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The Mechanisms and Boundary Conditions of the Einstellung Effect in Chess: Evidence from Eye Movements

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Abstract

In a wide range of problem-solving settings, the presence of a familiar solution can block the discovery of better solutions (i.e., the Einstellung effect). To investigate this effect, we monitored the eye movements of expert and novice chess players while they solved chess problems that contained a familiar move (i.e., the Einstellung move), as well as an optimal move that was located in a different region of the board. When the Einstellung move was an advantageous (but suboptimal) move, both the expert and novice chess players who chose the Einstellung move continued to look at this move throughout the trial, whereas the subset of expert players who chose the optimal move were able to gradually disengage their attention from the Einstellung move. However, when the Einstellung move was a blunder, all of the experts and the majority of the novices were able to avoid selecting the Einstellung move, and both the experts and novices gradually disengaged their attention from the Einstellung move. These findings shed light on the boundary conditions of the Einstellung effect, and provide convergent evidence for Bilalić, McLeod, & Gobet (2008)'s conclusion that the Einstellung effect operates by biasing attention towards problem features that are associated with the familiar solution rather than the optimal solution.

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Introduction

During creative problem-solving, prior knowledge and experience can enhance performance by efficiently guiding us towards solutions that worked in the past. However, prior knowledge can also harm performance if the problem requires a novel solution. One of the most famous examples of the negative impact of prior experience on problem-solving is the Einstellung (mental set) effect (e.g., [1–5]). This effect was first demonstrated using a problem-solving task that required participants to use water jugs of known volumes to measure a specific quantity of water [1]. The participants were first shown five introductory problems that could be easily solved using a simple algorithm. Next they were shown a superficially similar problem that required a new algorithm (i.e., the "extinction problem"). Interestingly, many participants claimed that the extinction problem was insoluble, even though it was easily solved by a control group of participants who had not experienced the introductory problems. In this example, the participants' prior experience interfered with problem-solving, because a familiar (but inappropriate) solution blocked the discovery of a new solution.

Of relevance to the present study, expertise in a domain has also been shown to induce "Einstellung-like" effects [6–13]. In particular, chess has proven to be a fruitful domain for investigating the mechanisms underlying the Einstellung effect (for a review, see [6]). Chess is widely considered to be an ideal experimental task for studying human cognition [14], and chess provides numerous methodological advantages, such as an interval rating scale for the measurement of chess skill [15,16]. Capitalizing on these advantages, [8] examined the Einstellung effect in chess experts with a wide range of skill levels (Candidate Masters, Masters, and International Masters). To induce the Einstellung effect, [8] asked chess players to solve chess problems that contained both a familiar (but not optimal) solution, and a less familiar optimal solution (for a similar paradigm see [17]). Like the participants in the water-jugs experiment [1], many of the chess players failed to find the optimal solution. Importantly, [8] showed that the presence of the familiar solution reduces the performance of chess players to the level demonstrated by much weaker players (three standard deviations lower in skill level) who were given a control problem that only contained the optimal solution. Thus, the Einstellung effect can have a dramatic effect on the performance of experts in a domain-specific problem-solving situation.

Building on these findings, [7] used eye tracking to investigate the mechanisms underlying the Einstellung effect. Specifically, [7] instructed chess experts to find the fastest way to win (i.e., to find checkmate in the fewest possible moves). Replicating prior findings [8,17], the chess experts initially discovered the familiar but longer solution (i.e., checkmate in five moves), but failed to find the shortest solution (i.e., checkmate in three moves). Importantly, the chess experts continued to look at the chess squares associated with the familiar solution, even though they reported that they were searching for alternative solutions. Moreover, as evidence that the optimal solution was not inherently difficult, a control group of chess experts successfully discovered the optimal solution when they were shown a modified version of the problem that did not contain the familiar solution. Based on this pattern of results, [7] concluded the Einstellung effect operates by biasing attention towards problem features associated with the first solution that comes to mind – thus preventing the discovery of new solutions.

