Journal of Experimental Psychology:
Learning, Memory, and Cognition
2014, Vol. 40, No. 2, 532–543

0278-7393/14/$12.00 DOI: 10.1037/a0034304

Facilitating Representation Change in Insight Problems Through Training

John Patrick and Afia Ahmed
Cardiff University

Our aim in this article is to elaborate the role of training in representational change theory (RCT), particularly in terms of Ohlsson's (2011) spread of activation explanation (named *redistribution theory*), and to develop novel training manipulations that effect the re-encoding mechanism proposed by RCT (Ohlsson, 1992). Two experiments are reported that aim to help solve verbal insight problems and to enable some constraint to be relaxed. In Experiment 1, participants were trained to use heuristics to solve unseen problems from the same category that shared the same representational obstacle, namely, ambiguous word and ambiguous name problems. Concurrent verbal protocols were collected and analyzed in terms of the hypotheses proposed by participants. Training improved solution rate of unseen problems from the trained categories and, as expected, positive transfer was specific to the trained category of problem. Analysis of the incorrect hypotheses proposed during problem solving provided supplementary evidence of the effectiveness of training at inducing representation change. In Experiment 2, a similar approach to training was developed to help solve functional fixedness problems. Solution rate increased with training, although transfer was specific to the trained category of problem. Theoretical and methodological issues are discussed.

Keywords: representation change, insight problem solving, training, transfer

The problem of how to improve insight is important for many reasons and has seen a resurgence of research over the last few decades (e.g., Ansburg & Dominowski, 2000; Chronicle, MacGregor, & Ormerod, 2004; Jones, 2003; Kaplan & Simon, 1990; Ohlsson, 1992; Ormerod, MacGregor, & Chronicle, 2002; Segal, 2004; Sternberg & Davidson, 1995). One reason is that different theoretical explanations have been proposed concerning how to overcome an impasse (Jones, 2003; Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001; MacGregor, Ormerod, & Chronicle, 2001; Ohlsson, 1992; Öllinger, Jones, & Knoblich, 2006). A second reason is that insight has been linked to important activities such as scientific discovery (e.g., Chi & Hausmann, 2003; Finke, 1995) and creativity (e.g., Dow & Mayer, 2004; Hélie & Sun, 2010). Also, processes underlying lack of insight in laboratory studies can be responsible for errors committed by experienced personnel, sometimes experts, and result in industrial incidents (e.g., Sternberg & Davidson, 1995; Patrick et al., 1999; Wiley, 1998).

Researchers have used three approaches in investigating how to improve insight: designing the problem solving situation by, for example, providing a break during problem solving (Schooler, Ohlsson, & Brooks, 1993; Segal, 2004; Sio & Ormerod, 2009; Wallas, 1926); prompting problem solvers with a hint concerning the solution, for example, that they could extend their line beyond the boundary of the nine-dot square (Burnham & Davis, 1969; Kaplan & Simon, 1990; Moss, Kotovsky, & Cagan, 2011; Weisberg & Alba, 1981); and training the problem solver, which is the approach adopted in the present study. Training involves teaching the problem solver a specific or general heuristic or procedure or the like that is intended to be recalled subsequently and improve unsupported problem solving. This differs from studies that provide a hint with no teaching at the beginning of each problem or sometimes at an impasse during problem solving.[1]

Two major challenges face the development of training to improve insight that the present study addresses. First, we need to understand the nature of an impasse and how it can be overcome. For this purpose, we use representational change theory (RCT; e.g., Kaplan & Simon, 1990; Knoblich et al., 1999), particularly Ohlsson's (1992, 2011) contributions, which explains how cognitive processing can lead to and overcome an impasse in insight problem solving. However, RCT does not elaborate on how training can affect the mechanisms of re-encoding and constraint relaxation, thereby effecting representational change, and we make

This article was published Online First September 23, 2013.

John Patrick and Afia Ahmed, School of Psychology, Cardiff University, Cardiff, United Kingdom.

Afia Ahmed is now at the University Graduate College, Cardiff University.

The authors would like to thank Phil Morgan, Tanya Patrick, and Vicki Smy for their assistance in coding and analyzing some of the data.

Correspondence concerning this article should be addressed to John Patrick, School of Psychology, Tower Building, 70 Park Place, Cardiff University, Cardiff CF10 3AT, United Kingdom. E-mail: patrickj@cardiff.ac.uk

[1] It is possible to conceptualize training as necessarily involving hints or prompts because in any teaching or training program, it is inevitable that the student or trainee is informed and made aware of how particular problems should be solved. However, training, unlike hints or prompts, always includes some type of teaching that aims to develop some form of competence in the student or trainee that can be recalled to solve subsequent problems without any support. Typically, training will involve the trainee practicing the application of some form of knowledge during problem solving, and this will be coupled with feedback from the experimenter concerning either the product of problem solving (e.g., correctness of the solution) and/or the process of problem solving (e.g., how strategy could be more efficient).

some proposals in terms of Ohlsson's (1992, 2011) development of spread of activation theory (named *redistribution theory*). The second challenge for training is to strike a balance between one specific training solution that is of great help to only one problem and a more generalizable training solution that is less helpful but intended to solve many problems. Some training studies of visuospatial problems have provided specific training oriented to the solution of only one particular problem, such as the four-dot problem (e.g., Weisberg & Alba, 1981, Experiment 4) and the nine-dot problem (e.g., Chronicle, Ormerod, & MacGregor, 2001, Experiment 3; Kershaw & Ohlsson, 2004; Weisberg & Alba, 1981, Experiment 2). Surprisingly, such training has demonstrated relatively modest transfer effects. Other studies have investigated how training can be designed to facilitate the solution of not only one specific problem for which the training was designed but also various previously unseen problems (e.g., Ansburg & Dominowski, 2000; Chrysikou, 2006; Walinga, Cunningham, & MacGregor, 2011; Wicker, Weinstein, Yelich, & Brooks, 1978). One novel solution to the balance between specific and generalizable training lies in developing training at an intermediate level that aims to facilitate the solution of a category of problems sharing some common characteristic. This is the approach we use in the present study.

Both of these challenges and related issues are reviewed below. First, we discuss the nature of insight, the mechanisms proposed in RCT for changing representation (Ohlsson, 1992, 2011), and how training can trigger such a change. Second, evidence from some relevant training studies is reviewed.

