The Experience of Insight Facilitates Long Term Semantic Priming in the Right Hemisphere

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Draft date: February 21, 2018

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Article type : Original Article

Abstract

While past research has demonstrated a link between the subjective "Aha" experience of insight and verbal insight problem solution activation in the right hemisphere, no one has yet linked insight to long term semantic priming. We propose that through a shared process of semantic integration both of these concepts are linked and thus the experience of insight should facilitate semantic priming in the right hemisphere. Participants attempted to solve a group of compound remote associate problems and afterwards completed a lexical decision task. The results showed that the experience of insight facilitated semantic priming in the right hemisphere, but only for unsolved CRA problems. It was also shown that participants who indicated that they generated more solutions through insight that were incorrect also showed the most semantic priming in the right hemisphere. These results indicate that long term semantic priming can occur as a result of insight solutions, and that this activation occurs predominantly in the right hemisphere. This study extends both the evidence for long lasting semantic priming as well the theory of coarse semantic coding in the right hemisphere.

The Experience of Insight Facilitates Long Term Semantic Priming in the Right Hemisphere

When faced with solving a difficult problem, it is not uncommon to become stuck during the course of problem solving with seemingly no progress being made towards the answer for an extended period of time. During such a mental impasse, the solution to the problem can suddenly arrive in conscious awareness without any conscious deliberative processing of the solution (Metcalfe, 1986). This experience of sudden insight during problem solving is more commonly referred to as an "Aha!" moment, consistent with the feeling of surprise at achieving the solution (Kounios & Beeman, 2009). These subjective feelings of self-reported insight during problem solving have been widely reported throughout the history of mankind, including by both Archimedes and Albert Einstein (Stein, 1999; Öllinger & Knoblich, 2009).

Experience of Insight

Due to the idiosyncratic nature of the experience of sudden insight during problem solving, it has been difficult to define it as a singular concept (Dominowski & Dallob, 1995). However, there is general agreement for several key facets of insight problem solving. Typically for an insight to occur problem solvers first come to an impasse during problem solving where solution progress stops, which is then followed by solving the problem in a way that subjectively feels abrupt and surprising (Bowden & Jung-Beeman, 2003a). This process is believed to occur due to a restructuring of the problem, wherein the features of the problem are reconceptualized so that the elements of the problem important for finding the solution become salient (Ohlsson, 1984); although the mechanisms behind this restructuring process are a matter of debate (see Chu & MacGregor, 2011). In addition to these aspects of problem solving, people are often unable to articulate exactly how they solved the problem after an insight solution has been achieved

(Bowden & Jung-Beeman, 2003a). Thus, insight problem solving is theorized to occur below the level of conscious awareness.

While the qualitative experience of insight is rarely disputed, quantifying this subjective experience of insight has proved difficult for a number of reasons. As insight is an inherently subjective experience, it is difficult to pinpoint precisely when it has or has not occurred (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). In addition to problems inherent in self-report, participants do not always categorize their own insights the way they are typically defined in the literature and may classify problems which they solved quickly as insight solutions even when no "true" insight has occurred (Cranford & Moss, 2012). It is also possible for problems categorized as requiring insight-based solutions to be solved analytically (Bowden et al., 2005).

However, despite these criticisms there is substantial experimental evidence that the self-reported experience of insight is an accurate indication that a problem has been solved through insight. Past research has shown that people are aware of their own thought processes during problem solving and can accurately report their problem-solving process. In one such demonstration, a speed-accuracy decomposition was used to assess progress towards a solution when solving anagram problems which are primarily solved with insight (Smith & Kounios, 1996). This technique was used to measure the aggregation of information over time towards the problem solution with the hypothesis that analytical problem-solving strategies should show incremental progress towards a solution while insight solutions should not. Consistent with solving problems without conscious deliberation, participants reported little or no partial solution information while solving anagram tasks which typically require an insight solution, providing evidence that people are aware of when they are not making incremental progress towards a solution. In a similar study, Metcalfe and Wiebe (1987) found that metacognitions, or the awareness and understanding of one's own thought processes, before and during problem solving of anagrams (an insight task) and math problems (an analytical task) differed. Specifically, participants' ratings of how close they felt they were to a solution were uncorrelated with their progress on an anagram task, but these ratings did correlate with their progress while solving math problems.

In addition to eliciting different levels of self-reported solution progress during problem solving, self-reported insight solutions versus analytical solutions have been shown to produce measurable differences in brain activity. Research by Jung-Beeman and colleagues (2004) examined the difference between insight solutions and analytical solutions while solving verbal insight problems. Using fMRI and EEG in separate experiments, increased activation was found in the area of the right anterior superior temporal gyrus (aSTG) for insight solutions versus analytical solutions. Supporting the role of the right aSTG in generating insight solutions, this finding has been replicated in a more recent paper (Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009). In another study, Kounios et al., (2009) used fMRI and EEG in two different experiments to measure differences in neural activation between insight and non-insight solutions before problem solving began. Again, distinct differences in brain activity were revealed between self-reported insight and non-insight solutions, providing further evidence that participants can accurately distinguish insight versus non-insight solutions via self-report.

