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Memory Inhibition as a Critical Factor Preventing Creative Problem Solving

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The hypothesis that reduced accessibility to relevant information can negatively affect problem solving in a remote associate test (RAT) was tested by using, immediately before the RAT, a retrieval practice procedure to hinder access to target solutions. The results of 2 experiments clearly showed that, relative to baseline, target words that had been competitors during selective retrieval were much less likely to be provided as solutions in the RAT, demonstrating that performance in the problem-solving task was strongly influenced by the predetermined accessibility status of the solutions in memory. Importantly, this was so even when participants were unaware of the relationship between the memory and the problem-solving procedures in the experiments. This finding is consistent with an inhibitory account of retrieval-induced forgetting effects and, more generally, constitutes support for the idea that the activation status of mental representations originating in a given task (e.g., episodic memory) can unwittingly have significant consequences for a different, unrelated task (e.g., problem solving).

Keywords: forgetting, creative thinking, inhibitory control

In everyday life, most mundane problems are successfully solved without much complication, by applying solutions that have proven to be appropriate in earlier similar circumstances. However, at other times, a situation may demand novel responses, solutions to be creatively elaborated and applied. The ways in which cognitive processes operate during creative problem solving have been the object of interest by many psychological scientists, and a good deal of relevant empirical evidence has accumulated over decades of research on various potentially explanatory variables (Guilford, 1950; Simonton, 2012; Smith & Ward, 2012; Sternberg, 2006; Weisberg, 2006). In what follows, the importance of information accessibility as a critical factor in problem solving is analyzed, and new findings are reported demonstrating that basic inhibitory mechanisms may underlie successes and failures in the quest for adequate solutions.

Access to relevant information at the time a problem needs to be solved is of critical importance, as evidenced by studies demonstrating that exposure to solutions before attempting to solve problems facilitates performance in a variety of tasks and situations (Dodds, Smith, & Ward, 2002, with incubation effects; Howe, Garner, Threadgold, & Ball, 2015, with analogies; Moss, Kotovsky, & Cagan, 2007, 2011, with verbal creativity; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995, with general-knowledge problems; or Steegen & De Neys, 2012, with syllogistic reasoning). Complementarily, if the relevant information is not at hand, either in the context or in the memory of the solver, the resolution of the problem is impossible or extremely unlikely (Holyoak & Thagard, 1995; Sternberg, 2006; Weisberg, 2006). One obvious reason why critical information may fail to be used is the absence of relevant knowledge in the mind of the solver. Interestingly, another important reason is that the critical information, while available in memory, may be temporarily unusable by a variety of intervening conditions that render it inaccessible.

Accessibility to a given piece of information in our mind is modulated by a number of factors that often interact with each other, as extensively exemplified in the literature on interference effects in memory (for a review see Anderson & Neely, 1996). In the realm of problem solving, interference is well exemplified in the phenomenon of fixation, whereby undue focusing on incorrect solutions stands in the way to the appropriate solutions. In order to study this effect, Smith and Tindell (1997) adapted a well-known paradigm of implicit memory to induce fixation during problem solving. In the original procedure (Graf & Schacter, 1985), the participants read first a list of words, and later, without any instructions referring to the previous study episode, they completed word fragments, with some of the solutions corresponding to the words in the previously processed list. In their version of the task, Smith and Tindell (1997) used the same experimental procedure, with the difference that the fragments of words to be completed were orthographically similar to the previously read words, but not fully compatible with them. The idea was to explore whether the early presentation of the words would create interference in the subsequent word-fragment task, due to the priming of related but incorrect responses. The results of several experiments conducted in this study showed that the participants' attempts to complete the test fragments were impaired by involuntary retrieval of the primed inadequate solutions. Interestingly, this effect seems to be implicit in nature, because it was not eliminated when the participants were explicitly warned not to use the words in the list. Smith and Blankenship (1989) found a similar pattern of results in picture–word problem-solving tasks.

Fixation effects have been also investigated in several studies using the remote associates test (RAT, Mednick, 1962), an instrument extensively employed to study creative performance in the verbal domain (e.g., Bowden & Jung-Beeman, 2003; Dorfman, Shames, & Kilhstrom, 1996; Mednick, Mednick, & Mednick, 1964; Schooler & Melcher, 1995; Smith & Blankenship, 1991). The procedure involves a series of trials in each of which participants are provided with three cue words from mutually distant associative clusters and asked to provide a target word that establishes an associative connection with all the cues (e.g., for the cues *rat*, *blue*, and *cottage* a viable target would be *cheese*). Using this paradigm, it has been demonstrated that a difficulty in finding appropriate solutions for problems may result from the fixation caused by highly accessible but inadequate words. For example, Smith and Blankenship (1991) showed how strong semantic associates of each cue word, readily coming to mind upon processing these cues, induced fixation on them and blocked access to the appropriate solution word. Other studies have shown that recently processed words, acting as cue-related distractors, can also produce fixation effects in the RAT, resulting in fewer problems correctly solved (e.g., Kohn & Smith, 2009; Vul & Pashler, 2007). All these results indicate that creative solutions in this paradigm may be negatively affected by exaggerated accessibility to responses other than the appropriate target, and demonstrate that the degree to which a representation is available, even to the point of blocking access to other representations, can be controlled by simple experimental manipulations.

