight problems. Fleck (2008) contrasted 4 insight and 4 non-insight problems and found links between working memory span (which does require attentional control) and non-insight problem solving, and between insight problem solving and simple short term storage (which does not require attentional control). Fleck concluded that these results supported theories of re-structuring in insight which do not involve attentional control and so Fleck concluded in favour of a smaller role for Type 2 and a larger role for Type 1 processes in insight v. non-insight problem solving. Lavric, Forstmeier and Rippon (2000) drew a similar conclusion from a dual task study which found less interference from a concurrent counting task for insight problems than for non-insight problems. Ash and Wiley (2006) contrasted insight problems with large and small search spaces. In problems with large search spaces many initial moves and move sequences were possible and would have to be explored before an impasse triggering re-structuring would be encountered. With the small search space problems, the initial representation allowed very few or no moves and so impasse and re-structuring would be reached sooner. Ash and Wiley found that individual differences in ability to control attention (as indicated by working memory spans which involve attentional control) were not associated with solving small space insight problems but were associated with solving larger space insight problems. The results were interpreted as supporting automatic (Type 1 process) accounts of re-structuring since small space problems only required re-structuring, while large space problems required search plus re-structuring.

Present study

The present paper reports a further examination of the possible contributions of specific Type 2 executive processes to insight problem solving compared with non-insight problem solving. The "special process" approach to insight problem solving would predict less involvement of executive Type 2 processes in insight as against non-insight problems. On the other hand, the "business as usual" approach would suggest similar degrees of involvement of Type 2 processes in both types of problem. In broad terms, it may be argued that all problems involve an initial structuring stage followed by a search stage during which interim results of possible steps are held in working memory while further possible steps are generated. In non-insight problems these stages, which would seem to draw largely on Type 2 processes, are sufficient for solution. In Insight tasks, when search fails repeatedly within the initial structuring, solvers need to engage in a re-structuring stage. Thus, involvement of Type 2 processes may be expected in both types of problem during searching through possible actions. However, according to the "special process" view of re-structuring, Type 2 processes would play smaller role in insight tasks than in non-insight tasks, as the crucial re-structuring stage in insight problem solving is seen, on this view, as involving Type 1 automatic processes. If the "business as usual" view of re-structuring in insight problem solving is more accurate, and re-structuring is largely dependent on Type 2 processes, then a similar degree of involvement of Type 2 processes should be found between insight and non-insight problem solving.

It may be noted that the present study is based on a generic view of working memory rather than on any one specific detailed model. As Baddeley (2003) pointed out, while there are many approaches to the study of working memory (e.g., see Miyake & Shah, 1999; Conway, Jarold, Kane, Miyake & Towse, 2007), most theories agree on the essence of working memory being a system of limited attentional capacity (executive system) linked to more peripherally based storage systems (typically, verbal and visuo-spatial stores are distinguished, at a minimum). The work here is based on the broad consensus view of working memory as indicated by Baddeley (2003) and assumes that Type 2 processes in problem solving draw on executive functions.

Previous individual difference studies have tended to use relatively broad measures of executive functioning, such as Figural Fluency (Gilhooly & Murphy, 2005) and working memory span (Ash & Wiley, 2006); Murray & Byrne, 2005; Fleck, 2008; Gilhooly & Murphy, 2005). These measures are broad in that performance on such tasks is underlain by a number of more specific factors. Thus, Figural Fluency is thought to tap both switching and inhibition and working memory span involves attentional control as well as storage. The present study examined relatively specific and so purer measures of particular executive processes (*viz.*, inhibition and switching). These specific functions were examined because both seemed likely candidates for roles in re-structuring in that re-structuring would arguably involve inhibiting previous interpretations of the task materials and switching to new interpretations. The up-dating function identified by Miyake *et al*. (2000), in addition to inhibition and switching, was not examined in the present study as Miyake *et al*. found up-dating to be linked to working memory capacity as against problem solving, as exemplified in their study by the Tower of Hanoi problem and the Wisconsin Card Sorting Task, which were linked to inhibition and switching respectively.