Hemispheric Differences in Verbal Insight Problem Solving

Past research on verbal comprehension has demonstrated that both the left and right cerebral hemispheres contribute differently to language comprehension. One important distinction between the two hemispheres pertains to semantic processing, where the left hemisphere (LH) creates strong activation for associations closely related to a concept and the right hemisphere (RH) creates weaker activation for associations that are distantly related to a concept (Beeman, 1993; Beeman, 1998). In support of this idea, it has long been demonstrated that the LH shows a processing advantage during language processing especially for single words (e.g. Isseroff, Carmon, & Nachshon, 1974). However, more recent work has shown that there is a RH advantage for single word processing in situations that involve the semantic overlap of multiple words (Beeman et al., 1994).

To demonstrate this effect of facilitated word processing in the RH, a task must be used which requires participants to recognize semantic associations between a group of words. One of the most commonly used tasks in demonstration of this is the compound remote associates test (CRA; Bowden & Jung-Beeman, 2003b) which is a variant of the remote associates test developed by Mednick (1962). This task is designed to function as an insight problem which involves forming diffuse associations between semantic concepts. In the CRA task, participants are presented with a triad of words (e.g. pine crab sauce) and must identify a fourth word that functions as a compound word with the other three words (e.g. apple).

To test whether CRA problems facilitated the processing of words in the RH, Bowden & Beeman (1998) performed two experiments assessing the priming of the solution word for CRA problems in the RH. In the first experiment, after attempting to solve each CRA problem participants were presented with the solution word for that problem or an unrelated word in either the left or right visual field. Participants were instructed to read this target word aloud as soon as they recognized it. As expected from past research, overall participants recognized words faster that were presented to the right visual field, which sends visual information to the LH. However, compared to words unrelated to the solution, solution words showed more priming in the RH than the LH for both solved and unsolved problems demonstrating a RH advantage in word recognition. The second experiment used the same procedure, only instead of reading the word aloud participants were instructed to press a button after each problem to indicate if the solution word was presented. In this experiment, a RH advantage relative to the LH for recognizing solution words was found for unsolved problems only. These results provide evidence that the RH has an advantage for single word processing relative to the LH when semantic cues are presented that share overlapping information about the target word. In addition, due to the nature of the CRA as an insight problem this supports a prominent role of the RH in solving verbal insight problems.

In order to further evaluate the hypothesis that insight is associated with the RH, Bowden & Jung-Beeman (2003a) performed a similar experiment utilizing CRA problems. As in their other experiments, participants named either a solution word or a word unrelated to the solution that was presented to either the left or right visual field after attempting to solve each problem. In this experiment however, after each problem participants rated the amount of insight that they had when recognizing the solution on a scale of 1-5. As predicted, greater insight during solution recognition predicted greater RH priming for the solution word for unsolved CRA problems. In addition, this priming effect was shown to be robust only at high ratings of insight, indicating that increased insight during verbal problem solving is associated with RH semantic processing.

Semantic Integration and Long Term Semantic Priming

While the exact mechanism behind facilitated RH processing for semantic information is unknown, evidence points to semantic integration in the RH as a possible culprit. As discussed previously, increased activity in the RH aSTG distinguishes insight solutions from non-insight solutions (Jung-Beeman et al., 2004; Subramaniam et al., 2009). Additional work using fMRI has also shown that activity in the RH aSTG is increased during tasks that require semantic integration such as during discourse processing (St. George, Kutas, Martinez, & Sereno, 1999), for processing discourse that is only moderately causally related (Mason & Just, 2004), and when repairing sentences with syntactic violations (Meyer, Friederici, & von Cramon, 2000). In addition, the RH aSTG is activated during the lexical decision task when semantic priming is used (Rossell, Bullmore, Williams, & David, 2001). Thus, evidence exists for a common brain region between semantic integration, verbal insight problem solving, and semantic priming.

However, while this body of research demonstrates an overlap in the neural substrates of these three processes, the behavioral evidence is less clear on their interrelatedness. Many studies have found that the effects of semantic priming are short-lived during a lexical decision paradigm (e.g. Perea & Gotor, 1997). In contrast to these findings, Joordens & Becker (1997) demonstrated that under certain conditions, long term semantic priming can occur at much longer intervals. Critically, one of these conditions was to use pairs of semantic stimuli that shared many semantic features. In a related line of research, it has been shown that the degree of causal relatedness between two sentences predicts later recall of these sentences independent of reading times (Keenan, Baillet, & Brown, 1984). The authors found that while reading times increased linearly as the causal relatedness of the sentences decreased, recall was best for sentences that were only moderately causally related. These results are proposed to occur due to elaboration, whereby a participant integrates and forms new conceptual information around a concept in addition to the explicitly stated conceptual information which then facilitates later retrieval (Myers, Shinjo, & Duffy, 1987). Furthermore, it has been proposed that the number of relationships established between paired words is the most important predictor of whether an association will be formed between them (Bradley & Glenberg, 1983).