Nature of Insight Problems and RCT

Ohlsson (1992) defined insight problems as those that "have a high probability of triggering an initial representation which has a low probability of activating the knowledge needed to solve the problem" (p. 10). To differentiate the negative effect of mental set from that of lack of insight (e.g., Öllinger, Jones, & Knoblich, 2008), we add to this definition that the initial representation was a familiar one generated from much experience over a period of time rather than the more immediate and temporary situation in which mental set is developed, as in Luchins's (1942) experiments. Two main types of insight problem have been studied that are consistent with Ohlsson's (1992) definition. These fall into a visuospatial category (including the *Mutilated Checkerboard* problem, Kaplan & Simon, 1990; the *Nine-Dot* problem, Chronicle et al., 2001; *Matchstick Algebra* problems, Knoblich et al., 1999; the *Six-Coin* problem, Chronicle et al., 2004; and the *Unlimited Move Car Park* game, Jones, 2003) and a verbal category (including the *Inverted Pyramid* problem, Ohlsson, 1992; and various problems cited by Dominowski, 1994). In the present study, we focus on verbal insight problems that have received less research attention and are essentially lateral thinking problems (DeBono, 1967), although they have generally not been so labeled in the literature.

Anthony and Cleopatra is an example of a verbal insight problem:

> Anthony and Cleopatra are lying dead on the floor in an Egyptian villa. Nearby is a broken bowl. There are no marks on their bodies and they were not poisoned. Not a person was in the villa when they died. How did they die? (Sloane, 1992, p. 13)

Comprehension of such a problem requires the reader to elaborate the information provided by making inferences (Lea, 1995) that go beyond any information explicitly stated in the text (McKoon & Ratcliff, 1992). The problem solver, on the basis of past experience, tends to initially draw unhelpful stereotypical inferences from certain words or phrases or from the theme of the problem and is thus unable to generate a novel solution (Ohlsson, 1992). This is an example of the negative effect of habit (James, 1890) or what Reason (1990) termed *strong but wrong rules*, where a person tends to default to high frequency responses to find meaning in cognitively underspecified situations. A distinguishing feature of a verbal insight problem is that it contains a word or a phrase that must be interpreted in an unusual way. Hence, the *Anthony and Cleopatra* problem is difficult because these names are typically associated with humans. This stereotypical association or assumption has a high probability of being triggered and, in turn, this constrains solution of the problem.

RCT (Ohlsson, 1992, 2011) explains how normal cognitive processing in problem solving can lead to an impasse and also how it can be overcome by representation change. This explanation conceptualizes long-term memory as constituted by layered cognitive structures made up of nodes and links with different levels of activation amongst them. Retrieval from memory depends on both the spread and the level of activation, which, in turn, is determined by past experience. When a person is initially confronted with a problem, an automatic interpretive and constructive process takes place that develops a sort of situation model that contains knowledge from parts of the cognitive structure where activation levels pass a threshold value. Consequently, an inappropriate representation is usually developed on the basis of past experience such that, for example, Anthony and Cleopatra are assumed to be human beings. What is particularly relevant to the present study is how a change in representation is triggered according to RCT. Ohlsson (2011) posited that as the problem solver receives increasing amounts of negative feedback during the impasse phase, this results in some activation being subtracted from the parts of the cognitive structure found to be unsuccessful in generating a solution that is then redistributed across other parts, such that gradually there will be sufficient activation in other parts to provide a revised solution space for the problem solver. What is activated and to what level will vary among both individuals and problems. Solution will not be guaranteed within either the revised solution space or within subsequent revisions of it.

Consequently, if the goal is to improve insight problem solving, we need a mechanism for triggering representation change that results in a high probability that a correct solution space will be generated. One solution is for the problem solver to learn, through training, a procedure that will have sufficient activation strength to be recalled during an impasse and will facilitate not only representation change but also the subsequent search process. Such a procedure needs two attributes. First, it has to specify when the problem solver should attempt to revise the solution space. This is because the problem solver cannot assess whether the solution lies within the current solution space and therefore requires more perseverance to find or whether the solution lies outside the current solution space, which requires revision. Therefore representation change should only be triggered when current possible solutions have been exhausted. Second, the procedure needs to direct the person with respect to how to attempt to change the solution space.

We should not underestimate the difficulty of effecting this representation change, as it requires the identification and abandonment of a well-learned, implicit, and automatically generated assumption (Jones, 2003; Knoblich et al., 1999; Ormerod et al., 2002). Ohlsson (1992) suggested three processes may be associated with representation change. These are (a) elaboration or addition of new information; (b) re-encoding, which entails focusing on correcting the faulty representation of a problem that is mistaken rather than incomplete by recategorizing or deleting some information; and (c) constraint relaxation, in which initial incorrect assumptions or constraints on the goal are revised. There is some uncertainty over the delineation between the latter two processes, as re-encoding that involves changing an incorrect representation can also be conceptualized as revising an inappropriate assumption or constraint on the goal state. For example, in the *Anthony and Cleopatra* problem, the incorrect representation includes the assumption that these names refer to humans, which can also be construed as a limiting condition incorrectly imposed on the goal. Empirical evidence consistent with the notion that differentiating re-encoding from constraint relaxation is problematic comes from results of studies by Ansburg and Dominowski (2000), who found elaboration was effective in problems supposedly requiring either elaboration or constraint relaxation. In the present study, we are concerned with developing training that facilitates representational change by encouraging the problem solver to re-encode information in the problem specification, thus enabling some stereotypical constraint to be identified and relaxed. We attempt to achieve this by training participants in an appropriate heuristic-based process that has sufficient activation to be recalled after training during attempts to solve the test problems.