In addition to blocking, there is at least one other situation in which the search for the appropriate representation can be impaired while looking for the right answer in a problem-solving task; namely, when the target representation is difficult to find

because of its own low accessibility. If one assumes that the accessibility of a particular representation depends, at least in part, on its current level of activation (Anderson, 1983; Gillund & Shiffrin, 1984; Nelson, Kitto, Galea, McEvoy, & Bruza, 2013; Nosofsky, Cao, Cox, & Shiffrin, 2014; Raaijmakers, & Shiffrin, 1981), any situational factor that diminishes the level of activation of a target representation would result in a lower probability of producing that representation as the correct answer. In sum, access to a representation could be reduced not only because of blocking by other, more salient representations (as in the case of fixation), but also because of processes that act to reduce the representation's level of activation. On the basis of previous research on memory, action, and attention, it has been postulated that such a reduction can be the result of inhibitory mechanisms that can render a representation temporarily less likely to be accessed, independently of the retrieval cue being used and the activation status of other representations (Dempster & Brainerd, 1995; Storm & Levy, 2012). From a convergent approach, recent brain-oriented studies, using electrophysiological (e.g., Waldhauser, Johansson, & Hanslmayr, 2012) and neuroimaging techniques (e.g., Wimber, Alink, Charest, Kriegeskorte, & Anderson, 2015), have found patterns of cortical activity specifically associated with the forgetting, and purportedly the inhibition, of competing memories. Could inhibitory mechanisms of this kind play a role in modulating the accessibility of potential solutions in problem-solving situations?

In interesting relevant work, Storm and Angello (2010) tried to verify if the ability to overcome fixation and solve RAT problems was directly related to the ability to inhibit memories. They hypothesized that those individuals who show a high level of performance in solving RAT problems should also show strong inhibitory effects in memory tasks, such as the retrieval-induced forgetting (RIF) effects found with the retrieval practice procedure (Anderson, Bjork, & Bjork, 1994). RIF refers to the phenomenon whereby practicing retrieval of some studied items causes the temporary inaccessibility of related nonpracticed items that compete for retrieval, and inhibition has been proposed as the primary mechanism underlying this memory impairment (i.e., Anderson, 2003; Anderson & Levy, 2009; Bäuml, 2007; Bjork, Bjork, & Caughey, 2007; Storm & Levy, 2012; but see Jonker, Seli, & MacLeod, 2013; Raaijmakers & Jakab, 2013 for noninhibitory accounts of RIF). Capitalizing on empirical evidence showing that individuals may vary in their ability to inhibit information, Storm and Angello (2010) hypothesized that if inhibitory processes can help to reduce accessibility, then those participants who show more inhibitory ability in a retrieval practice paradigm (i.e., higher RIF scores) should also show superior ability to overcome the fixation created by the exposure to the misleading associates in a RAT task. Their results showed a significant positive correlation between RIF scores and RAT performance in the presence of misleading associates, which seems to constitute the first proof of the relationship between fixation reduction and information inhibition.

A more direct proof of the involvement of basic inhibitory effects in the performance in a RAT situation would be established, however, if it could be shown that recently inhibited items in memory become less accessible as target responses. And that was precisely the aim of the experiments reported here, in which the general hypothesis under consideration was that inhibition of a

set of words, induced by retrieval practice in a prior memory task, would result in lower production of those words as creative solutions to a number of RAT problems.

Experiment 1

The specific goal of this experiment was to test the hypothesis that words previously inhibited, as a consequence of selective retrieval of their associates in a previous memory task, would have a diminished probability of being chosen as the appropriate creative solutions in RAT word problems.

The use of a selective retrieval procedure as a means of inducing episodic forgetting is of particular interest here. Researchers who have examined forgetting as a cost of retrieval (i.e., RIF effects) have frequently found that diminished accessibility in memory situations is not task specific. For example, the competitors' memory impairment that is induced by retrieval practice has been shown to survive completion of the task at hand and negatively affect performance in a posterior memory task of a different kind (e.g., Anderson & Spellman, 1995; Gómez-Ariza, Fernandez, & Bajo, 2012; Gómez-Ariza, Lechuga, Pelegrina, & Bajo, 2005; Spitzer & Bäuml, 2007; Veling & van Knippenberg, 2004; Weller, Anderson, Gómez-Ariza, & Bajo, 2013). Effects of this kind are also observed across what are assumed to be different memory systems, with inhibition originating in explicit tasks transcending to implicit tasks (e.g., Bajo, Gómez-Ariza, Fernandez, & Marful, 2006; Veling & van Knippenberg, 2004; but see Camp, Pecher, & Schmidt, 2005), or episodic-memory manipulations affecting subsequent performance in semantic memory operations (Carter, 2003; Levy, McVeigh, Marful, & Anderson, 2007; Starns & Hicks, 2004). More importantly, there are indications that the inhibited status of a representation originating in a given task can unwittingly have consequences in an unrelated cognitive realm (Iglesias-Parro & Gómez-Ariza, 2006; Storm, Angello, & Bjork, 2011). For example, Iglesias-Parro and Gómez-Ariza (2006) showed, using a decision-making paradigm, that retrieval-induced inhibition led to biased choices in a subsequent personnel-selection task: induced inhibition of features in a character that were desirable for a certain job were systematically related to a lower probability of that character being chosen for that job (see also Lechuga, Gómez-Ariza, Iglesias-Parro, & Pelegrina, 2012). Altogether, these findings suggest that the reduced accessibility to information that results from a given cognitive activity may affect other mental activities in need of using the same information. Following this line of thinking, it seems reasonable to expect inhibition created in the context of a memory task to modulate performance in a RAT context in which access to the same representations is necessary for the creative solution of the problems.