Extending the investigation of [7], the goal of the present study was to further explore the bias in the spatial distribution of fixations towards locations on the chessboard that are related to the familiar but non-optimal move (henceforth, the Einstellung move). Specifically, we monitored the eye movements of both novice and expert chess players while they selected white's best move (i.e., choose-a-move task) for a variety of chess problems that were designed to induce the Einstellung effect. As shown in Figure 1, all of these problems contained an Einstellung move that resembled a familiar checkmate solution but which was modified such that checkmate was no longer possible. The Einstellung move was located inside a target region in one corner of the board (in Figure 1 the target region is indicated with a dotted line), and there was always an optimal move located outside of the target region.

As described in Figure 1 and Appendix S1, we examined two different types of problems. The first type of problem (see Problem 1 in Figure 1) closely resembled the problems used by [8] (Experiment 2), because the Einstellung move constituted a good move that was advantageous for white, although it was not as good as the optimal move. For this type of problem, we expected to replicate [7] and [8] by showing that many of the chess players would choose the Einstellung move, rather than the optimal move. Moreover, based on the findings of [7], we expected that the chess players would have trouble disengaging their attention from the familiar solution, as shown by a high percentage of time spent fixating the target region containing the Einstellung move. In contrast, for the second type of problem, we examined a novel situation in which the Einstellung move was a blunder rather than a good move (see Problems 2, 3 and 4 in Figure 1). We expected that this change might reduce the magnitude of the Einstellung effect, such that chess players would be better able to select the optimal move, and to disengage their attention from the familiar solution. Thus, our rationale for including two different types of problems was to try to uncover boundary conditions that might modulate the strength of the Einstellung effect. In addition, we explored expert/novice differences in the magnitude of the Einstellung effect as reflected in the quality of the chosen moves and the degree to which looking behavior was biased towards the target region.

Method

Ethics Statement

Written informed consent was obtained from each participant (or from a parent/guardian if the participant was a minor). The research programme was approved by the Ethics Review Unit at the University of Toronto.

Participants

Thirty-four chess players (17 experts and 17 novices) were recruited from online chess forums and from local chess clubs in Toronto and Mississauga (Canada). The mean age was 30 (range = 15 to 56 years) in the expert group, and 26 (range = 17 to 47 years) in the novice group. There was one female player in the expert group, and there were three female players in the novice group. For the expert players, the average CFC (Canadian Chess Federation) rating was 2223 (range = 1876 to 2580). All of the novice players were unrated but active club players. All of the participants had normal or corrected-to-normal vision.

Materials and Design

The four experimental problems are shown in Figure 1. These problems were designed to give the impression that there was a familiar checkmate solution inside a target region (shown in Figure 1 with a dotted line) that was always located in one corner of the board. However, in all four problems, the checkmate solution was not possible due to the location of black's defender pieces. For example, Problem 4 resembles the familiar "smothered mate" checkmate sequence in which a player sacrifices a valuable piece (i.e., by moving the white rook to g8) in order to draw an opponent's piece onto a square that will block the escape route for the king (i.e., the black rook on f8 captures the white rook on g8). This checkmate solution is not possible in Problem 4 because the black bishop on h5 is protecting the f7 square, which prevents the white knight from moving to f7 to checkmate the king.

As shown in Figure 1 and Appendix S1, each problem contained one (or more) familiar moves (i.e., Einstellung moves) that were associated with the familiar checkmate solution. All of these moves involved putting the black king in check, and all of these moves were located within the target region. For Problem 1, the Einstellung move was as an advantageous but suboptimal move (i.e., Ba7), whereas for the remaining problems (i.e., Problems 2, 3 and 4), the Einstellung moves were always blunders (Problem 2: Qg7; Problem 3: Qa7 or Qa8; Problem 4: Rg8 or Nf7) that led to material loss and/or severely weakened white's position. In all four problems, there was a better move (i.e., the optimal move) located outside of the target region (Problem 1: Ng2; Problem 2: Na3; Problem 3: Rg5; Problem 4: Rb3).

In addition to the four experimental problems, the players were shown eight filler trials that were designed to mask the purpose of the experiment. The filler trials incorporated a variety of solutions that ranged from checkmate to material gains to defensive tactics. Thus, every player completed a total of 12 problems (i.e., 4 experimental problems and 8 filler problems) that were always shown in the following trial order: two fillers, Problem 1, three fillers, Problem 2, one filler, Problem 3, two fillers, Problem 4.

