Executive processes and working memory in solving insight and non-insight problems.

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Acknowledgement: This work was supported by a grant from the Leverhulme Trust (F/00281D) to KJG.

ABSTRACT

This study aimed to investigate the roles of executive processes of inhibition and switching and 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 and executive functions of switching and inhibition were administered to 120 participants. Performance on insight problems was linked positively to measures of verbal and visuo-spatial working memory storage capacity but not with executive function measures. Non-insight task performance was positively linked to the executive function of switching and to verbal and visuo-spatial working memory capacity. The results are discussed in relation to dual process theories of thinking.

INTRODUCTION

This study aimed to investigate the relative roles of executive processes of inhibition and switching and verbal and visuo-spatial working memory capacities in insight and non-insight problem solving tasks.

First, some key terms will be defined. A *problem* exists when someone has a goal for which they are unable to generate a suitable sequence of actions either from memory or by applying a routine method. To solve a problem requires *representing* the problem situation and goal, followed by *search* for an appropriate sequence of actions within the framework of the initial problem representation. Sometimes success is achieved within the initial representation. In other cases, the initial representation leads to an *impasse* (Ohlsson, 1992) in which progress halts; to break the impasse, the problem representation must be changed or *re-structured* to allow fresh directions of search. A re-structuring that leads to a rapid and complete understanding of how the solution can be reached is often referred to as an *insight.* Phenomenologically, insight is accompanied by an “Aha” experience.

Insight has been studied in laboratory conditions by presenting participants with problems which initially induce misleading problem representations within which solution is impossible. In such cases, restructuring of the initial representation is crucial (Ohlsson, 1992). A classic laboratory example is provided by the *Matchsticks problem*: “Given six matches, make four equilateral triangles, with one complete match making up the side of each triangle.” Participants nearly always adopt an over-restricted representation of the goal and confine their attempts to two-dimensional patterns; however the problem cannot be solved unless the matches are used in three dimensions to form a triangular based pyramid. Thus with the typically derived initial problem representation the goal cannot be reached; with the restructured goal representation, in which matches may be used in three dimensions, solution is possible.

Previous approaches contrasting insight v. noninsight tasks

A number of studies have focussed on examining differences between insight and non-insight problem solving processes. Metcalfe and Weibe (1987) contrasted 5 insight and 5 non-insight problems and found that feeling of warmth judgements (i.e. how close participants felt to solution) behaved differently for presumed insight as against non-insight tasks. With non-insight problems, feelings of warmth predicted solution imminence but with insight problems, feelings of warmth were unrelated to solution. Schooler, Ohlsson and Brookes (1993) in a study contrasting 3 insight and 4 non-insight problems, also found a separation between insight and non-insight problems in that concurrent thinking aloud verbalisation interfered with the former but not with the latter. This result was interpreted as suggesting that insight problems normally involved non-verbal processes which were over-shadowed by concurrent verbalisation.

Jung-Beeman, Bowden, Haberman et al. (2004) carried out functional magnetic resonance imaging (FMRI) and electroencephalogram (EEG) studies of people solving Remote Associates Test items. In these problems, 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) had previously found that participants sometimes reported solving such problems "with insight" and sometimes reported solutions were obtained "without insight". Self described "insight" solutions were associated with primes sent to the right hemisphere but not with left-hemisphere primes. ("Insight" was explained to the participants as a sudden "Aha" experience coupled with a certainty that the solution was right.) In the FMRI study it was found that "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 problems with and without insight. It may be noted that in the Jung-Beeman et al. studies, "insight" has been defined in terms of the suddenness of solution rather than in terms of restructuring. In solving an RAT item it would seem that the participant moves from an initial structure where the problem words are unrelated to one where they are tightly related via the solution word, so that re-structuring always occurs in solution, but sometimes through a basically sequential procedure ("noninsight") and sometimes through highly simultaneous or parallel processes (leading to experience of "insight").