In memory situations, item inhibition can be induced with a (retrieval practice) procedure involving three different phases. In the first phase, participants study a list of category-exemplar pairs (i.e., fruit-banana, insect-butterfly, fruit-orange, insect-mosquito). Then, in a second phase presented as the memory test, participants are asked to repeatedly retrieve some exemplars (i.e., banana; hereinafter Rp+ items) from some of the presented categories. Critically, this manipulation allows researchers to compare two types of nonpracticed items: those from practiced categories (i.e., orange; hereinafter Rp− items) and those from unpracticed categories (i.e., butterfly; hereinafter Nrp items). Finally, in the third phase, the participants' memory for all studied items is tested. Not surprisingly, previously retrieved (Rp+) items are often better recalled than control Nrp items, suggesting that repeatedly activated items become more accessible in a later memory test. More interesting, however, is the fact that participants usually exhibit worse memory for Rp− items than for equally unpracticed Nrp items (the RIF effect). In this, and in the next experiment, this procedure was used to reduce the accessibility of specific Rp− items, with the aim of testing the hypothesis that their forgetting in the context of an earlier memory task would make those items less likely to be later found and produced as creative solutions to selected word problems in a subsequent RAT task.

Method

Participants. Thirty students from the Universities of Salamanca and Jaén (mean age = 19.5, SD = 2.6) took part in this experiment for course credit. This sample size was determined after considering the number of participants taking part in previous experiments (e.g., Iglesias-Parro & Gómez-Ariza, 2006; Iglesias-Parro, Gómez-Ariza, & Arias, 2009) that also looked at the effect of retrieval practice on a subsequent independent task. All participants were native speakers of Spanish and had normal or corrected vision.

Materials. The orthography-based word categories created by Bajo Gómez-Ariza, Fernandez, and Marful (2006; Gómez-Ariza et al., 2012) to study RIF in memory were used in the present experiments with minor modifications (see the Appendix for the complete set of stimuli). This material consisted of 36 items from six different categories (six items per category). Two more sets, of two words each, were used as fillers. The six items belonging to each category did so only by virtue of the orthographic overlap between them. Thus, the six items in a certain orthographic category were words beginning with the same two letters (e.g., *Bacalao, Balanza, Bañera, Barrera, Basura,* and *Batalla* for the category *BA*). Bajo et al. (2006) established the following three criteria to select the words: (a) length between two and five syllables; (b) no evident semantic or associative relationship among the words within the category; and (c) uniqueness of the third letter in the words within a category (for reasons having to do with the cues used in the retrieval-practice procedure). Following the same selection criteria, three of the 36 words from the original set were replaced in order to facilitate the creation of the RAT problems. All the words were selected from the Alameda and Cuetos (1995) normative database according to their lexical frequency. The items to work as *Rp−* and *Nrp* items were formed with medium-high frequency words (range = 34–98, M = 59.8) and the *Rp+* items were formed with medium-low lexical frequency words (range = 10–36, M = 21.1). Two counterbalanced versions of the materials were created so that the high frequency items appeared in both unpracticed item conditions (*Rp−* and *Nrp*). In one version, three certain categories were practiced (e.g., *BA, DI, PE*) and produced *Rp+* and *Rp−* items, and the other three categories were not practiced (e.g., *CA, MA, RE*) and produced *Nrp* items. In its counterbalanced version, the distribution of categories was the opposite. The two filler categories, with their corresponding words, were used at the beginning and the end of the learning list to avoid contamination by primacy and recency effects.

The RAT, composed of 36 problems, was specifically created for the experiment. Each problem consisted of three cue words with no obvious relationship among them (, e.g., *equilibrio, libra, justicia* [equilibrium, pound, justice]). The problems were made so that each could be solved with one of the 36 items studied in the first phase of the experiment (e.g., *balanza* [*scale*] for the three words above). Most of the RAT problems were constructed by selecting cue words associated to each solution word according to free association norms in Spanish (Fernandez, Díez, & Alonso, 2014; Fernandez, Díez, Alonso, & Beato, 2004). The associative relation between the RAT's problem cues and their solutions was moderate (forward/backward associative strength $< .20$), and it could be based on synonymy, contextual co-occurrence, or semantic relatedness. As previously mentioned, three words of the original set of 36 words used by Bajo et al. (2006) were replaced by normatively equivalent items (*capellan* became *capilla*, *mariscal* became *marinero*, and *retorno* became *retrato*). The reason for this modification was the difficulty to create adequate RAT problems for the original words.