Apparatus and Procedure

Eye movements were measured with an SR Research EyeLink 1000 system with high spatial resolution and a sampling rate of 1000 Hz. The experiment was programmed and analyzed using SR Research Experiment Builder and Data Viewer software. Viewing was binocular, but only the right eye was monitored. A chin rest and forehead rest were used to minimize head movements. Following calibration, gaze-position error was less than 0.5°. The chess problems were presented using images (755×755 pixels) that were created using standard chess software (Chessbase 11). These images were displayed on a 21 in. ViewSonic monitor with a refresh rate of 150 Hz and a screen resolution of 1024×768 pixels. Participants were seated 60 cm from the monitor, and the width of one square on the chessboard equaled approximately 3.4 degrees of visual angle.

Prior to the experiment, the participants were instructed to choose white's best move as quickly and as accurately as possible, and they were told that they would be given a maximum of 3 minutes to respond to each problem. At the start of each trial, the participants were required to look at a fixation point in the center of the screen, prior to the

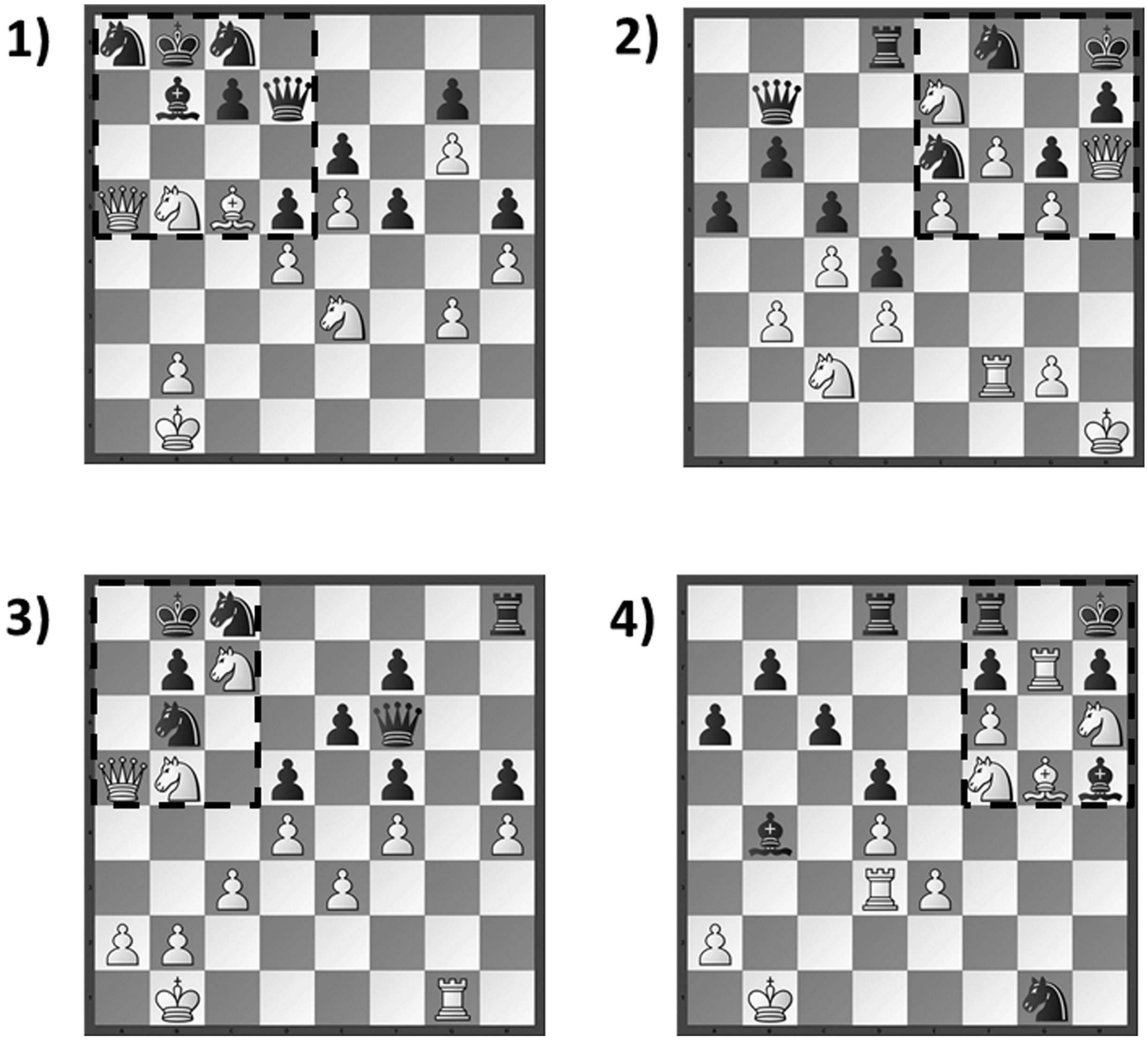

Figure 1. The four experimental problems (1,2,3,4). White is to move in all problems. As discussed in the text, each problem contained a familiar move (i.e., the Einstellung move) that was associated with a checkmate solution that was not possible due to the position of Black's defenders. The Einstellung moves were always located within the target region (shown here with a dotted line). For problem 1, the Einstellung move was a reasonable move (i.e., Ba7), and for the remaining problems the Einstellung moves were blunders (i.e., Problem 2: Qg7; Problem 3: Qa7 or Qa8; Problem 4: Rg8 or Nf7). For all four problems, the optimal move on the board was located outside of the target region (i.e., Problem 1: Ng2; Problem 2: Na3; Problem 3: Rg5; Problem 4: Rb3). See Appendix S1 for further details.
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presentation of the chessboard. The participants were asked to press a button as soon as they had made their decision, and they then reported their move verbally to the experimenter. If three minutes elapsed prior to the button press (this occurred on 10% of the experimental trials for the novices, and 0% of trials for the experts), then the chessboard was removed from the screen and the chess player was prompted to immediately provide their best answer. At the end of the experiment, we interviewed both the experts and novices to obtain retrospective subjective responses concerning their problem-solving strategies. Specifically, we provided the chess players with a picture of each of the four experimental problems (with a dotted line surrounding the target region), and we asked them to try to recall their thought processes with regards to the target region of the board.