Training for Insight Problem Solving

One challenge, mentioned earlier, is to devise training that avoids being a solution for just one insight problem and is applicable to a range of problems. One solution is to target training at one category of insight problem, although how such a category is defined needs some consideration. A study by Dow and Mayer (2004) categorized the nature of the insight problem as verbal, visuospatial, mathematical, or a combination of these. In Experiment 2 of their study, participants were trained on one or more of these types of problem and then tested on problems from both trained and untrained categories. Participants were trained in a three-step process for solving each type of problem. For example, training in verbal problems instructed participants to notice that "one of the words is a trick or play on words" (Dow & Mayer, 2004, p. 394) and then demonstrated, using three training problems, how this could facilitate problem solution through a three-step explanation process of defining key words in the problem, analyzing the meaning of these words in the context of the problem, and concluding with the solution. Neither verbal nor mathematical training improved transfer to the same category of test problem, and an improvement using this criterion was only found with visuospatial training. Another experiment included a control group that received no training; again, the group that received verbal training was no better than the group that received visuospatial training or the control group at solving verbal problems. Therefore, this study provides no evidence of training being effective at facilitating between problem category transfer, given the nature of the categories used. Similarly, Cunningham and MacGregor (2008) found no positive transfer from training with spatial insight problems to the solution of verbal problems. Furthermore, any positive transfer was restricted to the same puzzle-type spatial problems as those used in training. Possibly the categories used in these studies were too broad, resulting in too much intra- and intercategory variability in the nature of the problem constraints to facilitate positive transfer as a consequence of training.

One potential solution is to target training directly at more fine-grained categories that concern specific representational obstacles or constraints. However, the nature of these constraints can vary greatly, even among verbal insight problems. Isaak and Just (1995) listed 21 insight problems and the different constraints associated with each problem. These constraints are so idiosyncratic that it is difficult to envisage how practice in breaking any one of these would facilitate solving the other problems. Cunningham, MacGregor, Gibb, and Haar (2009) reached a similar conclusion in their study that differentiated six types of restructuring required in insight problem solving and concluded that training should be focused on one particular type of restructuring. Therefore, the training used in both Experiments 1 and 2 of the present study was developed to target specific representation obstacles, as also advocated by Ash, Cushen, and Wiley (2009).

An essential part of any training is to make the problem solver aware of the general nature of any difficulties that the task poses so that the person will have the competence to solve these types of problem (Brown, Campione, & Day, 1981; Campione & Ambruster, 1985; Gick & Holyoak, 1987). A similar strategy was used in a recent study by Walinga et al. (2011), although this was in the context of spatial insight problems. The reason that initial training should raise awareness of the nature and difficulties of insight problem solving is that the changes of context in each problem can often obscure access to the means of solution. There is also evidence that training should provide opportunities for practice with feedback to facilitate verbal insight problem solving (Ansburg & Dominowski, 2000), and there is much evidence in the general training literature concerning the potency of practice with feedback as an effective training strategy for a range of tasks (e.g., Goldstein & Ford, 2002; Salas & Cannon-Bowers, 2001; Patrick, 1992; VanLehn, 1996).

Experiment 1

In Experiment 1, we devised training that provided participants with awareness of two types of representation obstacle coupled with practice at using different heuristics to break these constraints and facilitate re-encoding the problem according to RCT (Ohlsson, 1992). As far as we know, other training studies of insight problem solving have not used heuristics to trigger when and how the solution space can be revised. The importance of using an appropriate heuristic was highlighted by Kaplan and Simon (1990) in their study of the mutilated checkerboard insight problem in which the notice invariants heuristic was effective at focusing the search and facilitating solution. Search heuristics concerning hill climbing and means–ends analysis have been found to be important in general problem solving (Newell & Simon, 1972), and other heuristic-based training has been successful in other problem-solving domains, including industrial fault finding (Shepherd, Marshall, Turner, & Duncan, 1977) and mathematics (Schoenfeld, 1979). In the present study, we specified that the two heuristics involved in the training should only be used if participants could make no sense of the problem and that, in this eventuality, participants should search for alternative interpretations to any ambiguous names or words in the problem statement. The *Anthony and Cleopatra* problem, discussed earlier, in which the solution is that the names refer to fish, is an example of a problem with a representation obstacle from the ambiguous name category. Participants were trained to use a heuristic relevant to this category of problem, which suggested searching for a name and considering alternative animals to which the name(s) may relate. An example of a problem from the ambiguous word category is the *Shoot* problem (see Appendix) in which a woman shoots her husband, although the word *shoots* refers to taking a photograph rather than firing a gun. Participants were trained in another heuristic relevant to this category of problem that suggested searching for ambiguous words and identifying their alternative meanings.

In terms of RCT, these heuristics should have been learned during training such that during testing they had sufficient activation to be recalled and used to effect a revised solution space. Recall and use of this knowledge was predicted to support representation change through re-encoding of some critical parts of the problem statement. None of the ambiguous words or names used in the transfer tests was the same as those used during training; they therefore represented novel exemplars of the trained categories. To shed light on the level of specificity associated with any possible transfer of this training, we used a third "other" category of verbal insight problem that could not be solved by either of these heuristics. This was an important and novel feature of the design of both Experiments 1 and 2. It provided a means of testing whether the training inhibited problem solving outside of the trained categories, which could be a disadvantage of training. However, we predicted that any positive transfer would be specific, as suggested by theoretical formulations and empirical evidence (Anderson, 1983, 1987; Bassok, 1990; Clawson, Healy, Ericsson, & Bourne, 2001; Gick & Holyoak, 1980; Healy, Wohldmann, Sutton, & Bourne, 2006; Thorndike & Woodworth, 1901) and therefore would be restricted to the two trained categories of verbal insight problems.

Method

Participants. Forty-six psychology students from Cardiff University participated in this experiment as partial fulfillment of course requirements and were randomly allocated to training or no-training conditions. Ten participants were rejected, as they were familiar with at least one of the test problems. The final sample comprised 36 participants, 18 in each condition, and ages ranged between 18 and 27 years ($M = 20.69$ years, $SD = 2.16$).

Training program. All problems used in training and testing together with their constraints can be found in the Appendix. Training covered two categories of problem concerning either ambiguous words or ambiguous names. Training for each category involved three stages: providing information on the nature of insight and how it could be overcome in these categories of problem, providing practice at solving each type of problem with support from the experimenter, and providing unsupported practice. In the latter two stages of training that involved practice, participants were instructed to "think aloud" (see below for these instructions).