More recently, additional work has bolstered the evidence for the existence of long term semantic priming. In one study, Woltz and colleagues (2015) used a sentence completion task to demonstrate the occurrence of semantic priming at long time intervals (>15 minutes), providing evidence that semantic priming can occur over long intervals when the semantic representations of a prime are strengthened. A similar result has been obtained when studying word lists that contain related semantic associates, whereby long term semantic priming effects are observed during a lexical decision task (Tse & Neely, 2005; Tse & Neely, 2007). Taken together, these findings demonstrate that the degree to which strong semantic associations are formed appears to be a critical variable in whether semantic priming can occur at long intervals. This conclusion is consistent with a study conducted by Beeman & Bowden (2000). In this study, over the course of five different experiments, participants attempted to solve CRA problems within different time intervals. The results of these experiments demonstrated that a RH advantage existed for naming the solution to unsolved CRA problems, but only at longer time intervals. It is likely that semantic integration in the RH was only possible at these longer time intervals, and thus the effect was only present when participants had enough time to integrate the semantic information in each problem.

Current Study

In the current study, participants were given up to 40 seconds to solve CRA problems, including the time they had to enter a response. Unlike previous studies examining the role of the RH in verbal insight problem solving (e.g. Bowden & Jung-Beeman, 2003a), participants were not tested for semantic activation of the solution immediately after attempting to solve each problem. Instead, participants completed a set of CRA problems in succession and then afterwards were tested for hemispheric priming using a lateralized lexical decision task. Thus, a large amount of time elapsed between the presentation of a given CRA problem and the corresponding solution word in the lexical decision task. Given the commonalities between the processes of semantic integration and semantic priming, we predicted that RH semantic priming for CRA solution words would be facilitated even at a longer interval.

In line with this prediction, we also hypothesized that the experience of insight, even if not resulting in the correct answer, would result in increased semantic integration in the RH due to the common neural substrates involved in insight problem solving and semantic integration. Specifically, solving problems through insight should facilitate semantic priming in the RH during the lexical decision task for unsolved problems when an insight solution was reported, due to the coarse semantic coding of the RH.

Method

Participants

The Ball State University Psychological Science subject pool was used to recruit 68 subjects (30 Female, 6 Left handed). All subjects were compensated with course credit for participating.

Experimental Materials

The stimulus materials for the CRA consisted of 40 problems chosen from a set of published normed problems (Bowden & Jung-Beeman, 2003b; Appendix A). These problems were chosen to reflect a wide range of problem difficulty. The stimulus materials for the lexical decision task (LDT) consisted of 160 words (Appendix B).[1] Of these words 40 were the solutions to the CRA problems, 40 were a list of control words, and 80 were a list non-words. The English Lexicon Project Web Site (http://elexicon.wustl.edu) was used for selecting the control words. The control words were matched with the CRA solution words in terms of number of letters, lexical decision accuracy, lexical decision reaction time, and Kučera-Francis frequency. There were no significant differences between the CRA and control words on any of these dimensions ($p > .15$). Half of these words were presented to the left hemifield and the other half were presented to the right hemifield. E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002) was used for stimulus presentation. A standard keyboard was used to collect responses on both tasks.

Procedure

After giving informed consent, participants were seated approximately 57 cm in front of a monitor with the resolution held at 1680x1050 pixels. Participants then both read and verbally received detailed instructions on how to solve the CRA problems as well as how to distinguish an insight solution from a non-insight solution based on prior studies (e.g. Bowden & Jung-Beeman, 2003a). Feedback was given from the experimenter regarding their performance during the practice trials if participants had difficulty understanding the nature of the problem. Once the practice trials concluded, the participants began the experimental trials. All CRA problems were presented in a random order for each participant. These problems were separated into 4 blocks of 10 trials each.

On each problem, participants were given a maximum of 40 seconds to enter their answer. For the first 33 seconds, the CRA problem appeared in white font on the screen. Afterwards, the words on the screen turned green and participants had 7 seconds to enter their response before the next problem appeared. If participants solved a problem before the 33 seconds were elapsed, they could immediately advance to the second screen and enter their answer. On problems where participants entered an answer, they were then asked whether they had reached their solution using insight which they indicated with either a yes or no response. After each trial, participants received feedback on whether they entered an answer or not but were not told whether their answer was correct. The feedback remained on the screen for 1500ms.