Procedure. Participants were tested individually in a quiet room, randomly assigned to one of the two counterbalance conditions. Stimuli presentation at study and at retrieval practice was controlled by E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). The instructions for the each phase (study, retrieval practice and creativity test) appeared on the screen of the computer immediately before the phase started. In the study phase participants were informed that pairs of stimuli would be presented during 5 s, with 1-s interval between the items. Each pair was composed by a category identifier (i.e., *BA*) and by a word belonging to the category (i.e., *balanza*). The participants were told to pay attention to the syllable that identified the lexical category because it would be a retrieval cue in an upcoming memory test. The list of 36 stimuli was presented twice in random order during the study phase, with the first two and the last two pairs of stimuli acting as fillers. Next, in the retrieval-practice phrase, participants were shown the syllable identifying the lexical category (e.g., *BA*) during 2 s, followed by an empty 1-s interval and the presentation of a three-letter word stem for 6 s (e.g., Bal_ _ _ _), and they were asked to recall the unique word from the study list that matched that stem (Bajo et al., 2006). As it is usually the case in this procedure, the cue stems belonged to half of the items of half of the studied categories, and therefore a total of nine studied items were probed. This type of practice was repeated five times in random blocks, with each block including one item from each of the practiced categories plus one filler item at the beginning and at the end. After retrieval practice, participants solved arithmetical operations for 5 min and then were provided with instructions on how to solve the RAT problems. Specifically, they were required to find a word that could link the three words appearing in each trial on the screen and say the word aloud. No reference to the previously studied materials was made. Two practice problems, with solutions not corresponding to the study words, were presented before the beginning of the experimental trials. The test consisted of a randomized sequence of 36 problems divided in two blocks specifically organized to avoid output interference effects on the responses of most interest. Thus, the problems for which the solution word corresponded to unpracticed items ($Rp-$ and Nrp) in the previous memory task were presented in the first block, whereas the problems with solution words corresponding to pre-viously practiced items ($Rp+$) were presented in the second block. The three words of each problem were simultaneously presented in a row, on the center of the computer screen, for a maximum of 1 min. After a response was given, the participant pressed the space bar and the problem solution was presented on the center of the screen during 1 s, as feedback. If no response was provided after 1 min, the feedback window appeared on the screen automatically. The duration of the experimental session depended on participants' speed in solving the RAT problems, and it took approximately 1 hr.

Results and Discussion

The mean percentage of correct recall during the practice phase was 59% ($SD = 17.5$), and the mean percentage of correctly solved RAT problems was 45% ($SD = 18.8$), indicating adequate levels of performance by the participants and an absence of ceiling and floor limitations. To evaluate the effects of retrieval practice on subsequent problem solving, two separate repeated-measures ANOVAs were conducted on the percentages of RAT problems that were solved with items from the prior memory task. An analysis examining the effect of an item's retrieval-practice status ($Rp-$ vs. Nrp) on the probability of using the item as a RAT solution showed that participants solved significantly fewer problems whose solutions were $Rp-$ items than problems whose solutions were Nrp items, $F(1, 29) = 4.91$, $MSE = 167.45$, $p < .05$, $\eta_p^2 = .14$ (see Table 1). In other words, items putatively inhibited in a previous unrelated memory task were less prone to be later produced as solutions than control words that were left unaffected by that previous task.

A similar ANOVA with $Rp+$ and Nrp showed the benefit of earlier repeated retrieval in subsequently solving RAT problems: Problems whose solutions were well practiced words were more frequently solved than problems for which control unpracticed items were the solutions, $F(1, 29) = 22.00$, $MSE = 303.75$, $p < .01$, $\eta_p^2 = .43$.

These findings are consistent with the hypothesis that selective retrieval of verbal material in an independent memory task may significantly affect subsequent attempts at creative problem solving involving the same set of materials. First, we observed a facilitation effect in the RAT for the ($Rp+$) items that were activated during the retrieval practice phase. Second, and more relevant here, $Rp-$ items were less likely to be generated as solutions in the RAT than Nrp (control) items were. Thus, it could be assumed that repeated retrieval of $Rp+$ items made Rp- items less accessible from long-term memory, and that the posterior attempt to solve certain RAT problems was negatively affected by this loss of accessibility.

Table 1
Mean Percentages (and Standard Deviations) of Correctly Solved RAT Problems in Experiment 1 and 2 as a Function of the Status of the Solutions in the Previous Memory Task

	Rp+	Rp−	Nrp
Experiment 1	63 (26)	34 (19)	41 (21)
Experiment 2	66 (14)	23 (14)	46 (19)

Experiment 2

The results of Experiment 1 provide empirical support for the idea that the forgetting of nontarget information, previously competing for retrieval, may have negative consequences for creative thinking when the forgotten information turns out to be relevant in the generation of potential creative solutions. A procedural feature of Experiment 1, however, could limit the drawing of such a strong conclusion from the results. Because participants were given feedback at the end of each RAT trial, they could potentially notice that the words studied in the first phase of the experiment could work as solutions in the RAT task. If so, at least for some of the participants, the RAT could end up being an episodic memory test rather than a creativity task implicitly affected by changes in the activation level of relevant memory representations. In order to deal with this issue, and with the further aim of replicating a novel result, a new experiment was conducted in which special care was taken to present the retrieval practice task and the RAT as different and unrelated parts of the experimental session. In sum, we expected to obtain the same findings as in Experiment 1, and to strengthen the validity of the conclusions with additional controls aimed at minimizing participants' awareness of procedural interconnections.