Results

Our main goal was to explore the impact of the level of expertise of the chess players (i.e., expert versus novice) and the type of Einstellung problem (i.e., suboptimal versus blunder) on the magnitude of the Einstellung effect. Accordingly, in the analyses below, we assessed the magnitude of the Einstellung effect by examining the quality of the chosen moves, and the degree to which looking behavior was biased towards the target region containing the Einstellung move. Following these analyses, we will then discuss the retrospective responses that were provided by the expert and novice chess players during the post-study interview. For all of the analyses reported below, we excluded two of the trials from the novice chess players. Specifically, we excluded one trial from Problem 2 because the chess player selected an illegal move, and we excluded another trial from Problem 3 because the chess player did not fixate on the target region.

Analysis of Move Quality

As summarized in Appendix S1, we first examined the quality of the moves selected by the expert and novice chess players, for each of the four experimental problems (1,2,3,4). To assess move quality, we asked five expert chess players who did not participate in the study to rate each move on a scale from 1 to 10 (1 = a blunder, 10 = a very strong move). Three of these expert raters were International Masters with FIDE (World Chess Federation) ratings above 2300, and two of the raters were Grand Masters with FIDE ratings above 2500. In addition, we consulted two chess programs (Houdini 2 Pro and Deep Rybka 4). Both of these chess programs have Elo ratings of approximately 3000. Appendix S1 contains the move quality ratings (averaged across the five expert raters), the program scores (averaged across the two programs), the location of each move on the board, and the frequency with which each move was selected by the expert and novice players. Not surprisingly, as shown in Appendix S1, the experts were better able to select the optimal moves than the novices, and the experts showed superior overall performance for both of the dependent measures of move quality (i.e., expert ratings: $t(32) = 6.04$, $p < .001$; chess program scores: $t(32) = 4.93$, $p < .001$).