Since both insight and non-insight tasks require temporary storage of possible results of imagined actions while generating further possible results, storage aspects of working memory were expected to be implicated in both types of tasks. The study reported here involved both predominantly verbal and spatial content tasks and so measures of both verbal and visuo-spatial working memory spans were taken. The division of problems into spatial and verbal is supported (i) by Gilhooly and Murphy’s (2005) finding that individual differences in vocabulary were associated with better performance on verbal insight tasks and differences in spatial flexibility were associated with better performance on spatial insight tasks and (ii) by Sio and Ormerod’s (2009) meta-analytic report on incubation studies that indicated different processes underlying verbal and spatial insight tasks.

Previous studies have tended to use rather small sets of problems (Ash & Wiley, 2006; Fleck, 2008; Murray and Byrne, 2005) and small samples of participants (Murray & Byrne, 2005). The present study involved larger samples of tasks (18 insight and 10 non-insight, detailed below) and of participants (N = 120) than have generally been employed.

METHOD

Problem tasks

The problems used here were largely drawn from a set investigated in a previous study in which Gilhooly and Murphy (2005) reported a cluster analysis that supported the distinction between insight and non-insight problems. It was also found in that study that individual differences in vocabulary were associated with better performance on tasks classed as verbal insight and differences in spatial flexibility were associated with better performance on tasks classed as spatial insight tasks. These findings support the distinction drawn in later analyses between spatial and verbal insight problems.

The *insight problems* were as follows: *Inverted Pyramid* (On a steel table is a 50-pound note. On the note is a large steel pyramid which is balanced upside down. Remove the note without upsetting the pyramid. Ohlsson, 1992.); *X ray* (A patient has an inoperable tumour in the middle of his body. A ray machine destroys tissue as well as tumours. How can the ray machine be used to destroy the tumour without damaging healthy tissue? Duncker, 1945); *Triangle* (Given a diagram of circles arranged in a triangle shape with 1 in top row then 2, 3, and 4 in lower rows, how can you move 3 circles to make the triangle point the other way? Schooler et al, 1993); *Pound Coins* (Why are 1992 pound coins worth more than 1991 pound coins?, after Dominowski, 1994.); *Football scores(* Joe Fan has no psychic powers but he can tell you the score of any football game before it starts. How? Dominowski, 1994*); Marriage.* (A man in a small town married 20 different women of the same town. All are still living and he never divorced. Polygamy is unlawful but he has broken no law. How can this be? Dominowski, 1994); *Matchsticks.* (Given a diagram showing 6 matchsticks lying on a table, make 4 equal sided triangles. Ohlsson, 1992); *Pigpen problem* (9 pigs are kept in a square pen. Build 2 more square enclosures that would put each pig in a pen by itself , Schooler , Ohlsson & Brooks, 1993); *Farm problem* (How could you divide an L shaped piece of land into 4 equally shaped pieces of equal sizes? Metcalfe, 1986a.); *Matching socks* (There are black and brown socks in a drawer mixed in a ratio of 4 to 5. How many socks would you have to take out without looking to be sure of getting a pair of the same colour? Sternberg, 1986); *Murples problem* (There is a container of Murples. The Murples double in number every day. The container will be full in 60 days. In how many days will it be half full? After Sternberg and Davidson, 1983); *Candle problem* (You have a candle , some matches and a box of tacks. How can you support the candle on the wall? Duncker, 1945.); *Trains and bird problem.* (Two trains 50 miles apart start towards each other at 25 mph. As the trains start a bird flies from the front of one train towards the second. On reaching the second train the bird turns round and flies back to the first train and so on until the trains meet. If the bird flies at 100 mph how many miles will the bird have flown before the trains meet? Posner, 1973); *Earth in hole problem* (How much earth is there in a hole 3 ft by 3 ft by 3 ft? Dominowski, 1994.); *Horse trading problem*. A man buys a horse for £60, sells it for £70, buys it back for £80 and sells it finally for £90. How much has he made? Dominowski, 1994; *Ocean liner problem* (At 12 noon a porthole in an ocean liner was 9 ft above the water line. The tide raises the water at a rate of 2 ft per hour. How long will it take the water to reach the porthole? Dominowski, 1974); *Reading in dark*.(A man is reading a book when the lights go off but even although the room is pitch dark the man goes on reading. How? Dominowski, 1994); *Lake problem.* (Someone walked for 20 minutes on the surface of a lake without sinking but without any form of floatation aid. How? Dominowski, 1994).