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 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 process approaches and insight

Recently, *dual process* approaches to thinking, which are potentially relevant to understanding the differences between insight and non-insight problems, have been developed by Stanovich and West (2003), Kahneman (2003) and others. In these accounts two distinct cognitive systems are proposed. System 1 is seen as automatic, implicit, not constrained by working memory limitations and as generating fast, intuitive responses. This system is assumed to be relatively old in evolutionary terms and is very similar between humans and other animals. It comprises a "*set* of systems in the brain (partially encapsulated modules in some views) that operate autonomously" (Stanovich and West, 2003, p.182) such as reflexes, instincts, innate input modules and processes formed through associative learning. Only the final product of such processes is available to consciousness. System 2, on the other hand, is seen as evolutionarily recent and is peculiar to humans. It permits abstract reasoning and hypothetical thinking, operates relatively slowly and sequentially, is constrained by working memory capacity and is highly correlated with general fluid intelligence and with performance on sequentially solvable non-insight problems in general. System 2 processes are impaired by dual task activity but

System 1 processes are not. Interference by dual tasks is a signature of involvement of working memory as conceptualised by Baddeley (2000) in his very infuential model and the concepts of System 2 and working memory are closely interrelated. System 2 can be seen as incorporating working memory as an integral component system involving both storage and executive control. Evidence for working memory involvement, particularly central executive involvement may be taken as an indication of System 2 involvement. On this basis, dual task and individual difference studies have implicated working memory and hence System 2, in a range of non-insight tasks such as Tower of London (Gilhooly et al., 2002) and syllogisms (Gilhooly et al., 1999).

From a theoretical point of view, System 2 processes would be expected to be strongly implicated in insight problem solving by approaches which regard re-structuring as requiring explicit, executively demanding processes. For example, Kaplan and Simon (1990) proposed that insight resulted from explicit search processes at the level of problem representations. On the other hand, the original Gestalt analyses of insight proposed automatic processes which resolved "stresses" inherent in misleading representations and led to useful representations free from internal stresses. For example, Maier (1931, p. 193) stated: "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." More recently, Ohlsson (1992) and Schooler *et al*. (1993) have argued that insight solutions result from automatic, implicit, non-executive processes such as spreading activation. Similarly, Jung-Beeman et al. (2004) argued that insight "…involves seeing a problem in a new light, often without awareness of how that new light was switched on." (p.14). Such views which stress the role of automatic, unconscious, implicit processes in insight problem solving suggest that System 2 processes would *not* be heavily implicated in insight problem solving. However, although the role of System 2 in non-insight tasks has been extensively documented, the degree of involvement of System 2 in insight tasks was not directly examined until recently.

Gilhooly and Murphy (2005) found a relationship between insight problem solving and the Figural Fluency task (Phillips, 1997) which is generally taken to involve inhibition of dominant responses and switching of bases of responses. This result supported possible involvement of the System 2 processes of switching and/or inhibition in insight problem solving. Similarly, Murray and Byrne (2005) in a study using 8 insight tasks reported relationships between insight problem solving and measures of attentional switching and of working memory storage capacity. However, Fleck (2008) contrasted 4 insight and 4 non-insight problems and found links between working memory capacity and non-insight insight problem solving and between insight problem solving and short term storage rather than with working memory capacity. Fleck concluded that these results supported the spontaneous theory of restructuring in insight, i.e., relatively small role for System 2 and a larger role for System 1 processes in insight v. non-insight problem solving. Ash and Wiley (2006) contrasted insight problems with large and small search spaces and found that individual differences in ability to control attention (as indicated by working memory spans) was not associated with solving small space insight problems but was associated with solution of larger space problems. The results were interpreted as supporting automatic (System 1) accounts of restructuring.

The present paper reports a further examination of the possible contributions of specific System 2/ executive processes to insight problem solving compared with non-insight problem solving. Previous studies have tended to use relatively broad measures of executive functioning, such as Figural Fluency (Gilhooly & Murphy, 2005) and working memory capacity (Ash & Wiley, 2006); Murray & Byrne, 2005; Fleck, 2008; Gilhooly & Murphy, 2005). These measures are broad in that the performance on such tasks will be 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 will examine relatively “pure” measures of individual differences in the executive processes of Inhibition and Switching in relation to insight and non-insight problem solving. The individual difference measures were used to investigate whether insight and non-insight problem solving were predicted equally well by measures of inhibition, switching , and working memory capacities which were taken to be indices of System 2 functioning. 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 various kinds of problems.