Most strikingly, although the experts showed superior overall performance, an equal proportion of novices and experts selected the suboptimal Einstellung move in Problem 1 (i.e., 8 out of 17 players for both groups) instead of the optimal move on the board. Thus, Problem 1 replicates prior findings that the presence of a familiar good solution can prevent chess players from choosing a better solution [7–8,17], and reveals that an equal proportion of experts and novices were attracted to the Einstellung move. However, when the Einstellung move was a blunder (i.e., Problems 2, 3 and 4), all of the experts and the majority of the novices were able to avoid selecting the Einstellung move. Overall, this pattern of results supports our hypothesis that a reduction in the move quality of the familiar solution can weaken the strength of the Einstellung effect.

Analysis of Target Region Eye Movement Measures

To further investigate the Einstellung effect, we next examined the extent to which the expert and novice players' eye movements were directed towards the target region of the board. As a starting point for this analysis, we used the following measures (averaged across all four problems) to compare the eye movements of the expert and novices players: (1) Time to first fixation (i.e., the interval of time between the start of the trial, and the start of the first fixation on the target region); (2) Average dwell duration (a dwell is defined as one or more consecutive fixations on the target region, prior to the eyes moving to a different region of the board); (3) Total dwell time (the sum of the duration of all of the dwells on the target region); (4) Number of dwells (the total number of dwells on the target region); (5) Percentage of looking time (the proportion of time that the chess players spent looking at the target region of the board). Table 1 displays the means and standard errors of the different measures and the corresponding t test results.

As shown in Table 1, the experts displayed significantly shorter times to the first fixation on the target region, relative to the novices. This ability of the experts to rapidly fixate on the target region in the corner of the board is consistent with their previously demonstrated processing advantage for domain-related perceptual patterns in their peripheral vision ([18–21]; for reviews see [22–23]). Given that the chess players began the trial by fixating on the center of the board, it is remarkable that the chess players were able to fixate on the target region within an average of 407 ms for experts, and 719 ms for the novices. Moreover, such rapid fixations on the target region indicate that both the novice and expert players began the trial by considering the Einstellung move, which coincides with prior investigations of the Einstellung effect that showed that the familiar solution comes to mind first [7–8]. In addition, relative to the novices, the chess experts displayed shorter average dwell times and higher numbers of dwells in the target region. There were no significant expert/novice differences for the remaining two measures (i.e., percentage of looking time and total dwell time).

Analysis of Looking Behaviour Over Time

Next, we examined the extent to which looking behaviour changed over time, by dividing each of the trials into four time intervals of equal length (for a similar analysis procedure, see [7,24]). Thus, the length of these intervals varied depending on the duration on the trial, which allowed us to combine the data from trials of different durations. We then calculated the percentage of looking time and the number of dwells, for each of the time intervals (1,2,3,4), for each level of expertise (expert, novice), and for each type of Einstellung problem (i.e., suboptimal versus blunder).

Suboptimal move Einstellung problem. The pattern of results for the suboptimal move problem (i.e., Problem 1) revealed expert/novice differences for both the percentage of looking time and the number of dwells measures. As shown in Figure 2 (Panel A), the percentage of looking time measure revealed that the experts spent more time in the target region than the novices during the first quarter of the trial. However, for the remaining three time intervals, the experts (but not the novices) gradually looked away from the target region. This difference in the pattern of results for experts and novices was reflected by a significant linear trend for the experts ($F(1, 66) = 13.12$, $p < .01$) but not for the novices ($F(1, 66) = 2.25$, $p = .138$), and by a significant two-way interaction between expertise and time interval ($F(3, 96) = 3.95$, $p < .05$). In addition, as shown in Figure 2 (Panel A), the number of dwells in the target region increased over time for expert players (but not the novices), as reflected by a significant interaction between expertise and time interval, ($F(3, 96) = 4.88$, $p < .01$).

However, the global expert/novice differences shown in Figure 2 (Panel A) are somewhat misleading given that there were two distinct groups of experts (i.e., the experts who selected the optimal move, and the experts who selected the Einstellung move). To test our hunch that the experts/novice differences were largely driven by the experts who chose the optimal solution, we conducted a more fine-grained analysis that contrasted the 9 experts who selected the optimal moves on the board (i.e., Ng2 or Nc2), with the 8 expert and 8 novice players who selected the Einstellung move (i.e., Ba7). As shown in Figure 2 (Panel B), this analysis replicated [7]'s findings for the percentage of looking time measure, by revealing that the chess players who chose the Einstellung move continued to fixate on this solution throughout the trial. Interestingly, the expert and novice players who chose the Einstellung move were equally unable to disengage from the target region, as indicated by a lack of linear trends for both the experts ($F < 1$) and the novices ($F(1, 30) = 1.76$, $p = .194$), and by the lack of an interaction between expertise and time interval ($F(3, 42) = 1.08$, $p = .369$). In addition, there were no differences in the pattern of results for the number of dwells when we contrasted the experts and novices who selected the Einstellung move, as shown by a lack of an interaction between expertise and time interval ($F(3, 42) = 2.34$, $p = .087$).