Non-insight problems were as follows: *Tower of London (*Manipulate 5 disks on pegs to match target configuration in minimum moves, Gilhooly *et al.*, 1999*); Syllogistic reasoning* (Given two categorical premises draw necessary conclusion, e.g., Gilhooly *et al*., 1999); *Hobbits and orcs* (Given a boat that can only take 2 creatures, how can you get 3 hobbits and 3 orcs across a river in such a way that the hobbits are never outnumbered by the orcs on either side? Thomas, 1974.) *Tower of Hanoi* ; (Given 4 discs stacked in decreasing size on a peg and 2 empty pegs move the discs to a target peg, 1 at a time, in such a way that a larger disc is never placed on a smaller disc, Egan & Greeno, 1974); *Dinner party problem.* (Given 5 guests with specified food aversions and a list of foods construct a menu all could eat, Schooler *et al.*, 1993); *Cards problem.* (Given 3 cards on table face down , from limited information identify which suit each card is, Schooler *et al*, 1993); *Heavy and light coins*. (Given 4 coins of which 2 are slightly heavy and 2 slightly light but which look and feel identical, how could you find which are which in 2 weighings on a balance scale? Schooler *et al.*, 1993); *Anagrams*. (Unscramble 8 five-letter word anagrams, Gilhooly & Johnson, 1978); *Raven's Progressive Matrices* (Raven, 1960). Participants worked through the booklet as far as they could within a 20-minute time limit. In this task, the items consist of visual patterns that are related by some rule and the participant has to identify the rule. The rules concerned vary markedly in complexity; *Latin Square task* (Birney *et al*., 2006). This is similar to the matrices task in that rules must be inferred to complete spatial patterns.

Working memory and executive function measures

Two measures of verbal working memory were used (Sentence and Operation Span).

Sentence span,(Baddeley, Logie, Nimmo-Smith and Brereton, 1985). Participants were read a series of statements, and had to state whether each was true or false, and then recall the final word of each sentence in the correct order. Participants heard two sets of two sentences to start with, then two sets of three, and so on up to eight. The stimulus sentences were read out from sheets on which the participants responses were also recorded. Span was measured as the maximum sequence length at which participants correctly recalled all the words in at least one of the trials. Such span tests (*c.f.* Daneman and Carpenter, 1980) are seen as reflecting central executive resources (since they require appropriate attentional control and switching) as well as storage.

Operation span. (Conway & Engle, 1996). In this task participants remember target items while performing a concurrent arithmetic task. The number of targets in a trial set varied between two and five, with three trials at each size.

Two measures of visuo-spatial working memory were used (Visual Pattern Span and Corsi Blocks).

Visual pattern span. Participants were required to recall grid patterns (Della Sala, Gray, Baddeley, Allamano and Wilson, 1999) with filled squares ranging from 2 to 15. Each pattern was presented for two seconds and participants were given as much time as required to complete each trial.

Corsi blocks. This was a computerised version of Corsi's (1972) nine block spatial span task. The sequences ranged from three to nine blocks, with two trials at each sequence length. The participant was seated in front of the computer monitor with the first practice trial on screen. They were instructed that certain of the blocks would light up in sequence and then the word 'recall' would appear on the screen. Participants then had to tap the blocks with the light pen in the same order as they lit up on the screen. There were three practice trials. Block selected and time taken to select each block was recorded. The task was automatically terminated when a participant had made errors in each of the two trials of a particular span. Again, span was measured as the maximum sequence length at which participants reproduced at least one sequence correctly.