Previous studies have also tended to use rather small samples of problems (Ash & Wiley, 2006; Fleck, 2008; Murray and Byrne, 2005) and/ or of participants (Murray & Byrne, 2005). The present study will involve larger samples of tasks (18 insight and 10 non-insight, detailed below) and of participants (N = 120).

METHOD

<u>Problem tasks</u>

The 18 *insight problems* were taken from Gilhooly and Murphy (2005) and were as follows: *Inverted Pyramid*; *X ray*; *Triangle*;*Pound Coins*; *Football scores; Marriage; Matchsticks*;. *Pigpen*; *Farm*; *Matching socks*; *Murples*; *Candle; Trains and bird*; *Earth in hole*; *Horse trading; Ocean liner*; *Reading in dark; Lake*.

The 10 *Non-insight problems* were also from Gilhooly and Murphy (2005) except the *Latin Squares* task (Birney et al., 2006). The remaining 9 were as follows: *Tower of London; Syllogistic reasoning*; *Hobbits and orcs; Tower of Hanoi* ;*Dinner party; Cards; Heavy and light coins; Anagrams; Raven’s Progressive Matrices*.

<u>Individual difference measures</u>

All individual difference dimensions were assessed by two indicators.

Verbal working memory was assessed by *Sentence span*(Baddeley, Logie, Nimmo-Smith et al., 1985)and *Operation span*. (Conway & Engle, 1996).

Visuo-spatial working memory was assessed by *Visual pattern span* (Della Sala, Gray, Baddeley et al., 1999) and *Corsi blocks* (Corsi ,1972).

Inhibition was assessed by the *Colour Stroop* (Ward, Roberts & Phillips, 2001) and the *Number Stroop* task (Ward et al., 2001) In both Stroop tasks the time taken in the control condition is subtracted from that in the Stroop condition to indicate the time cost of inhibiting the dominant response.

Switching was assessed by the *Arithmetic Switching* task (Ward et al., 2001) and the *Number-Letter Switching* task (Ward et al., 2001). In both tasks, the average time required for the non-alternating (non-switching) lists is subtracted from the time required for the switching list to measure switch cost. A smaller switch cost is taken to indicate more effective executive switching functioning.

Participants

120 students at University of Hertfordshire were tested. Participants were between 18 and 35 years of age (mean age = 22.64 years, sd = 6.38); 68 female and 52 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 only exceptions to this were the syllogisms, the Tower of London and the anagrams tasks. For the syllogisms participants were given 10 minutes to answer 10 problems presented in a multiple choice format. In the Tower of London tasks participants were allowed 2 minutes on each of 5 problems. Participants were allowed 2 minutes to attempt the 8 anagram problems. Scores for these three tasks were the number of problems correct in the time allowed. For the other problems, scores were obtained for whether correctly solved or not and for time to solution (non solutions were given a time score of 240 secs). 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.

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 AND DISCUSSION

Analyses of insight problems were based on time measures to solution (non solution scored as 240 secs) because time measures are more discriminating than simple solved/not solved scoring. All scores were oriented so that a larger score meant a better performance. For example, times were subtracted from 241, thus a quick solution would receive a high score. This procedure should make interpretation of the results more straightforward. Analyses of non-insight problems are based on standardised latency scores or standardised number of items solved scores, as appropriate.

Composite insight task scores for each participant were formed by averaging solution speed scores over the 17 insight tasks (Cronbach’s α = .77). Similar *non-insight task composite scores* were formed by converting the 10 non-insight task scores into standard scores and averaging these (Cronbach’s α = .74). The resulting composites were normally distributed and over the 120 participants correlated with each other, r =.67** indicating moderate overlap but with considerable unshared variance (c. 55%).

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. To facilitate interpretation, the executive function standard scores were then oriented so that higher scores indicated more effective functioning.