Table 1. Target region eye movement measures (averaged across all four experimental problems) and corresponding t-test results, by level of expertise (expert, novice).

Measure	Expert	Novice	Difference(Novice – Expert)	Significance
Time to first fixation (ms)	407(56)	719(89)	312	$t = 2.99$, $p < .01$
Average dwell duration (ms)	2395(197)	3440(355)	1045	$t = 2.58$, $p < .05$
Total dwell time (ms)	52005(5540)	51397(6887)	−608	$t < 1$
Number of dwells	27(3.5)	18(2.1)	−9	$t = 2.06$, $p < .05$
Percentage of looking time	.62(.01)	.63(.02)	.01	$t < 1$

Note – For the *t* tests shown above, $df = 32$.
The standard errors are shown in brackets.
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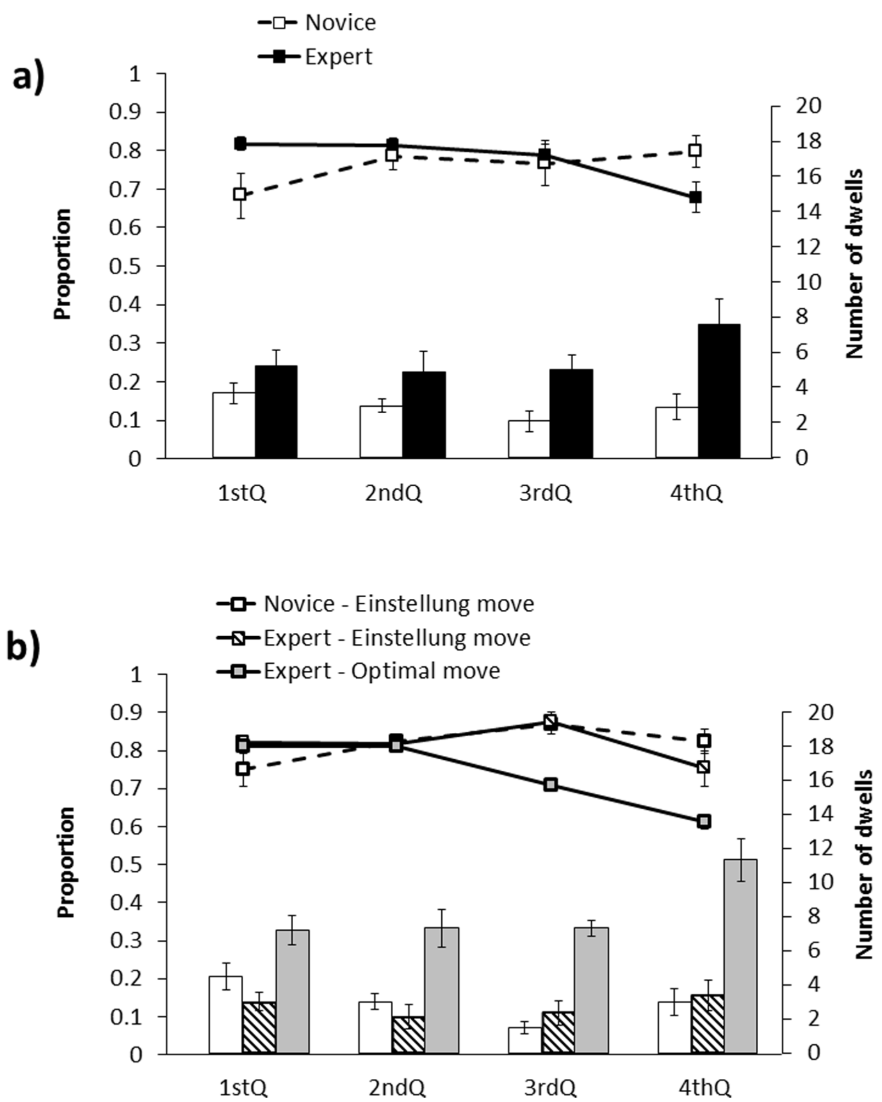