Method

Participants. Thirty students (mean age = 22.1, SD = 1.9) from the University of Granada participated in the experiment for course credit. Because the effect size in the previous experiment was relatively large (η_p^2 = .14), we decided to conduct the present experiment with a similar number of participants. Also contributing to this decision was the expectation that the new experimental procedure would minimize within-group variability by providing less opportunity for the participants to be aware of the connection between the two tasks of the experiment. All participants were native speakers of Spanish and had normal or corrected vision.

Material and procedure. The material used for this experiment was the same as in Experiment 1, with the addition of 12 new RAT problems obtained from a previous study with a Spanish version of the test (Romo, 1980). The procedure was identical to that used in Experiment 1, with a few exceptions. First, in the initial instructions, the experimenter introduced the session as consisting of two different and separate experiments, one about memory and one about creativity. Second, before performing the actual RAT, the participants familiarized themselves with the task by doing some practice trials (for 6–8 min) with filler RAT problems. Third, no feedback was provided to participants after any RAT problem. Fourth, the participants solved a larger set of RAT problems (now 48); 36 of these problems could be solved with one of the words studied in the first, memory phase, whereas 12 problems (control) had word solutions that were completely unrelated to the previous phase. And lastly, at the end of the experimental session participants completed a questionnaire with three questions regarding the use of strategies in the three tasks (study, retrieval practice, and RAT), plus a final question where they reported whether they noticed any relationship between the two parts of the experiment (memory and problem solving). Specifically, this question stated: "Did you notice any connection between the memory and the creativity tasks? If so, could you please tell us more about it?" The idea behind this questionnaire

was to assess the degree to which participants related the final problem-solving test to the memory task. The length of the experimental session depended on participant's speed in solving the RAT problems, and it took between 50 and 60 min.

Results and Discussion

Five participants were excluded from the analyses because they reported, in the final questionnaire, that they realized that the RAT problems were related to the items in the memory task. Specifically, they informed that some of items presented during the memory task could be used as solutions in the RAT. Importantly, the five participants noticed the relationship between the two tasks while performing the last block of RAT problems (where the solutions were Rp + items). Overall recall accuracy during the retrieval practice phase was 64% (SD = 20.0) and the mean percentage of correctly solved RAT problems was 46% (SD = 6.0). As in Experiment 1, an analysis compared the percentages of RAT problems that were solved with $Rp-$ and Nrp items (see Table 1). A repeated measures ANOVA revealed a significant effect of item's status, with participants significantly producing fewer $Rp-$ words than Nrp words as solutions in the RAT, $F(1, 24) = 24.53$, $MSE = 272.22$, $p < .01$, $\eta_p^2 = .51$. The same pattern of results was obtained when the data of the five participants who ended up noticing the connection between the two experimental tasks were included in the analyses.[1] As in Experiment 1, and due to enhanced activation during the retrieval practice, Rp + items were provided more frequently than Nrp items as RAT solutions, $F(1, 24) = 13.41$, $MSE = 356.40$, $p < .01$, $\eta_p^2 = .36$.

In sum, the main results found in the previous experiment were replicated in Experiment 2.[2] Specifically, fewer RAT problems were solved with items that had presumably been the target of inhibitory control than with control items. Because steps were taken to minimize noticing by the participants of the relationship between the "memory" and the "problem-solving" tasks, and because the effects were still large and reliable when data from suspecting participants were eliminated from the statistical analyses, the finding of impaired problem solving as a consequence of retrieval-induced forgetting in an unrelated task does not seem to depend on the participants' awareness about the episodic nature of the solutions. Rather, the impairment for Rp− items that was observed in the present work was larger under more implicit conditions (Experiment 2 or its replication relative to Experiment 1; see Footnote 2) or when the participants that reported some degree of awareness were excluded. This goes in line with the

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[1] The RAT problems were still resolved less frequently with Rp− items (M = 24.44; SD = 13.50) than with Nrp items (M = 47.04; SD = 17.67), $F(1,29) = 33.01$, $MSE = .023$, $p < .01$, $\eta_p^2 = .53$.

[2] Because this is a novel effect, and to make sure that the experiments were not underpowered, we conducted a replication of Experiment 2. Based on the effect size observed in that experiment, we calculated the necessary sample size to detect the experimental effect (G*Power 3.1; Faul, Erdfelder, Buchner, & Lang, 2009). The power analysis indicated that a sample of 18 participants was large enough to detect a main effect of retrieval practice (Rp− vs. Nrp), with 80% power and alpha set at 5%. The results of this follow-up experiment (with the same material and procedure of Experiment 2, and 18 participants) revealed the same pattern of significant findings as in Experiment 2. Specifically, Rp− items (M = 28.39; SD = 15.35) were reliably less used as RAT solutions than Nrp items (M = 41.36; SD = 14.67), $F(1,17) = 5.74$, $MSE = .026$, $p = .03$, $\eta_p^2 = .25$.

results reported in Weller, Anderson, Gómez-Ariza, and Bajo (2013) showing that when explicit retrieval strategies are induced, RIF effects become smaller (as further elaborated in the General Discussion).