Two measures of inhibition were used (Colour and Number Stroop).

In the *Colour Stroop* condition (based on Ward, Roberts & Phillips, 2001), participants were presented with a 44 item list made up by eleven repetitions in random order of the four words "Red", "Green", "Blue" and "Yellow" each of which was printed in colours different from the colour named by the word. The participants' task was to name each colour as quickly as possible. In the Colour

Stroop control condition, 44 strings of five Xs printed in different coloured inks, 4 of each possible colour, were used and the task was to name aloud the colour of each string as quickly as possible

In the *Number Stroop* task (Morton, 1969), participants were presented with a 36 item list made up by nine repetitions in random order of sequences of length 1 to 4 made up of strings of 1s, 2s, 3s, and 4s such that the length of a string was never equal to the kind of digit comprising the string. The participant's task was to name the length of each string as quickly as possible. In the Number Stroop control condition the strings were made up of the symbols "*", "&", "%" and "@" and the task was to report the length of each string as quickly as possible.

In both Stroop tasks the time taken in the control condition was subtracted from that in the Stroop condition to indicate time cost of inhibiting the dominant response and hence a low score indicated more effective inhibitory functioning.

Two measures of switching were used (Arithmetic and Number-Letter Switching).

In the *Arithmetic Switching* task (Spector & Biederman, 1976) participants were presented with three lists of 30 two-digit numbers. In one list the task is to add 3 to each number, in a second list to subtract 3 from each number and in the third list to alternate between adding and subtracting 3.

In the *Number-Letter Switching* task (Spector & Biederman, 1976) participants were presented with three lists of 30 letter-number pairs. In one list the task is to report whether the number is odd or even, in a second list the task is to report whether the letter is a vowel or consonant and in the third list the task is to alternate between reporting the category of the letter or the number.

In both tasks, the average time required for the non-alternating (non-switching) lists was subtracted from the time required for the switching list to measure switch cost. A smaller switch cost was taken to indicate more effective executive switching functioning.

Participants

120 students at the University of Hertfordshire were tested. Participants were between 18 and 35 years of age (mean age = 22.64 years, sd = 6.38); 68 were female and 52 were male. Participants were paid £20 for participation.

Procedure

Each insight and non-insight problem was presented on a separate sheet of paper and participants were allowed time to read through each problem once followed by 4 minutes within which to attempt a solution. The order of presentation of the problems was varied over participants and was such that problems of a similar type did not follow each other immediately.

Participants were not allowed to use blank sheets of paper to make notes in working on the tasks. In the Hobbits and Orcs, the Triangle, the Tower of London and the Tower of Hanoi problems, concrete versions of the tasks were provided to work with. For all the other tasks participants were allowed to ask questions to which only a “Yes” or “No” answer was provided. Participants were asked to propose solutions as soon as they could and time to solution was recorded.

RESULTS

Analyses of the problems were based on solution proportions in all cases. The individual difference measures were used to investigate whether insight and non-insight problem solving scores were predicted equally well by measures of inhibition, switching, and working memory capacities which were taken to be indices of Type 2 processes. If individual difference measures show different patterns of relationships to insight and non-insight problems, this would suggest that distinctive processes and capacities are involved in tackling the different kinds of problems.

Individual difference analyses

Distributional data on the Stroop costs, the switching costs, the verbal and visuo-spatial working memory measures are given in Table 1.

The raw scores on the two Stroop, the two switching, the two verbal and the two visuo-spatial working memory measures were converted into standard scores and averaged to give composite measures of inhibition, switching, verbal working memory and visuo-spatial working memory respectively for the analyses reported below.