After completion of the CRA problems, participants completed a lateralized LDT. Participants were seated approximately 57 cm in front of the monitor and their head stabilized and held in position with the UHCO-Tech HeadSpot. Participants were told that letter strings would briefly appear and that their task was to decide, as quickly and as accurately as possible, if the letter string constituted a word. Participants were not given any information regarding the nature of the words. On each trial a fixation point (X) was presented in the middle of the screen. Participants were instructed to always focus on the fixation point and to make their judgements based on their peripheral vision. A tone (500 Hz) then sounded for 250ms and a target string was randomly presented to either the left or the right visual field. The centermost portion of the target was subtended by a visual angle of 3 degrees. While focusing on the fixation point, participants decided, as quickly as possible, whether the letter string was a word. Using their right hand, they pushed the key marked YES if the string was a word and the key marked NO if it was not a word. Target strings were presented for 1000ms[3]. After each trial, feedback regarding lexical decision accuracy was presented for 1000ms. The presentation of each word or non-word to either the left or right hemifield was counterbalanced across participants.

Data Analysis

To analyze the data in this study, mixed linear effect models were used for hypothesis testing (Baayen, Davidson, & Bates, 2008). To assess accuracy on the LDT, logistical mixed models were utilized (Jaeger, 2008). These models are robust to different numbers of observations per condition, and in the case of missing observations in a condition the model estimate tends to be more conservative in its estimate of p-values (Baayen, Davidson, & Bates, 2008; Quené & Van den Bergh, 2008). The models were fit using the lme4 package in R with restricted maximum likelihood to provide an estimation of the parameters for the linear models (Bates, Mächler, Bolker, & Walker, 2014). The use of these models allows for the modeling of subjects and items as random effects in the same model rather than using separate ANOVAs for each. To fit each model, first the maximal random effect structure was used for model specification (Barr, Levy, Scheepers, & Tily, 2013). This model was then simplified according to the method outlined by Bates, Kliegl, Vasishth, & Baayen (2015) to produce the final random effects structure for each model. P-values for the coefficients in each model were obtained using the lmerTest package in R (Kuznetsova, Brockhoff, & Christensen, 2015). These models were used to assess priming for both reaction time and accuracy in the LDT. For data analysis, 3 subjects were excluded for solving 0 of 40 CRA problems, leaving a total of 65 participants for analysis. In addition, a total of 4 trials (2 CRA solution words and 2 control words) were excluded from analysis due to duplication. When analyzing the LDT, all trials where non-words were displayed were not examined.

Results

Descriptive Statistics

Overall, participants solved on average 9.66 CRA problems (SD = 4.76) out of 40 and reported solving an average of 12.08 problems with insight (SD = 5.89). A more detailed breakdown of CRA performance is shown in Table 1. For the LDT, participants correctly classified a mean of 84.2% of the critical words and on these words had a mean reaction time of 643.2 ms (SD = 59.91 ms).

[Insert Table 1 About Here]

Within Subjects Analyses

To assess whether priming occurred for CRA solutions in the RH, accuracy on the LDT was assessed using a binomial generalized linear mixed model with accuracy for each word as the DV. In line with past analyses of solution word priming for the CRA (e.g. Bowden & Beeman, 1998), only unsolved CRA problems were included. In addition, LDT trials where no answer was attempted were excluded from this analysis. The IVs in this model were Laterality (Left hemisphere/Right hemisphere) and Word (CRA solution word/Control word). The laterality results for all tests are referenced by the target hemisphere, so that RH refers to target words presented in the left visual field and LH refers to target words presented in the right visual field[2]. Wald's z tests were used to calculate the significance of the coefficients of the model. Neither the main effect of Laterality (z = -0.352, p = .153) or Word (z = -0.996, p = .3194) were significant. However, the interaction of Laterality x Word was significant (z = -2.041, p = .0412). To assess this interaction, post hoc Wald's z tests were used to examine the differences within the main effects of both terms of the interaction (see Figure 1). A significant difference in accuracy was found between the LH (M = .88, SE = .017) and the RH (M = .82, SE = .027) for Control words (z = 2.872, p = .0041). In contrast, there was no significant difference between the LH (M = .9, SE = .016) and the RH (M = .89, SE = .019), for the CRA solution words (z =

0.352, p = .724). In addition, post hoc tests also showed that within the RH, accuracy was significantly greater for CRA solution words (M = .89, SE = .019) than for Control words (M = .82, SE = .027), (z = 2.928, p = .0034), a difference that was not significant in the LH (z = 0.996, p = .319). These results demonstrate that there was a clear RH advantage for identifying CRA words but not for control words.

[Insert Figure 1 About Here]

To test the effect of priming for CRA solutions in the RH on reaction time, a linear mixed model with reaction time as the DV was used. Only error-free trials were used in this analysis. The IVs used in this model were the same as for the accuracy model. No significant interaction or main effects were found using this model (ps > .1).