Also, as in Experiment 1, the RAT problems that could be solved with practiced items benefited the most from previous test-study cycles, which further points to the crucial role that accessibility, as determined by the dynamics of memory mechanisms, may have on solving problems demanding creative solutions.

General Discussion

In the majority of views, knowledge provides the building blocks from which new ideas and novel solutions are constructed (Smith & Ward, 2012; Weisberg, 2006). From this perspective, the processes that intervene in making relevant knowledge more or less accessible when solving a problem are crucial for understanding creative thinking. While previous research has focused on how inhibition of highly available interfering information may facilitate finding novel solutions by making old ideas less accessible (Angello, Storm, & Smith, 2015; Storm et al., 2011; Storm & Patel, 2014), no empirical evidence had been collected on the logical implication that these inhibitory processes may also have undesirable effects on appropriate target information, making it less accessible and, as a consequence, hampering the solution of creative problems.

As previously stated, our aim was to explore to what extent retrieval-induced forgetting might hinder performance in a subsequent unrelated task that required participants to solve creative verbal problems. The results from three experiments employing a retrieval-practice procedure, followed by a RAT, showed that items that had previously been retrieved (Rp+) were more frequently produced as creative solutions in the RAT than unpracticed control items (Nrp), suggesting that extensive practice increases the accessibility of these items and facilitates problem solving. More relevantly, items that were unpracticed but strong competitors during repeated retrieval (Rp−) were consistently and reliably less prone to be produced as solutions than the equally unpracticed control (Nrp) items. Therefore, the overall pattern of results is consistent with the idea that the activation level of target information modulates problem-solving performance, and provides new evidence supporting the assumption that accessibility to pertinent solutions, can be increased (in the case of Rp + items) or reduced (in the case of Rp− items) as a consequence of previous engagement in an unrelated memory task.

One aspect of our results that is worth mentioning is the increment in effect size from Experiment 1 to Experiment 2 (and its replication, see Footnote 2). At first sight, this increment might seem at odd with some previous experiments reporting small (see Murayama, Miyatsu, Buchli, & Storm, 2014 for a recent meta-analysis) or null effects (Camp et al., 2005; Perfect, Moulin, Conway, & Perry, 2002) of retrieval practice in implicit tasks. However, in our view, these discrepancies may reveal the role of additional factors during implicit retrieval. Although effect sizes depend on a variety of factors (i.e., sample characteristics, test requirements, experimental designs) that usually differ from one experiment to the next, the fact that Experiment 2 (and its replication) exhibited a larger impairment for Rp− items (relative to

Nrp items) than Experiment 1 may point to the role that the degree of implicitness and the involvement of strategic processing can play in our results. This argument is in line with the findings by Weller et al. (2013), who in three experiments convincingly demonstrated that the use of strategies, such as covert cuing,[3] might mask retrieval-induced forgetting. Going back to the present experiments, because in Experiment 2 and its replication the connection between the memory phase and the RAT phase was much less evident to participants than in Experiment 1, covert cuing (or other memory-search strategies) would be harder to implement, resulting in larger RIF effects. In other words, the fact that the final tests required participants to "think" more than "recall" could largely contribute to the size of the effect by discouraging participants from using retrieval strategies (see, e.g., Iglesias-Parro & Gómez-Ariza, 2006 or Lechuga et al., 2012). In this line, these results also add to the evidence suggesting that RIF can be obtained in indirect memory tasks (such as the RAT in our experiments) whenever the conditions minimize the use of retrieval strategies, and when the memory task taps into the same type of memory representation that was inhibited during selective retrieval (Bajo et al., 2006; note that performance in the RAT tasks requires both retrieval of semantic and lexical information).

From a theoretical stand, our interpretation of the present results is based on the assumption that the reduced accessibility to the Rp− items is due to inhibitory processes acting on their memory representations during selective retrieval. According to the inhibitory theory (Anderson, 2003; Levy & Anderson, 2008), access to the target traces during retrieval may require a reduction in the activation level of related but inappropriate memories that compete for awareness/retrieval, with inhibition subserving this control function. In this view, in the presence of the retrieval cue during retrieval practice, an inhibitory control mechanism acts on the (inappropriate) Rp− items' memory representations to facilitate the retrieval of the (target) Rp+ items. Importantly, while inhibition of competing items comes with facilitated access to the target items during the practice phase (a benefit), it may also come with a cost, if the inhibited items turn out to be needed as target items later. Our finding, of fewer RAT problems solved with Rp− items than with Nrp items, fits well with such an inhibitory theory of memory control if one assumes that inhibitory control during the memory task made Rp− items to remain less accessible during the later RAT.