INSERT TABLE 1 ABOUT HERE

Composite insight task scores for each participant were formed by averaging solution scores over the 18 insight tasks (Cronbach's α = .77). Similar *non-insight task composite scores* were formed by averaging the 10 non-insight task scores (Cronbach's α = .74). The resulting composites were normally distributed and over the 120 participants and correlated with each other (r =.66, df =118, p <.01) indicating moderate overlap but with considerable unshared variance (*c*. 55%). Means and standard deviations of the problem solving scores are given in Table 1.

Table 2 shows the correlations of the cognitive function measures with composite insight and non-insight scores.

INSERT TABLE 2 ABOUT HERE

The pattern of simple correlations of working memory and executive function measures with composite insight scores is similar to that with composite non-insight scores except that switching efficiency correlates with non-insight solving but not with insight problem solving. However, in view of the complex pattern of inter-correlations among the individual difference variables, apparent links may be due to confoundings among the variables. To take account of such inter-correlations and possible confoundings we undertook separate hierarchical multiple regressions of the insight and non-insight composites as dependent variables with the individual difference scores as independent variables. Since it is generally held that working memory span measures tap both storage *and* executive functions, the executive measures were entered in the first stage of the hierarchical analyses and the working memory measures were entered in the second stage. Thus, in the second stage the contribution of working memory storage capacity separate from the contribution of the executive functions of switching and inhibition is assessed.

Hierarchical multiple regression analyses

The results of the hierarchical multiple regression analyses for insight and non-insight composite scores are shown in Table 3.

INSERT TABLE 3 ABOUT HERE

From Table 3, insight problem solving was predicted significantly by visuo-spatial and verbal working memory span while non-insight problem solving was predicted by switching efficiency as well as by verbal and visuo-spatial working memory span scores after executive functions partialled out. This suggests that the two types of problem tasks were differentiated by the extent to which they drew on executive functions, particularly that of switching.

The problems used in this study involved a mixture of predominantly verbal and predominantly spatial tasks. As a check on the generality of the finding that executive processes were more implicated in non-insight than insight tasks the insight and non-insight composite scores were split into verbal and spatial insight and non-insight composites and these measures were then entered as dependent variables in four separate hierarchical regressions. The Verbal insight problems were: Inverted Pyramid, Trains and Bird, Pound Coins, Ocean Liner, Marriage, Matching Socks, Earth in hole, Reading in dark, Lake, Murples, Horse trading, and Football scores. The Spatial insight problems were: Triangle of coins, Pigpen, Farm, Matchsticks, X ray and Candle. The Verbal Non-insight problems were: Syllogisms, Dinner Party, Cards, and Anagrams. The Spatial Non-insight problems were: Tower of London, Hobbits and Orcs, Tower of Hanoi, Ravens Matrices, Latin squares and Heavy and Light Coins.

Descriptive statistics for the verbal and spatial insight and non-insight problem composite scores are given in Table 4 together with correlations between the separate problem solving scores and the individual difference measures of executive functioning and working memory.

INSERT TABLE 4 ABOUT HERE

The results from hierarchical regression analyses of the verbal and spatial insight and non-insight composites are given in Table 5.

INSERT TABLE 5 ABOUT HERE

The regression results in Table 5 are similar to those in Table 3 and indicate that the finding of lack of relationship with executive function scores holds for verbal and spatial insight problems when analysed separately as well as for the overall insight problem solving measure. Similarly, the role of executive processes, especially of switching, holds for verbal and spatial non-insight problems considered separately.

DISCUSSION

This study sought to add to available knowledge regarding the extent to which insight and non-insight problems can be empirically differentiated from each other in terms of the degree of involvement of the specific executive (Type 2) processes of inhibition and switching in solving such problems; and it was intended that the study should thus contribute to the debate between the “special process” (Schooler, Ohlsson & Brooks, 1993; Ollinger, Jones & Knoblich, 2006) and the “business as usual” (Fleck & Weisberg, 2004; Weisberg, 2006) views of insight problem solving. Previous studies had generally contrasted relatively few examples of presumed insight and non-insight problems and the present study used larger sets of problems than had been used in single studies hitherto together with a large sample of participants and so the present results should be reliable compared with those of previous studies.