To further evaluate the effect of priming on CRA solution words, a second analysis was conducted. This analysis was designed to measure what impact insight solutions may have on the priming effect seen for CRA solution words in the LDT. Because past research has shown different patterns for incorrect and correct solutions on RH solution recognition, both correct and incorrect CRA solutions were included. Thus, CRA accuracy was also included in the model. Again, accuracy on the LDT was assessed using a binomial generalized linear mixed model with accuracy for each word as the DV. This analysis was carried out only on all CRA solution words in the LDT regardless of performance on the CRA. LDT trials where no answer was attempted were excluded. The IVs in this model were Laterality (Left hemisphere/Right hemisphere), CRA Accuracy (Correct/Incorrect), and Insight (Yes/No). Neither the main effects of CRA Accuracy (z = -.708, p = .479) or Insight (z = -1.8, p = .0719) were significant. A main effect of Laterality was observed (z = -2.484, p = .013), but this main effect was involved in higher level interactions. There was also a significant two-way Laterality x Insight interaction (z = 2.753, p = .006). However, this interaction was further qualified by a significant three-way interaction Laterality x CRA Accuracy x Insight interaction (z = -2.174, p = .03). To assess this interaction, post hoc Wald's z tests were used to examine the differences within the main effects of both terms of the interaction (see Figure 2). Significantly greater accuracy was found for the LH (M = .91, SE = .015) versus the RH (M = .87, SE = .02) for incorrect CRA problems solved without insight (z = 2.484, p = .013). The reversed pattern was observed for incorrect CRA problems solved with insight (z = -1.984, p = .0472), where greater accuracy was found for the RH (M = .93, SE = .021) versus the LH (M = .86, SE = .036). Taken together, this pattern of results suggests that the experience of insight moderated the effect of semantic priming in the RH, so that when insight occurred recognition was facilitated in the RH for unsolved CRA problems.

[Insert Figure 2 About Here]

To test the effect of insight on priming for CRA solutions in the RH on reaction time, a linear mixed model with reaction time as the DV was used. Only CRA solution words and trials on which the LDT solution was correctly chosen were used in this analysis. The IVs used in this model were the same as for the accuracy model. No significant interaction or main effects were found (ps > .099).

Between Subjects Analyses

While the reported results provided evidence for semantic priming in the RH within-subjects analyses, according to our hypotheses it should also be true that subjects who reported having more insights should show greater RH semantic priming effects than subjects who reported having few insights. To test this possibility, a correlation was computed to assess the strength of the relationship between the total number of insights reported regardless of the number of correct solutions, and the number of CRA solution words that were correctly identified when presented to the LVF/RH whether the CRA problem was answered correctly or not. Because in the previous analysis whether a CRA solution was solved or unsolved was a significant predictor of accuracy, the number of CRA problems solved was used as a covariate in the correlation. Thus, a partial correlation was used to determine the strength of the relationship (see Figure 3). A significant correlation was found between the number of CRA solution words correctly identified in the RH and the total number of insights reported when controlling for the total number of correct CRA solutions $r(60) = .286$, $p = .022$. This same correlation was non-significant for the LH $r(60) = .173$, $p = .172$.

[Insert Figure 3 About Here]

The correlation between total insights reported and the number of CRA solution words correctly identified by the RH on the LDT shows a relationship between insight and semantic priming. However, in the previous within subjects analysis a significant effect of semantic priming was shown for insight solutions on the CRA that were not correct. In order to replicate this analysis between subjects, the total number of insight solutions that a participant had was subtracted from their total number of correct insight solutions. Thus, this new variable was a measure of how many insights were reported for CRA problems that were incorrect by each participant. If semantic priming in the RH is facilitated for incorrect insight solutions, then this variable should also correlate with the amount of CRA solution words identified by the RH on the LDT. To measure this relationship, another partial correlation was used where the amount of CRA problems solved was used as a covariate in the correlation (see Figure 4). Again, a significant correlation was found between the amount of CRA solution words correctly identified in the RH and the total number of insights reported when controlling for the total number of correct CRA solutions $r(60) = .259$, $p = .039$. The same correlation was negligible in the LH $r(60) = .097$, $p = .446$.

[Insert Figure 4 About Here]

Discussion

The purpose of this experiment was to examine semantic priming in the RH for CRA solution words after attempting to solve CRA problems. Unlike past experiments using similar methods, this study tested the effects of RH semantic priming for CRA solutions over a long time interval rather than immediately after each problem. This allowed for the examination of the relationship between verbal insight problem solving and semantic integration, processes which share a common neural substrate (Jung-Beeman et al., 2004), and their impact on long term semantic priming in the RH. While many past studies have found that semantic priming effects tend to be short lived (e.g. Perea & Gotor, 1997), more recent work has demonstrated that under certain conditions long term semantic priming can occur (Tse & Neely, 2007). Specifically, studies that show this effect tend to use paradigms where increased semantic integration can occur during the initial presentation of a stimulus (e.g. Woltz et al., 2015). CRA problems are ideal candidates for semantic integration to occur, because, by definition, they must be solved by integrating overlapping semantic concepts to find the solution. If the experience of insight is correlated with semantic integration, then when insight occurs semantic integration should be facilitated which should then result in increased semantic priming. This view is consistent with the existing view that memory for insight problem solution should be relatively impervious to decay (Dominowski & Dallob, 1995).