Although, retrieval-induced forgetting effects can also be accounted for mechanisms other than inhibition under some circumstances (i.e., Soriano, Jiménez, Román, & Bajo, 2009), the fact that in our experiments accessibility to memory representations was tested with cues different than the ones used during selective retrieval (cue-independence) leads us to favor an inhibitory account of our main findings. Because participants were tested with word-triplets that were (at the semantic and lexical levels) totally unrelated to the practiced items, we posit that interference from the more recently processed Rp+ items was minimized during the contextually unrelated RAT phase. By circumventing the practiced items, independent cues are thought to isolate the activation state

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[3] Cover cuing refers to the participants' tendency to use the practiced categories as memory cues even though they are not provided overtly at test.

of the Rp− items, so providing an index that is not contaminated by interference (see Weller et al., 2013).

Hence, and although the focus of our experiments was not to explore competing explanations of RIF, the finding of a negative aftereffect of selective retrieval in an unrelated creativity test favors inhibitory interpretations of the effect (see Weller et al., 2013). Cue independence is a unique prediction of inhibitory models, and one that is difficult to accommodate by alternative explanations (Anderson, 2003; Anderson & Spellman, 1995; Weller et al., 2013). Thus, in the experiments discussed here, observing poor accessibility of Rp− items in a creativity task, in which item-specific cues (triplets) are uniquely associated with the Rp− items represents a challenge to interference-based accounts (e.g., Raaijmakers & Jakab, 2013; Verde, 2012) proposing that impaired access to Rp− items in the final test would be a consequence of the interference created by the RP+ (strengthened) items initially associated to the same cue.

It might still be argued that interference might not be acting at the semantic level, when retrieving the proper semantic information (the word semantically related to the three presented words), but at an orthographic level during lexical selection. Obviously, retrieving the right solution to the RAT problems requires both access to the semantic information linking the three words in the problem, but also selection and retrieval of the appropriate lexical information (the actual word) to be produced as a response to the problem. Thus, it is possible that Rp− items could be less produced as RAT solutions because when the lexical information for the appropriate word has to be selected, competition from the strengthened Rp+ items, which share the first syllable with the Rp− items, may act to hamper lexical retrieval of the RAT solution. Although support for this "lexical interference" explanation is based on empirical evidence showing that lexical selection may be hindered by competition from orthographically related items (i.e., White, Abrams, McWhite, & Hagler, 2010), these data also show that orthographic competition is eliminated when the context includes semantic information that is congruent with the target meaning (White, Abrams, Palm, & Protasi, 2012). In the present context, the presence of the three congruent semantic cues for the appropriate lexical item to the RAT problem should override the possible orthographic competition coming from the shared syllable of the Rp+ items. Hence, although it might be argued that this additional interference mechanism might explain the present results, the existing data suggest that in the present conditions lexical interference by Rp+ shared syllables is not likely to play a significant role in the observed decrement in accessibility to Rp− items during RAT problem solving. Further research should be conducted specifically aimed to clarify this point, and to further document the generalization of probe-independent effects when semantic competitors are included in the retrieval practice phase.

Cue-independent RIF also challenges the main assumptions of the context-based account of RIF. According to this recent proposal (Jonker et al., 2013), the loss of accessibility to Rp− items relative to Nrp items stems from inappropriate contextual cuing during the final test, on the assumption that the study and retrieval-practice phases represent two different contexts. In this view, practiced categories become associated with both the study and the retrieval-practice phases, whereas unpracticed categories are uniquely associated with the study phase. As a consequence, providing the names of the categories as retrieval cues to partici-

pants at test (such as it has been done in many studies) may make it harder the access to Rp− items than Nrp items, since participants might inappropriately use the retrieval-practice context to search for Rp− items. The usage of independent cues and an unrelated task to assess Rp− accessibility, as done in the present study, however, cannot be easily explained by a context-based account of RIF. It is difficult to argue that the triplets provided to participants were harder to solve in the case of the Rp− items because participants attempted to use the (irrelevant) context of the retrieval practice phase to come up with creative responses in the RAT.

In sum, while the Rp− impairment observed in in the present experiments is predictable from an inhibitory account, both associative and contextual-change approaches would need additional assumptions, mechanisms, and empirical data to explain it. However, because the goal of our experiments was not to provide evidence of the inhibitory nature of RIF, we did not include specific conditions (i.e., a restudy condition) to test the assumptions of inhibitory theories (i.e., retrieval specificity, strength independence, etc.). Thus, further research might be needed to clarify if the properties of our observed RIF fully support its inhibitory nature. Still, and regardless of what might eventually be the best explanation of the underlying mechanism, the present results show, for the first time, that reducing memory accessibility through selective retrieval may negatively influence performance in a subsequent creative problem-solving task. A vast number of studies with the retrieval-practice and related procedures have shown that retrieving specific memories makes competing pieces of information harder to recall or recognize later (see Murayama et al., 2014). However, much less attention has received the idea that retrieval-induced forgetting may influence tasks other than recall or recognition, a reasonable hypothesis considering that information's accessibility should affect performance in virtually any task requiring the use of that information. The main findings of the present experiments clearly support this idea, showing that insight problem-solving may be effectively modulated by previous selective retrieval, and adding converging evidence to previous findings with decision-making tasks (Iglesias-Parro & Gómez-Ariza, 2006; Iglesias-Parro et al., 2009; Lechuga et al., 2012) to show that RIF has the power to influence thinking. Additionally, the present results show that such an influence extends to creative thinking, and that it does so even when participants are not aware of the relation between the memory task and the subsequent creativity task. Thus, ours join previous findings showing that the negative aftereffect of selective retrieval can be observed in indirect memory tasks (as described by Murayama et al., 2014), albeit, to our knowledge, ours are the very first to do so in the context of creative thinking.