Hierarchical regression analyses were carried out on composite insight and non-insight scores and on finer measures of verbal and spatial insight and non-insight composite scores. The results of the regressions indicated that for insight problems overall, visuo-spatial and verbal working memory spans, after executive function scores were partialled out, were predictive. However, neither of the executive measures of switching or inhibition contributed to predicting insight problem solving scores. In the case of non-insight problems switching as well as visuo-spatial and verbal working memory spans made contributions to predicting solution scores. This pattern of results held for the overall insight and non-insight composite scores and for the more fine grain separate verbal and spatial insight and non-insight composite scores. Thus, the results reported here provide further behavioural evidence in support of empirical distinctions between insight and non-insight tasks and so add to the differences reported by Metcalfe and Weibe (1987), Schooler *et al*. (1993), Beeman-Jung *et al.* (2004), Murray and Byrne (2005), Gilhooly and Murphy (2005) and Fleck (2008).

We propose that the patterns of loading of non-insight tasks and insight tasks on individual difference measures of Type 2/executive functions differ in interpretable ways. Let us first consider the broad steps that seem to be involved in insight and non-insight problem solving. With both types of problem there is an initial structuring phase in which the problem's starting conditions, goal and possible actions, as given in the problem statement, are represented internally. A second general stage is search within the problem space, which may take the form of means-ends analysis (*i.e*., working backwards from the overall goal to sub-goals and sub-sub-goals and so on) or forward search (*i.e*., exploring alternative action sequences from the starting state onwards). In non-insight problems this search phase can lead to solution; however, in insight problems the initial structuring is misleading and solution cannot be reached without re-structuring of the problem representation. Thus, with insight tasks, only when the correct structuring is reached can the problem be solved; but, given the correct structuring, the solution seems obvious and little or no search is required to solve.

From the above analysis, to solve a non-insight problem, such the Tower of Hanoi, a well controlled search process within the original structuring will generally be necessary and sufficient to reach the solution. Carrying out a well controlled search process should be easier for participants who can exercise good levels of executive control. This is consistent with the present finding that participants who scored well on the executive tasks of switching tended to perform better on non-insight problems than participants who scored less well on the switching tasks. Switching ability was measured by tasks that required participants to alternate between goals over a series of trials, such as alternating adding or subtracting 3 over a series of digits. Ability to switch goals would be helpful in carrying out systematic searches of possible actions in non-insight problems. For example, in the Tower of Hanoi, participants have to frequently switch the currently active goal either from an achieved subgoal up to a higher level goal or from a high level goal to a more concrete subgoal.

In the insight tasks the key step is to achieve an appropriate re-structuring of the problem representation. It could be that strong executive control is actually inimical in such problems. For example, if the person persists in systematically exploring all possible layouts of matchsticks flat on the table in the Matchsticks problem, they may be slower to reach the re-structuring phase than a solver who does not search exhaustively. Regarding the re-structuring phase, previous analyses have differed as to whether re-structuring involves a form of consciously controlled search at the level of representations (Kaplan & Simon,1990; Weisberg, 2006) or rather, spontaneous, uncontrolled processes, such as automatically spreading activation, of which only the final result, the correct representation, is available to consciousness. An example of a consciously controlled search at the level of representations would be deliberately checking each word in the problem statement for ambiguities and considering how different meanings of the same words might lead to different representations (e.g., “married” as “became married to” or as “caused others to become married” in the Marriage problem), It appears from the present results that success in the insight tasks did not draw on the executive functions of switching or inhibition and this is consistent with the view that re-structuring solutions involved spontaneous, implicit, non-executively loading processes. That is to say, the present results support the “special process” view of re-structuring in insight problem solving as against the “business as usual” view. For future work, it may be noted that the present study examined a limited range of executive functions and research could fruitfully explore the possible involvement of a wider range of executive functions, including up-dating (Miyake et al., 2000) and focussing and dividing of attention (Baddeley, 2003).