In the first stage, participants read the training material, which was presented as typed text in a paper booklet that was intended to develop declarative knowledge and awareness of the nature of the difficulty in insight problem solving and how this could be avoided in line with recommendations from the training and transfer literature (Brown et al., 1981; Gick & Holyoak, 1987). Therefore, participants were made aware of how a problem's solution could be obscured by a familiar ambiguous word or name. In the training material, participants were given two examples of the difficulty of insight problem solving and how heuristics could be used to overcome an inappropriate representation. The *Shoot* problem was used for ambiguous words together with the heuristic "If you cannot make sense of the problem then search for and identify any ambiguous word and its alternative meaning." The *Charlie* problem was used for ambiguous names with the heuristic "If you cannot make sense of the problem then search for a name and identify what animal could be involved." The self-explanatory training material provided the trainee with explanations of how both of these problems could be solved by the use of these heuristics.

In the second stage of training, each participant was given practice at using each heuristic for an ambiguous word problem (the *Bar* problem) and an ambiguous name problem (the *Spike* problem). Both problems were again presented in typed text in a paper booklet, and solution feedback was provided by the experimenter after each problem. Such feedback is an important instructional and should be paired with progressively reduced instructor support; otherwise this approach may improve performance only during training rather than during learning (Goldstein & Ford, 2002; Patrick, 1992; Salas & Cannon-Bowers, 2001).

In the third and final stage of training, participants were presented with two problems (*Professor Quantum* and *Bobby*), one from each trained category, in the same paper text format as above, and were asked to apply their training to solve each problem with no support from the experimenter except in the form of solution feedback. A maximum of 4 min were allowed for each problem. The training took, in total, approximately 30 min. Participants were not explicitly cued that their training was relevant to the solution of the test problems, although it is highly likely that they made this inference.

Test problems. Each of the nine test problems was presented in typed text on A4 paper: Three contained ambiguous words (*married, guide,* and *king and queen*) and three contained ambiguous names related to animals rather than humans (*Anthony and Cleopatra*, *Mr. Jones*, and *Jason*). A further three problems were used for which neither heuristic was relevant, and thus this category was labeled *out of scope* to the training (*bombs away, prisoner and rope*, and *sons*).

Design and procedure. Participants were individually tested and trained. During the test phase, we collected concurrent verbal protocol data. Participants were instructed in how to think aloud and make concurrent verbalizations during problem solving. To facilitate this, we provided practice exercises involving a multiplication problem, calculating the number of windows in the participant's house, and naming 20 animals, as recommended by Ericsson and Simon (1980, 1993). If participants fell silent during problem solving, the experimenter used two nondirective prompts

("What are you thinking?" and "Please keep talking"). Verbalizations were recorded continuously.

Participants in the no-training condition completed the test problems, and participants in the training condition completed the training program before completing the test problems. The test problems were presented in random order for each participant. There was a 4-min time limit for each test problem. After completing a test problem, participants were required to rate their familiarity with that problem on a 5-point scale (1 = *very unfamiliar,* 5 = *very familiar*). Participants with ratings of 4 or 5 on any problem were excluded from the final sample. Participants were not given solution feedback and were asked not to reveal information about the experiment to others.

Identification of hypotheses and intercoder reliability. Verbal protocols were transcribed and analyzed to identify and categorize not only correct hypotheses and solutions but also the nature of other proposed hypotheses that provide further evidence concerning the nature of participants' representations during problem solving and the effect of training. Qualitative evidence from the process of problem solving is important because it is not possible to unequivocally verify that training has produced the necessary representation change from solution data alone (Ash et al., 2009). The analyses of transcribed verbal protocols had two phases that are described in detail below. First, all hypotheses were identified and, second, each hypothesis was classified into one of four categories: correct solution, incorrect out-of-scope hypothesis, incorrect ambiguous word hypothesis, and incorrect ambiguous name hypothesis. The out-of-scope hypotheses failed to break the problem constraint by not identifying the alternative interpretation of the ambiguous name or word; therefore, problem solvers generated these hypotheses under an inappropriate representation. In contrast, incorrect ambiguous word and name hypotheses were so called because participants correctly identified an alternative interpretation of the ambiguous word or name but then failed to identify the correct one involved in the solution of the problem. Nevertheless, hypotheses in these two categories indicate that the constraint was broken or relaxed even though the correct solution was not reached. For example, in the *Guide* problem, some participants correctly identified *guide* as the ambiguous word but then interpreted it with respect to a sheep or dog. Similarly, in the *Anthony and Cleopatra* problem, participants might consider that the names referred to insects, dogs, cats, butterflies, or birds rather than fish. Finally, use of the out-of-scope category of hypotheses enabled us to evaluate whether training had any effect on solving problems outside of the trained categories of problem. All coders were unaware of what condition was being coded.

In the first phase of analysis, three coders (Afia Ahmed and two researchers) individually identified from each transcribed verbal protocol the hypotheses and solutions proposed for each test problem. Practice at coding was undertaken on one verbal protocol that was excluded from the final data set. A total of 787 hypotheses were initially identified among all three coders, of which 750 (95.3%) were identified by all three coders, 14 (1.78%) were identified by two coders, and 23 (2.92%) were identified by one coder. After discussion about these discrepancies, eight hypotheses were rejected, leaving 779 as the total agreed set of hypotheses.

The second stage of the analysis involved the same three coders independently classifying each identified hypothesis into one of four categories: correct solution, incorrect out-of-scope hypothesis, incorrect ambiguous word hypothesis, and incorrect ambiguous name hypothesis. Of the 779 hypotheses, 774 (99%) were categorized the same way by all three coders, and the remaining 5 or 1% were categorized by two coders only. The Perreault and Leigh (1989) reliability index was used to calculate intercoder reliability between pairs of coders as it accounts for the number of categories (Kolbe & Burnett, 1991). The reliability indices across the 779 hypotheses for the three pairs of coders were 0.99 for each, which is considered acceptably high as it exceeds 0.80 (Gremler, 2004; Krippendorf, 1980).