In the current research, we assessed whether long term semantic priming would occur in the RH as a result of semantic integration during verbal insight problem solving as indexed by the experience of insight. Altogether, the results of this experiment suggest that long term semantic priming occurred in the RH, and especially so for incorrect CRA problems where insight was reported to occur. Consistent with past work using CRA problems with shorter intervals between problem presentation and assessment for solution activation in the RH (e.g. Bowden & Beeman, 1998), a significant effect for RH solution activation was found for CRA words versus control words. When only CRA solution words were examined, and no insight was reported for incorrect CRA problems, greater accuracy during the LDT occurred in the LH versus the RH. However, under the same conditions when insight was reported this effect reversed and words presented to the RH were classified more accurately than words presented to the LH. This suggests that insight moderated the degree of semantic priming in the RH for unsolved CRA problems.

Overall, these results provide evidence that semantic priming occurred in the RH for CRA solution words, and that this facilitation was especially pronounced when insight was reported but the solution reported was incorrect. This suggests that when semantic integration in the RH occurs, performance is facilitated only when a presented word is semantically related to the previously presented words. However, when an insight solution for a CRA problem was correct, this effect became smaller, suggesting that viewing the exact word did not facilitate performance. These results are consistent with past work examining semantic priming of both dominant and subordinate word meanings which showed that words presented to the LH were processed faster when the connection between this word and the prime was straightforward, while the RH performed better when multiple words were used, and the meaning was more ambiguous (Faust, & Lavidor, 2003).

In addition to the results of the within-subjects analyses, the between-subjects analyses show that subjects who report more insights overall show a greater RH priming effect for CRA solution words. This effect is also present when examining the amount of incorrect insight solutions that participants report, so that participants who report more incorrect insights show increased semantic priming in the RH for CRA solution words. These results are consistent with the results of the within subject analysis, with the number of insight solutions for unsolved CRA problems correlating with the number of CRA solutions recognized. Thus, participants who had more subjective insight experiences performed better at recognizing solution words for the CRA presented to the RH overall. These results are consistent with past studies of insight problem solving (Bowden & Jung-Beeman, 2003a), however this is the first study where this effect has been measured over long intervals between attempting to solve each CRA problem and completing a LDT.

We note several limitations in the current research. Because semantic integration can occur due to elaboration on the semantic interrelatedness of stimuli over a period of time (Myers, Shinjo, & Duffy, 1987), it is possible that the long presentation of the CRA problems facilitated semantic integration. Past research has shown that, in general, there is a positive relationship between how long a CRA problem is presented and how much RH semantic priming occurs (Beeman & Bowden, 2000). However, due to the pattern of our results this seems unlikely to explain the effect of insight solutions on RH semantic priming for incorrect CRA problems only. Another limitation of this study is that priming occurred for accuracy and not for reaction time. Although our instructions emphasized both accuracy and speed, it appears that participants may have placed greater emphasis on accuracy. Also, past priming research has demonstrated that reaction time and accuracy data can show different patterns (e.g., Keenan, Baillet, & Brown, 1984). It should be noted, however, that while the reaction time data did not achieve statistical significance, the pattern of the reaction time data mirrored the accuracy data. It is also notable that the smaller number of total trials in the reaction time models due to the exclusion of incorrect trials in the analyses may have prevented these patterns from reaching statistical significance.

This study has provided evidence of a link between the experience of insight during verbal problem solving and long term semantic priming in the right hemisphere. In line with past research and the design of our current study, we propose that semantic integration is a likely link between these two concepts. Future research can enhance our understanding of the link between semantic integration and the “Aha” insight experience, shedding new light on a subjective feeling that has enamored thinkers for centuries.

Footnotes

[1] Participants also completed the Schizotypal Personality Questionnaire (Raine, 1991) at the end of the experiment. This was an exploratory analysis and no significant effects were observed.

[2] For all models reported, both gender and handedness were added as covariates. These covariates did not meaningfully change the results, so the results reported do not include these variables.

[3] Our 1000 ms presentation is longer than typical in hemifield experiments, although others (e.g., Keil et al., 2001) have used the same presentation duration and observed laterality effects. Note that longer exposure times work against any laterality effects; if participants do saccade to the stimulus then the stimulus will be exposed to both hemispheres. Despite this possibility, laterality effects were observed in this study.