In view of the present results, the previous finding by Gilhooly and Murphy (2005) of an association of insight solving with the presumed executively loaded task of Figural Fluency may need re-interpretation. Figural Fluency is itself a complex task which is not necessarily a pure measure of executive functioning and it may be that performance on that task also reflects at least some spontaneous, implicit non-executively loaded processes that lead to new directions of work in producing new patterns in the Figural task.

The significant independent contributions of working memory capacity scores to predicting both non-insight and insight solving, after the executive function measures were partialled out, could reflect necessary use of some storage capacity in both types of problem solving, as Fleck (2008) suggested. In both types of problem the internal representation of the problem will generally be complex and must be held in working memory while possible actions or re-interpretations are considered. It is plausible to suppose that for re-interpretation of key elements in the representation to take place, even through unconscious processes, such elements must be present in working memory (e.g., to activate concepts related to the initial interpretation). Thus, the richer the representation of the problem in working memory, the more likely that key elements will be represented in working memory and be available for re-interpretation; so, the greater the working memory capacity the more likely is re-structuring or insight solution to occur. This proposal is consistent with the results here linking working memory capacity to insight problem solving.

It appears that verbal working memory capacity contributed to both verbal insight and verbal non-insight problem solving but not to either type of spatial problem solving. On the other hand, spatial working memory capacity contributed to all types of problem although somewhat more (in terms of β weights) to spatial as against verbal tasks of both types. This suggests that many tasks characterised as verbal may also evoke use of spatial short term storage processes in solving attempts, for example by evoking imagery based strategies.

Overall, the present results support the conclusion, also reached by Fleck (2008), using a different approach, that Type 2 executive control processes play a smaller role relative to Type 1 processes in insight problem solving than in non-insight tasks. Given the special role of re-structuring in insight tasks as against non-insight tasks, these results thus indicate a greater importance of automatic, implicit, Type 1 processes as compared to executively loading Type 2 processes in re-structuring, as suggested by "special process" views of insight problem solving from the early Gestalt theorists (e.g., Maier, 1931) to more recent spreading activation accounts (Ohlsson, 1992; Ash & Wiley, 2006).

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Table 1. Descriptive statistics for individual difference measures of inhibition, switching, verbal and visuo-spatial working memory measures. N = 120.

Measure	Mean	S.D.
Colour Stroop cost (s)	15.05	6.41
Number Stroop cost (s)	1.80	2.49
Switch 3 cost (s)	20.86	14.56
Number-letter switch cost (s)	23.73	18.77
Silly sentence span	3.02	1.05
Operation span	3.32	0.96
Corsi Block span	5.38	1.10
Visual Pattern span	8.82	1.32
Insight composite solution score	0.51	0.19
Non-insight composite solution score	0.65	0.14

Table 2. Correlations among individual difference measures and composite solution scores on insight and non-insight tasks. Variables oriented so that higher scores reflect better problem solving or more effective executive functioning. * $p < .05$; ** $p < .01$; $df = 118$.

	1.	2	3	4	5	6
1.Insight Comp.	-					
2.NonIns Comp.	.66**	-				
3.Inhibition	.12	.15	-			
4.Switching	.15	.26**	.12	-		
5.Vis-Sp Working Mem.	.42**	.49**	.12	.22**	-	
6.Verb. Working Mem.	.40**	.46**	.18*	.22**	.38**	-

Key: Insight Comp. = Composite solution rate score over 18 Insight problems; NonIns Comp. = Composite solution rate score over 10 non-insight problems; Inhibition = Average z-score over 2 Stroop tasks; Switching = Average z-score over 2 Switching tasks; Vis-Sp Working Mem. = Average z-score over 2 visuo-spatial working memory span tests; Verb. Working Mem. = Average z-score over 2 verbal working memory span tests.