Results and Discussion

Analysis of solution rates. The percentage of correct hypotheses (i.e., solution rates) for participants in the training and no-training conditions across problem categories are displayed in Figure 1. Training raised the solution rate of participants from 26% (14/54 problems correct) to 59% (32/54 problems correct) for the ambiguous word category and from 4% (2/54 problems correct) to 39% (21/54 problems correct) for the ambiguous name category. More problems were solved by trained participants, $F(1, 34) = 13.11$, mean square error (MSE) = 11.34, $p < .01$, $\eta^2 = .28$, although this effect interacted with problem category, $F(2, 68) = 6.94$, $MSE = 3.90$, $p < .01$, $\eta^2 = .06$. Simple main effect analyses indicated that trained participants were better than those without training in the ambiguous word ($p < .01$) and ambiguous name categories ($p < .01$), but there was no significant difference in solution rate for problems that were out of scope to the training, as predicted ($p > .05$). Thus, although training produced facilitation effects of 33% and 35% for the ambiguous word and ambiguous name categories, respectively, it neither benefitted nor handicapped solution of problems that were out of scope to the training, indicating that, as expected, positive transfer was specific and restricted to the trained categories.

Analysis of incorrect hypotheses. Incorrect hypotheses proposed by participants during problem solving provide supplementary evidence concerning not only the effectiveness of training but also the nature of participants' representations. The total frequen-

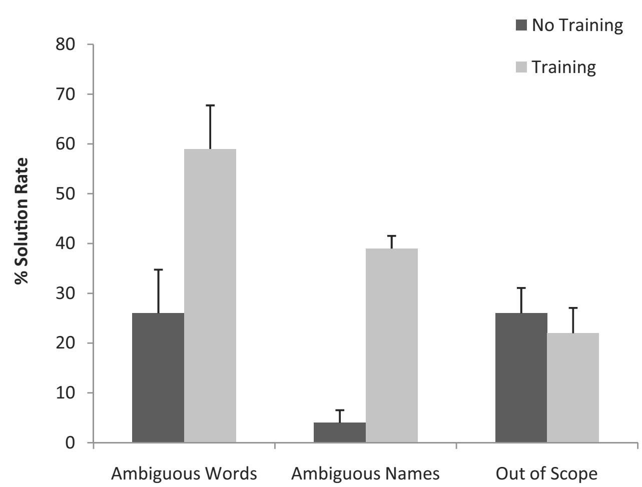

Figure 1. The effect of training on solution rates for different types of problem in Experiment 1. Error bars refer to standard error of the mean.

Table 1
Frequency of Types of Incorrect Hypothesis (Experiment 1)

	Incorrect hypothesis category		
Condition	Ambiguous word	Ambiguous name	Other
No training	6 (1.89%)	1 (0.31%)	311 (97.80%)
Training	45 (12.30%)	65 (17.76%)	256 (69.95%)

cies of the three categories of incorrect hypothesis proposed by all 36 participants in the training and no-training conditions across the nine problems are displayed in Table 1. In total, 684 incorrect hypotheses were proposed, and 117 of these were concerned with ambiguous words or names that broke the problem constraint. Participants who received training proposed considerably more of these hypotheses than did those who were not trained (see Table 1). This was confirmed by analyses of variance for ambiguous words, $F(1, 34) = 16.23$, $MSE = 2.60$, $p < .001$, $\eta^2 = .32$, and for ambiguous names, $F(1, 34) = 30.89$, $MSE = 3.68$, $p < .001$, $\eta^2 = .48$. Consequently, training not only had an effect on solution rate but also improved the generation of hypotheses that broke the problem constraint, albeit incorrect ones. Indeed, it is striking that only seven incorrect hypotheses were proposed in the no-training condition that fell into the target categories of ambiguous words or names. Consequently, apart from the 4% and 26% of problems in the ambiguous word and name categories, respectively, that were spontaneously solved by participants in the no-training condition, there was very little evidence that the constraints were being further broken in the incorrect hypotheses generated. In contrast, those participants in the trained condition, besides having solution rates of 59% and 39%, also broke the problem constraints on 110 occasions, even though these proposed hypotheses were incorrect (see Table 1).

Finally, it should be noted that training had no effect on the number of incorrect hypotheses generated in the out-of-scope category, $F(1, 34) = 1.79$, $MSE = 46.85$, $p > .05$ (see Table 1). These results further indicate that training had the intended effect on the nature of the hypotheses generated without affecting the amount of hypothesis generation for problems outside the scope of the two heuristics.

In summary, training that provided participants with awareness of and practice at using heuristics to identify ambiguous words and names improved solution rates for novel exemplars of each of these problem categories without affecting performance on other insight problems out of the scope of the training. Thus, the transfer of training effect was positive and specific and was observed only with respect to the trained problem categories, a finding consistent with theoretical notions of transfer and empirical evidence (e.g., Anderson, 1983; Bassok, 1990; Clawson et al., 2001; Gick & Hollyoak, 1980; Healy et al., 2006; Thorndike & Woodworth, 1901). Unlike untrained participants, trained participants produced 110 incorrect ambiguous name or word hypotheses, demonstrating that the heuristics were being applied, enabling the constraint to be broken and thereby increasing the probability of identifying the correct hypothesis. In terms of Ohlsson's (2011) spread of activation explanation of RCT, the heuristics taught during training had sufficient activation strength to be recalled during the test problems and trigger re-encoding of the insight problem that brought about representational change.

Experiment 2

Our aim in Experiment 2 was to further test the success of training in bringing about re-encoding to effect representational change, as suggested by RCT (Ohlsson, 1992) by using a different but classic type of insight problem, namely, functional fixedness problems. Experiments 1 and 2 are similar in that the relevant problem categories are defined with reference to the verbal components of problem statements: words that might be ambiguous, names that might refer to an animal, and nouns that refer to objects that might be used in many different ways. The training procedures of Experiments 1 and 2 are also similar, namely, to focus on one word of a specified type at a time, and generate alternative meanings or uses. The only difference is that in Experiment 2, participants were trained to use an iterative process in generating alternative functions of objects. The reason for this was that solution rates, even after the training in Experiment 1, could still be substantially improved, and one idea was to encourage participants to persist in generating alternative functions of objects by training them to use a simple repetitive procedure for hypothesis generation. The rationale was that the more unusual functions identified, the more likely that the solution would be identified. As found in Experiment 1 and consistent with the transfer literature, we predicted that training would again only result in an improvement in solution rate for novel exemplars of the specific category of problem trained, namely, functional fixedness problems. To test this proposition, we presented participants with some verbal insight problems that were out of scope to the trained category of problem in addition to functional fixedness problems.