As already mentioned, previous experiments addressing the relationship between forgetting and problem-solving behavior have focused on the role that forgetting (via inhibition) may play in problem solving and creative thinking to prevent fixation. The idea is that ignoring or forgetting information which otherwise would potentially interfere with new solutions should help people to solve problems. In support of this idea, Storm and colleagues have shown that the ability to forget relates to efficient performance in problem solving. Storm and Angello (2010), for example, had participants studying fixation-inducing associations before performing a RAT. Replicating previous findings, these research-

ers found that inducing fixation impaired solving RAT problems. More relevant here, Storm and Angello (2010) found that the amount of RIF exhibited by participants in a retrieval-practice task predicted their level of impairment in the RAT. Participants who exhibited high fixation in the RAT showed less RIF than participants who were more immune to fixation (for a related result see Koppel & Storm, 2014), suggesting a link between overcoming fixation and inhibitory control. These findings, and additional evidence by Storm Angello, and Bjork (2011) showing that words discarded as inappropriate RAT solutions become difficult to recall in a subsequent memory test, suggest that forgetting plays an important role during problem solving, as a way of overcoming interference from unwanted pieces of information, and somehow paralleling the role that forgetting has been shown to play during memory retrieval (Anderson, 2003).

In what can be seen as a complementary effort, the main motivation of the present work was to study whether the forgetting that stems from retrieving related information might hinder, rather than help, the process of problem solving. Thus, while previous work has (more or less directly) been based on the idea that forgetting may be beneficial, we have here documented clear negative consequences of retrieval-induced forgetting in the context of creative thinking. The relevance of the issue can be readily apparent by reflecting on many real life situations, in which we may start to tackle a problem by talking to other people about possible solutions, or by looking into the past for similar situations. Whereas we probably expect that all these would help us solve our problem, the fact that these activities usually require repeated retrieval of problem information might lead to the forgetting of related crucial information, preventing us from effectively dealing with the problem at hand. It would be an interesting line for future studies to further explore the dynamics of inhibitory mechanisms and their effects on creative thinking in relation to a wider variety of problems and under more naturalistic conditions.

To end the discussion with a more global perspective, our findings help to place level of activation as an important variable influencing cognitive operations, with the power to either facilitate or impair performance in a variety of tasks. It seems to be also the case that the way in which activation modulates cognitive performance is far from simple, and it depends on complex interactions with task demands, present and past. A long tradition of research in the realms of language, memory, and perception (e.g., Pickering, & Ferreira, 2008; Schacter & Buckner, 1998) has convincingly demonstrated that increasing the activation of stored information may facilitate performance in subsequent tasks requiring its use, and such priming effects have also been observed in problem-solving situations (e.g., Howe, Garner, Dewhurst, & Ball, 2010; Howe, Threadgold, Norbury, Garner, & Ball, 2013). And there is also ample evidence that highly activated representations can nonetheless have negative effects on performance in a variety of paradigms, including problem solving (e.g., biasing, blocking, or fixation effects: Banks, 2013; Dodds et al., 2002; Evans, Barston, & Pollard, 1983; Kohn & Smith, 2009; Smith & Blankenship, 1991). Now, in what conforms a parallel set of findings, recent research suggests that reducing the activation level of some representations (i.e., inhibiting them) may result in better performance in a problem-solving task (Storm et al., 2011; Storm & Patel, 2014), while the new findings reported here suggest that inhibition can actually result in an impediment toward solving the same type

of task. Better understanding of the more labile properties of cognitive representations, the ways in which their activation levels can vary, and a clearer discernment of the conditions likely to promote positive or negative effects on performance, should be the goal for future lines of research in this realm of cognitive science.

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(Appendix follows)

Appendix

Orthography-Based Word Categories Used in Experiments 1 and 2

	BA	CA	DI	MA	PE	RE
Practiced items	*Bacalao*	*Canario*	*Digestión*	*Maquillaje*	*Pedazo*	*Rebaño*
(Rp+)	*Balanza*	*Capilla*	*Dilema*	*Marinero*	*Pesimismo*	*Receta*
	Bañera	*Caracol*	*Divorcio*	*Matanza*	*Petición*	*Relámpago*
Unpracticed items	*Barrera*	*Cabello*	*Diciembre*	*Madurez*	*Pelota*	*Regalo*
(Rp−/Nrp)	*Basura*	*Camarero*	*Difunto*	*Maleta*	*Península*	*Reserva*
	Batalla	*Categoría*	*Diseño*	*Manifiesto*	*Pereza*	*Retrato*
Filler items	*Fidelidad*		*Lejanía*			
	Filosofía		*Leyenda*			