Table 3. Hierarchical multiple regressions of individual difference measures on Insight and Non-Insight Composite solution rate scores. Variables oriented so that higher scores reflect better problem solving or more effective executive functioning. ** = *p* <.01, * *p* < .05; N = 120.

		Dependent Variable					
		Insight Composite			Non-Insight Composite		
Entry set	Independent Variable	β Wt.	*t*	R sq	β Wt.	*t*	R sq
1.							
	Inhibition	.09	0.99		.10	1.12	
	Switching	.13	0.13	.03	.24	2.58**	.12
2.							
	Vis-Sp.Working Mem.	.31	3.46**		.37	4.39**	
	Verb. Working Mem.	.26	3.01**	.28	.23	2.68**	.31

Key: Insight Composite = Composite score over 18 Insight problems; Non-Insight Composite = Composite score over 10 non-insight problems; Inhibition = Average z-score over 2 Stroop tasks; Switching = Average z-score over 2 Switching tasks; Vis-Sp Working Mem. = Average z-score over 2 visuo-spatial working memory span tests; Verb. Working Mem. = Average z-score over 2 verbal working memory span tests.

Table 4. Descriptive statistics for verbal and spatial insight and non-insight problem composite solution scores and correlations with individual difference measures. N = 120. ** = *p* <.01, * *p* < .05

			Correlations with individual diff. measures			
Problem solving Measure	Mean	S.D.	Inhib	Switch	Vb WM	Vis-Sp WM
Verbal Insight	0.61	0.19	.14	.12	.37**	.36**
Spatial Insight	0.35	0.26	.08	.12	.28**	.33**
Verbal Non-Insight	0.56	0.16	.17	.34**	.43**	.38**
Spatial Non-Insight	0.72	0.16	.14	.22*	.28**	.41**

Key: Inhib = Average z-score over 2 Stroop tasks; Switch = Average z-score over 2 Switching tasks; Vis-Sp WM. = Average z-score over 2 visuo-spatial working memory span tests; Vb WM. = Average z-score over 2 verbal working memory span tests.

Table 5. Hierarchical multiple regressions of individual difference measures on Verbal Insight and Non-Insight Composite solution scores (A) and Spatial Insight and Non-Insight Composite solution scores (B). Variables oriented so that higher scores reflect better problem solving or more effective executive functioning. ** = *p* <.01, * *p* < .05; N = 120.

A. Dependent Variable

Entry set	Independent Variable	Verbal Insight Composite β Wt.	*t*	R sq	Verbal Non-Insight Composite β Wt.	*t*	R sq
1.							
	Inhibition	.12	1.21		.09	1.10	
	Switching	.10	1.01	.03	.32	3.61**	.11
2.							
	Vis-Sp.Working Mem.	.27	2.88**		.21	2.42*	
	Verb. Working Mem.	.27	2.88**	.20	.28	3.25**	.22

B. Dependent Variable

Entry set	Independent Variable	Spatial Insight Composite β Wt.	*t*	R sq	Spatial Non-Insight Composite β Wt.	*t*	R sq
1.							
	Inhibition	.01	.16		.09	1.06	
	Switching	.12	1.26	.04	.20	2.17*	.05
2.							
	Vis-Sp.Working Mem.	.27	2.78**		.37	3.60**	
	Verb. Working Mem.	.18	1.74	.16	.12	1.34	.20

Key: Verbal and Spatial Insight Composites = Composite scores over 12 and 6 problems; Non-Insight Verbal and Spatial Composites = Composite scores over 4 and 6 problems; Inhibition = Average z-score over 2 Stroop tasks; Switching = Average z-score over 2 Switching tasks; Vis-Sp Working Mem. = Average z-score over 2 visuo-spatial working memory span tests; Verb. Working Mem. = Average z-score over 2 verbal working memory span tests.