Table 1 shows the correlations of the cognitive function measures with composite insight and non-insight scores.

< INSERT TABLE 1 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 and may appear to support the view that working memory and executive function factors play a similar role in insight problem solving as in non-insight tasks. However, in view of the complex pattern of intercorrelations among the individual difference variables, apparent links may be due to confoundings among the variables. To take account of such intercorrelations and possible confoundings we undertook separate simultaneous multiple regressions of the insight and non insight composites as dependent variables with the individual difference scores as independent variables.

The results of the *multiple regression analyses* for insight and non-insight composite scores are shown in Table 2.

< INSERT TABLE 2 ABOUT HERE >

From Table 2 it appears that when measures were partialled out from each other, insight problem solving was predicted significantly by visuo-spatial and verbal working memory while non-insight problem solving was predicted by verbal and visuo-spatial working memory and by switching efficiency. This suggests that the two types of task are differentiated by the extent to which they draw on executive functions, particularly that of switching.

GENERAL DISCUSSION

This study sought to add to available knowledge regarding the extent to which insight and non-insight problems could be empirically differentiated in terms of involvement of specific System 2 processes of inhibition and switching. 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.

Regression analyses were carried out on composite insight and non-insight score from the 17 insight tasks and the 10 non-insight tasks. (Although the overall matrix showed numerous positive correlations none were so high as to cause concerns regarding multicollinearity.) The results of the regressions indicated that for insight problems, visuo-spatial and verbal working memory were predictive, however neither executive measure of switching or inhibition contributed independently. In the case of non-insight problems, visuo-spatial and verbal working memory and switching made independent contributions to predicting solution scores.

The results reported here provide further behavioural evidence in support of 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 & Byrne (2005), Gilhooly & Murphy (2005) and Fleck (2008).

Furthermore, we found that the pattern of loading of non-insight tasks and insight tasks on individual difference measures of System 2 functions differed in an interpretable way. The role of executive functioning and working memory in non-insight tasks was expected and has been frequently reported. It appears that the insight tasks did not draw on the executive functions of switching or inhibition suggesting that insight solutions were based on spontaneous, implicit, non-executively loading processes. The significant independent contributions of working memory scores when executive function measures are partialled out, in predicting insight solving, could reflect necessary use of some storage capacity in problem solving , as Fleck (2008) suggested, rather than the executive aspects of working memory. 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 non-executively loaded processes that lead to new directions of work in producing new patterns. Overall, the present results support the view that System 2 processes play a lesser role in insight problem solving than in non-insight tasks, reflecting a greater importance of automatic implicit processes in re-structuring as suggested by early Gestalt theorists (Maier, 1931) and more recently by spreading activation accounts (Ohlsson, 1992; Ash & Wiley, 2006).

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Table 1. Correlations among individual difference measures and composite scores on insight and non-insight tasks. Variables oriented so that higher scores reflect better problem solving or more effective executive functioning. * $p < .05$; ** $p < .01$; $df = 119$.

	1.	2	3	4	5	6

1.Insight Comp.	-					
2.NonIns Comp.	.67**	-				
3.Inhibition	.18	.21**	-			
4.Switching	.21**	.29**	.12	-		
5.Vis-Sp Working Mem.	.41**	.42**	.12	.22**	-	
6.Verb. Working Mem.	.43**	.34**	.18*	.22**	.38**	-

Key: Insight Comp. = Composite score over 18 Insight problems; NonIns Comp. = 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 2. βweights from simultaneous multiple regressions of individual difference measures on Insight and Non-Insight Composite scores. Variables oriented so that higher scores reflect better problem solving or more effective executive functioning. ** = p <.01, * p < .05; df = 115.

	Dependent Variable			
	Insight Composite		Non-Insight Composite	
Independent Variable	β Wt.	*t*	β Wt.	*t*
Inhibition	.09	1.09	.12	1 .44
Switching	.08	.92	.17	2.05*
Vis-Sp.Working Mem.	.28	3.16**	.30	3.44**
Verb. Working Mem	.29	3.26**	.17	1.91*

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.