Method

Participants. Twenty-four undergraduate psychology students from Cardiff University participated as partial fulfillment of course requirements. No participants were rejected because of overfamiliarity with any problem. Ages ranged between 18 to 21 years ($M = 19.13$ years, $SD = 0.90$).

Training program. Training involved the same three stages of training used in Experiment 1 but oriented to the solution of functional fixedness problems. All training materials were again presented as typed text in a paper booklet. At Stage 1, participants were made aware of how functional fixedness can block problem solution and were introduced to an iterative method for systematically identifying each object in the problem statement and its different possible functions. Participants were asked to select one object within a problem statement and to systematically consider all of its possible uses and functions with respect to the problem. If the solution was not found, then participants selected a different object and repeated the process until a correct solution was generated. This systematic iterative approach was designed to develop a more exhaustive examination of potential solutions in contrast to the training used in Experiment 1. The *String* problem was used as a worked example to illustrate how this systematic iterative approach could be applied to solve the problem.

In both Stages 2 and 3 of the training, participants were required to think aloud while attempting to solve the practice problems. In the second stage of training, participants were required to practice using the iterative approach to solve the *Paperclip* problem and the experimenter provided solution feedback. In the final stage of training, participants were given 6 min to solve the *Gimlet* problem with solution feedback provided by the experimenter. The training took, in total, approximately 30 min. Again participants were not explicitly cued that their training was relevant to the solution of the test problems, although it is highly likely that they made this inference.

Test problems. Six test problems were used: three functional fixedness problems (the *Two-String* problem, the *Candle* problem, and the *Hatrack* problem) and three verbal insight problems, which were out of scope to the training (the *Charlie* problem, the *Antique Coin* problem, and the *Prisoner and Rope* problem). The functional fixedness problems were presented in a written format similar to that of the verbal insight problems. All training and test problems are described in the Appendix.

Design and procedure. Participants were individually tested and trained. Participants were randomly allocated to the training or no-training condition. Those in the training condition completed the training program. Participants in both conditions then attempted the six test problems that were presented in random order for each participant with a time limit of 6 min for each, which was selected on the basis of pilot testing. After completing each test problem, participants rated how familiar they were with that problem on a 5-point scale. Participants were not given solution feedback.

Results and Discussion

We predicted that training would only result in an improvement in solution rate for novel exemplars of the specific category of problem trained, namely, functional fixedness problems (see Figure 2). Training raised participants' solution rate from 6% (2/36 problems correct) to 39% (14/36 problems correct) for functional fixedness problems, whereas the solution rate remained at 22% (8/36 problems correct) for the out-of-scope verbal insight problems. A 2 (training and no training) × 2 (functional fixedness and out of scope problems) analysis of variance revealed that more problems were solved by participants in the training condition, $F(1, 22) = 7.62$, $MSE = 3.00$, $p < .05$, $\eta^2 = .26$, although this effect interacted with problem category, $F(1, 22) = 6.60$, $MSE = 3.00$, $p < .05$, $\eta^2 = .13$. Simple main effect analyses indicated that trained participants solved more functional fixedness problems than did untrained participants ($p < .01$), but training had no effect on participants' solution rates of the out-of-scope problems ($p > .05$). Thus, training had a specific facilitation effect of 33% on the trained category of problem (the value of eta squared representing a large effect size) but no general effect on the untrained category. Although this percentage improvement is similar to the average facilitation effect of 34% found in Experiment 1, again representing a large effect size, it is not possible to disentangle the differential effects of introducing the iterative training method from that of the different type of problem used in Experiment 2.

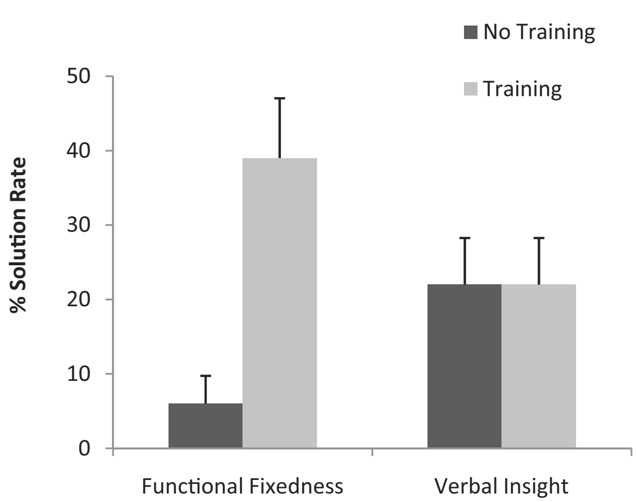

Figure 2. The effect of training on solution rates for different types of problem in Experiment 2. Error bars refer to standard error of the mean.

A further issue concerns the written verbal presentation of the functional fixedness problems in Experiment 2 that contrasts with the traditional presentation of the objects in a practical environment (Duncker, 1945; Maier, 1931, 1945). It could be argued that presenting functional fixedness problems verbally rather than in a practical context may have weakened the association between the objects and their stereotypical functions. Thus, the problems may have been easier given that they were presented in a less concrete manner in the problem specification, making the constraint less difficult to overcome. However, this interpretation seems unlikely given the solution rate was only 6% for participants in the untrained condition.

In summary, the results from Experiments 1 and 2 are consistent in demonstrating that it is possible to facilitate, through training, the representation change required to solve specific categories of problem. One solution, consistent with RCT (Ohlsson, 1992, 2011), is to provoke the re-encoding of problems by learning relevant heuristic procedures during training that have sufficient activation levels to be recalled as cues during the test phase to trigger re-encoding. We have demonstrated the robustness of this training effect across different categories of verbal insight problem.

General Discussion

The goal of this article was to make explicit the role of training in RCT as a means of effecting representation change through re-encoding to mitigate the difficulties of verbal insight problem solving. We have discussed training in terms of Ohlsson's (2011) development of spread of activation theory (named redistribution theory), and this facilitated the development of novel training manipulations for successfully effecting representation change. We gathered some strong and rich evidence that when participants do not receive training, the incorrect stereotypical assumptions or inferences made during attempts at problem solving create an initial representation with a relatively low probability of success (average for nontraining conditions of 10.33% correct, range of 4%–24% across the two experiments). Presentation of the problem triggered the retrieval or activation of prior knowledge and experience that blocked the solution path, making these verbal problems difficult if not impossible to solve (Ohlsson, 1992). Solution was only possible when the assumption or constraint was identified and, until then, hypothesis generation was constrained by the presumed veracity of that initial constraint.