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Appendix A

Compound Remote Associates Test Stimuli

Practice Stimuli

Stimuli	Answer
Cream Skate Water	Ice
Loser Throat Spot	Sore
Fish Mine Rush	Gold
Show Life Row	Boat
Safety Cushion Point	Pin

Experimental Stimuli

Stimuli	Answer
Chamber Mask Natural	Gas
Dream Break Light	Day
Knife Light Pal	Pen

Shine Beam Struck	Moon
Down Question Check	Mark
Piece Mind Dating	Game
Lift Card Mask	Face
Rain Test Stomach	Acid
Way Board Sleep	Walk
Tail Water Flood	Gate
Man Glue Star	Super
Foul Ground Mate	Play
Carpet Alert Ink	Red
Pike Coat Signal	Turn
Catcher Food Hot	Dog
Age Mile Sand	Stone
Dress Dial Flower	Sun
Horse Human Drag	Race
Eight Skate Stick	Figure
Mill Tooth Dust	Saw
Time Blown Nelson	Full
Type Ghost Screen	Writer
Pile Market Room	Stock
Boot Summer Ground	Camp
Officer Cash Larceny	Petty
Pine Crab Sauce	Apple
Tomato Bomb Picker	Cherry
Keg Puff Room	Powder
Test Runner Map	Road
Main Sweeper Light	Street
Oil Bar Tuna	Salad
Aid Rubber Wagon	Band
Hammer Gear Hunter	Head
Pie Luck Belly	Pot

Teeth Arrest Start	False
French Car Shoe	Horn
Change Circuit Cake	Short
Wagon Break Radio	Station
Fox Man Peep	Hole
Marshal Child Piano	Grand

Appendix B

Lexical Decision Task Stimuli

Compound Remote Associates Test Words

pot

apple

game

face

grand

stock
road
super
cherry
salad
false
full
short
play
petty
stone
gas
dog
gate
acid
band
sun
day
horn
hole
camp
street
turn
figure
red
walk
head
powder
writer
race
pen

mark

moon

station

saw

Control Words

contain

lasting

marine

garage

extent

prayer

period

ladder

called

force

lined

myths

equal

roses

coach

slide

radio

doubt

trail

holes

short

early

water

five

duke

asks

sins

cave

vote

keep

load

loss

eggs

hate

pen

fox

wet

tin

sit

six

<u>Non-Words</u>

aftes

agach

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beald

belk

berced

bere

cade

caguts

chelow

chrsks
clare
cole
equld
equls
fales
fer
fou
grdld
grok
gronk
gurch
halil
han
heenle
houly
jore
juch
larst
latang
leld
maip
mirths
mourre
nou
onll
onlp
othen
otont
pasind
pieing

pither
plwand
ponule
pormed
roel
seese
sefose
sharon
soich
sosual
spose
sppere
sthen
stold
tadey
tays
thiff
tho
thout
thrker
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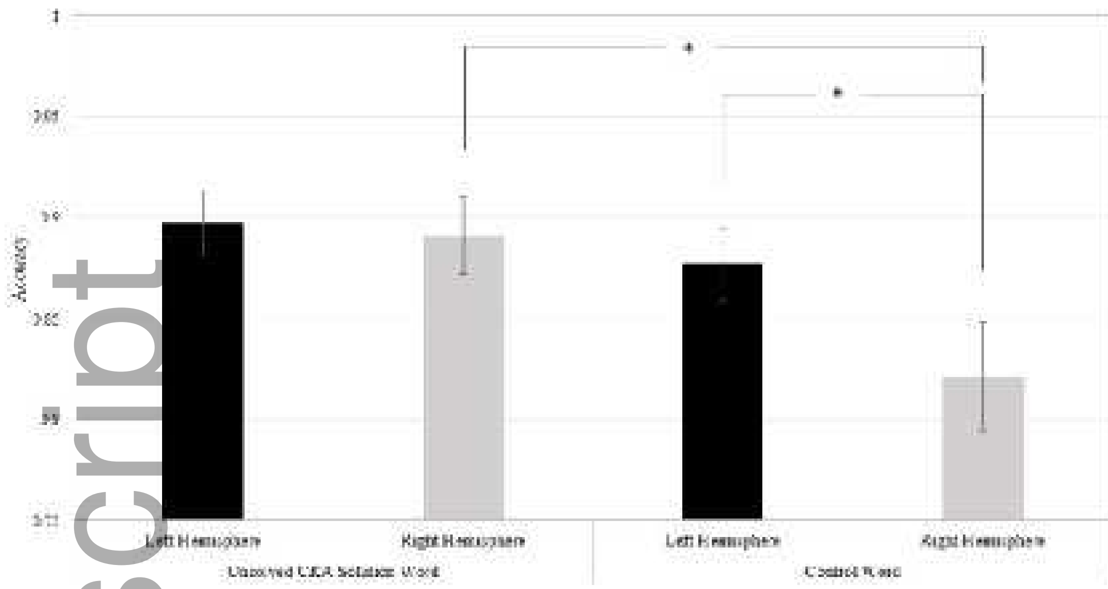