Training was designed to provoke the re-encoding of problems by getting participants to learn relevant procedures during training that would have sufficient activation levels to be recalled and act as cues to relevant re-encoding during the test phase. Training was designed to facilitate this re-encoding in Experiments 1 and 2 by identifying categories of verbal insight problem that could be solved by using relevant heuristics and procedures learned during training and successfully applied to novel exemplars of these categories during testing. The success of this type of training is consistent with the success of similar training, for example, in mathematical problem solving (Schoenfeld, 1979). Solution rates improved substantially with training for ambiguous word, ambiguous name, and functional fixedness problems. Facilitation rates were similar, ranging between 33% and 35% in comparison with no-training conditions, although the solution rates were far from perfect, being 59%, 39%, and 39%, respectively, even after training. Improvement of solution rates through training was associated with large effect sizes associated with the eta squared statistic, and the percentage of improvement that was due to training was similar to that found by Ansburg and Dominowski (2000). One factor that may have reduced the solution rates in the training condition of Experiment 1 was that participants had to select which heuristic to apply first to the problem statement. They may have selected the inappropriate one that resulted in the solution path being obscured. No advice or procedure was given to overcome this in the training. However, the design of the study in which testing directly followed training may have been a factor that maximized solution rates. It is also of interest that the posttraining solution rate was higher for the ambiguous word (59%) than the ambiguous name category (39%), as one might have expected that word problems would have been more difficult than name problems given the larger word than name vocabulary. However, the search for ambiguous words may have involved a trial-and-error process with each word in the problem statement until an alternative meaning for a word was found. In contrast, although an ambiguous name could have easily been identified in the problem statement, the search for the appropriate type of animal was dependent on the vocabulary and imagination of the participant.

An important potential criticism germane to not only the present but to any training study or indeed any study that provides the problem solver with some form of advance information was raised.[2] That is, in the training conditions of Experiments 1 and 2, we have assumed that after reading the problem, the participant will still automatically generate an inappropriate representation of the problem, thus a change in representation is required to solve the problem. However, the suggestion is that this assumption may not be correct because the training may obviate the need for a change in representation. Thus, for example, in the training condition of Experiment 1, the heuristic to search for an ambiguous word may result in the participant adopting this analytical approach immediately when reading the problem statement, thus avoiding the generation of an inappropriate representation. If this were so, then training would not be facilitating a change in representation.

There are various grounds for rebutting this suggestion. First, the generation of an inappropriate representation is considered to be an automatic and largely unconscious process in insight problem solving (e.g., Jones, 2003; Knoblich et al., 1999; Ohlsson, 1992, 2011; Öllinger et al., 2008; Ormerod et al., 2002). This is consistent with evidence in the areas of text comprehension and reading that stress the automatic generation of some aspects of meaning, which is strongly guided by past experience (e.g., Graesser, Millis, & Zwaan, 1997; Kamide, Altmann, & Haywood, 2003; Seidenberg, 2005; Trueswell, Tanenhaus, & Kello, 1993). Second, we have verbal protocol data, including the nature of the hypotheses generated, that are pertinent to this issue. If the criticism was correct, the first hypothesis proposed by participants in the training condition should not reflect a misrepresentation of the problem, as the training would have immediately cued some analytical problem solving that somehow avoided the automatic generation of the problem constraint. On the one hand, any evidence that the first hypothesis (or indeed any initial verbal behavior) is generated under a misrepresentation refutes this criticism. On the other hand, lack of such evidence does not necessarily support the criticism, as it is always possible that a fleeting misrepresentation is initially generated that changes quickly to an appropriate representation for the problem. In Experiment 1, 18 participants in the training condition tackled nine problems, creating 162 opportunities for examining evidence that their initial problem solving was dictated by a misrepresentation of the problem. All hypotheses in the protocols of Experiment 1 were already reliably identified and coded concerning whether they were generated under a misrepresentation. We therefore collated data concerning whether the first hypotheses proposed were consistent with a misrepresentation. In 97 (65%) of situations, the first hypothesis was consistent with a misrepresentation of the problem. Two researchers independently coded the verbal protocols associated with the remaining 65 situations regarding whether there was any verbal evidence in the initial part of the transcript, before a hypothesis was generated, of a misrepresentation of the problem. In 29 out of 65 situations (with a Perreault Leigh reliability index of .78), evidence of a misrepresentation was found. Thus, in total, including the hypothesis data, in 126 out of 162 (78%) problem-solving situations, there is evidence from the verbal protocols of an initial misrepresentation of the problem by participants in the training condition. Therefore, on both theoretical and empirical grounds, there is a strong argument that the training does not enable participants to avoid a misrepresentation of the problem.

Our conclusions should be tempered by various limitations of the reported studies. From a practical perspective, it is important to determine over what periods of time such training effects would persist. Also, it is not possible to disentangle the relative contribution of different aspects of the training to improved performance. Thus, we are unable to separate the effects of different parts of the training content from each other and also from how each part was designed to be learned. For example, it is problematic to separate the relative value of making participants aware of the problem of lack of insight from the effects of different types of practice and feedback provided in training.

In conclusion, we have elaborated the role of training in RCT in terms of Ohlsson's (2011) spread of activation mechanism. Our study demonstrates how training can effect representation change in verbal insight problem solving through the mechanism of re-encoding proposed by RCT (Ohlsson, 1992). Representation change is important because it is sometimes seen as a hallmark of creative endeavor; also, misrepresentation of a situation can underlie the failure of skilled and experienced personnel to perform optimally in practical aviation and industrial contexts. For exam-

[2] We thank Gary Jones for raising this point.

ple, in the Kegworth air crash on January 8, 1989, the pilots were used to the older version of this aircraft and therefore had an incorrect representation that the right engine was responsible for cabin air conditioning. Similarly, at the Three Mile Island nuclear incident in 1979, an operator team shared a flawed but familiar representation of the plant that erroneously involved water cooling the core of the reactor (Kemeny, 1979). Effecting representation change during insight problem solving is challenging because the incorrect assumptions that block problem solution concern well-learned, high-frequency responses that are implicit, are automatic, and would be correct on the majority of occasions in other contexts. We have demonstrated how representational change through re-encoding can be facilitated by heuristic-based training focused on a category of constraint.

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(*Appendix follows*)

Appendix

Training and Test Problems for Experiments 1 and 2

Experiment 1: Training Problems

Shoot. A woman shoots her husband. Then she holds him under water for over 5 minutes. Finally, she hangs him. But 5 minutes later they both go out together and enjoy a wonderful dinner together. How can this be?

Constraint: Shoot means kill.

Spike. Spike, an adult, brings the paper to Mr. Hopkins every day. Spike is never paid for this. Why does he do this?

Constraint: Spike was a human.

Bar. A man walked into a bar, and before he could say a word, he was knocked unconscious. Why?

Constraint: The man had walked into a drinking bar.

Charlie. It was a Sunday morning and music was playing in the background. Charlie was sitting, minding his own business. However, when the music stopped, a shadow fell over Charlie, which led to him being crushed to death. Why?

Constraint: Charlie is human and was involved in a murder.

Professor Quantum. While on safari in the wild jungles of Africa, Professor Quantum woke one morning and felt something in the pocket of his shorts. It had a head and tail but no legs. When Quantum got up, he could feel it move inside his pocket. Quantum, however, showed little concern and went about his morning rituals. Why such a casual attitude toward the thing in his pocket?

Constraint: It is some sort of animal with a head and tail.

Bobby. Bobby had not taken anything and was feeling fine but he couldn't help repeating everything Mr. Jenkins said. Why is that?

Constraint: Bobby is a person.

Experiment 1: Test Problems

Ambiguous Words

Married. A man who lived in a small town in the United States married 20 different women of the same town. All are still living and he never divorced any of them. In this town polygamy is unlawful; yet he has broken no law. How is this possible?

Constraint: The man married each woman himself.

Guide. A mountain climber in the Himalayas took along with him two mountain guides. After a few hours, one of the guides fell into a deep crevasse. The climber and the other guide continued the climb and did not raise the alarm. Why?

Constraint: The guide was a person.

King and Queen. Two sisters along with a large group of people watched as the queen attacked the king. No one said anything. Why?

Constraint: The king and queen were royal persons.

Ambiguous Names

Anthony and Cleopatra. Anthony and Cleopatra are lying dead on the floor in an Egyptian villa. Nearby is a broken bowl. There are no marks on their bodies and they were not poisoned. Not a person was in the villa when they died. How did they die? (Sloane, 1992).

Constraint: Anthony and Cleopatra were human.

Mr. Jones. Mr. Jones broke his leg on Saturday afternoon. He was immediately attended to by expert medical practitioners and suffered no other injury. Sadly, he died later that day as a result. Why?

Constraint: Mr. Jones was a person.

Jason. Jason is lying dead. He has a piece of metal across his back and some food in front of him.

Constraint: Jason was human.

Out-of-Scope Problems

Bombs Away. One night during the Second World War, an allied bomber was on a mission over Germany. The plane was in perfect condition and everything on it worked properly. When it had reached its target, the pilot ordered the bomb doors to be opened. They opened. He then ordered the bombs to be released. They were released. But the bombs did not fall from the plane. Why should this be so (Sloane, 1992)?

Constraint: The plane was flying the right way up.

Prisoner and Rope. A prisoner was attempting to escape from a tower. He found in his cell a rope that was half long enough to permit him to reach the ground safely. He divided the rope in half, tied the two parts together, and escaped. How could he have done this (Isaak & Just, 1995)?

Constraint: The rope was cut width ways and therefore remained the same length.

Sons. A woman had two sons who were born on the same hour of the same day of the same year. But they were not twins, and they were not adopted. How could this be so?

Constraint: Two sons born on the same day have to be twins.

Experiment 2: Training Problems

String. Several wooden poles, clamps, and string have been made available. The task is to hang the string from the ceiling to the floor without defacing the ceiling.

Paperclip. A piece of white cardboard with four black squares fastened to it is to be hung from a ring fixed to the ceiling. On the table in the room, the following objects available: paper, a pen, a ruler, and some paperclips. How could the cardboard squares be hung on the ring?

Note: From the original, the word *eyelet* was changed to *ring* to facilitate comprehension. Objects were selected from a list in Duncker (1945).

Gimlet. Three cords are to be hung side by side from a wooden ledge. On the table in the room there is paper, pencils, tinfoil, two short screw-hooks and a hand powered screwdriver. How could the three cords be hung up?

Note: From the original, the term *gimlet* was replaced with *hand-powered screwdriver*. Objects were taken from a list in Duncker (1945).

Experiment 2: Test Problems

Functional-Fixedness Problems

Two Strings. In a room, two strings are hanging from the ceiling. The distance between them makes it impossible to reach one string while holding the other. The task is to reach one string while holding the other. A variety of objects are available, including a chair, paper, a pair of pliers, drawing pins, and a jar. How may the two strings be tied together?

Note: Objects selected were taken from those presented in a picture by Isaak and Just (1995).

Candle. Your goal is to attach a candle to a wall so that it can burn upright. You have available a candle, some matches, and a box of drawing pins. How would you solve the problem?

Note: From the original problem, *book of matches* was changed to *some matches* and *box of tacks* was changed to *box of drawing pins* to facilitate comprehension.

Hatrack. Using two poles and a clamp, build a hatrack that is sufficiently stable to support a heavy coat and a hat. The opening of the clamp is wide enough so that both poles can be inserted and held together securely when the clamp is tightened.

Out-of-Scope Problems

Charlie. This problem is described in the section with problems for Experiment 1 above.

Antique Coin. A dealer in antique coins got an offer to buy a beautiful bronze coin. The coin had an emperor's head on one side and the date 544 BC stamped on the other. The dealer examined the coin and realized it was a fake. How did he know the coin was phony? (Ansburg & Dominowski, 2000)

Constraint: The date on the coin is correct.

Prisoner and Rope. This problem is described in the section with problems for Experiment 1 above.

Received January 20, 2013
Revision received July 29, 2013
Accepted July 30, 2013 ■