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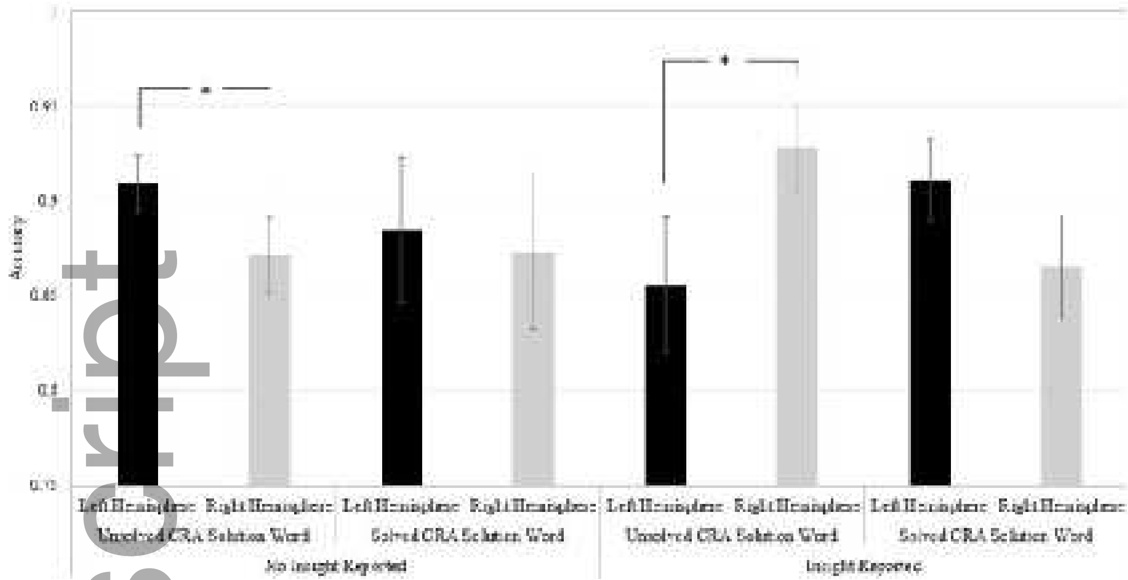

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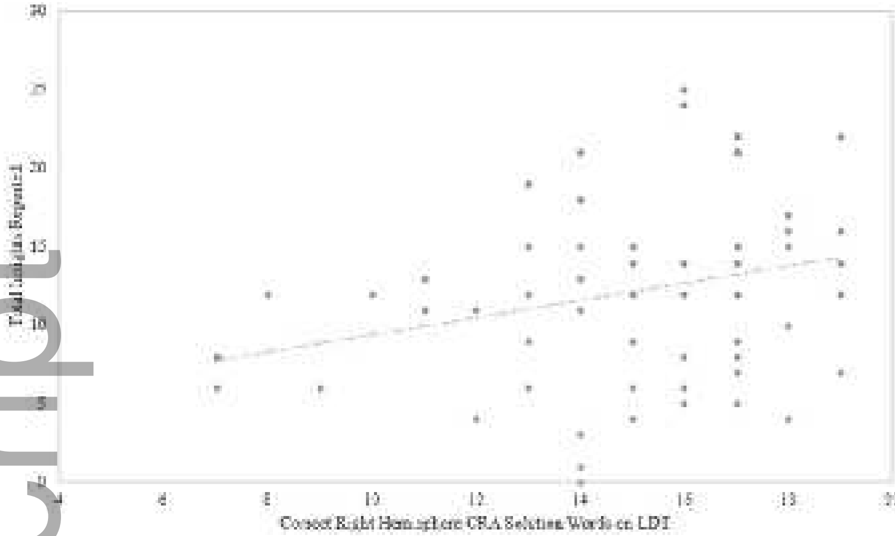

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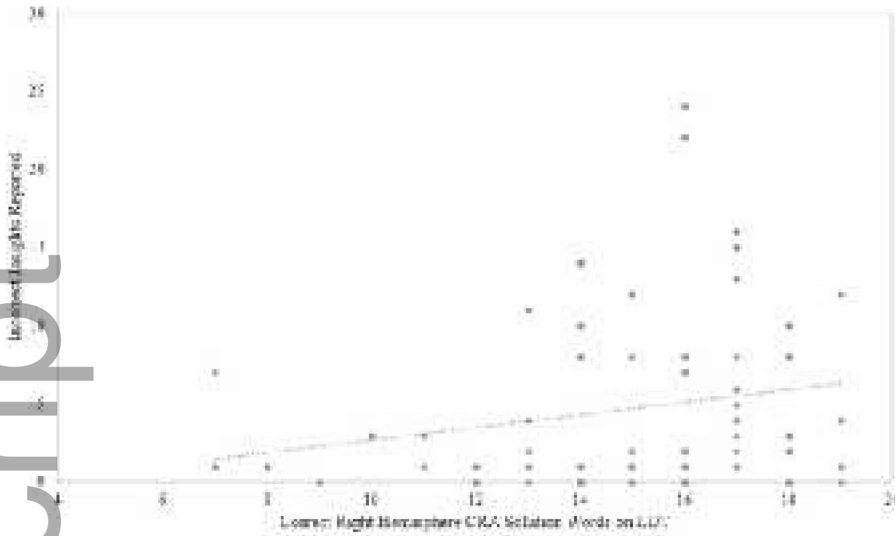

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