Figure 2. The percentage of looking time and the number of dwells in the target region in the suboptimal move Einstellung problem (i.e., Problem 1), as a function of time, for a) all expert and novice chess players, and b) the subset of expert players who selected the optimal moves on the board (i.e., Ng2 or Nc2) and the expert and novice players who selected the Einstellung move (i.e., Ba7). See text for further details.
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In marked contrast, the group of experts that selected the optimal move was better able to disengage their attention from the target region, as shown by a significant linear trend (F(1, 34) = 43.45, p<.001), as well as by significant two-way interactions between move choice (optimal vs. Einstellung) and time interval when we contrasted the optimal-move experts with the Einstellung-move experts (F(3, 45) = 3.65, p<.05) and with the novices (F(3, 45) = 9.21, p<.001). Moreover, the experts who selected the optimal move had a higher number of dwells than the Einstellung-move experts (F(1, 15) = 12.34, p<.01) and novices (F(1, 15) = 13.46, p<.01), and this difference increased over time as shown by significant two-way interactions between move choice and time interval when we contrasted the optimal-move experts with the Einstellung-move experts (F(3, 45) = 4.19, p<.05) and with the novices (F(3, 45) = 6.60, p<.01). Overall, this pattern of results confirms that the expert/novice differences in Figure 2 (Panel A) were driven by the subset of experts who selected the optimal move, since the experts and novices who selected the Einstellung move did not differ from one another on either the percentage of looking time measure or the number of dwells measure.

Blunder move Einstellung problems. As can be seen from Figure 3, the pattern of results for the blunder move problems (i.e., Problems 2, 3 and 4) revealed that both the experts and novices were able to gradually disengage their attention from the target region containing the Einstellung move. Consequently, unlike in the suboptimal move problem (i.e., Problem 1), the percentage of looking time measure produced a significant linear trend for both the experts (F(1, 66) = 79.88, p<.001) and novices (F(1, 66) = 10.84, p<.01), and there were no interactions between level of expertise and time interval (F(3, 96) = 1.80, p = .152). Thus, relative to the suboptimal move problem, both the experts and novices were better able to resist the Einstellung effect for the blunder move problems, as shown by their greater ability to disengage their attention from the target region (see Figure 3) and the fact that all of the experts and the majority of the novices avoided choosing the Einstellung move (see Appendix S1). Overall, this pattern of results supports our hypothesis that the Einstellung effect would be weakened when the Einstellung move was a blunder (i.e., Problems 2, 3, and 4) rather than an advantageous but suboptimal move (i.e., Problem 1).

Finally, similar to the suboptimal move problem, the number of dwells in the target region increased over time for the experts but not for the novices, as shown by a significant interaction between level of expertise and time interval (F(3, 96) = 4.03, p<.05). Thus, as shown in Table 1 and Figures 2 and 3, the number of dwells measure revealed a consistent qualitative difference in the pattern of looking behaviour for the experts versus novices, such that the experts displayed shorter and more frequent dwells on the target region as the trial progressed.

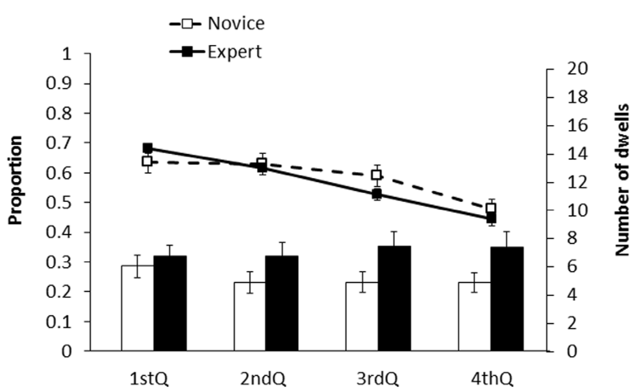

Figure 3. The percentage of looking time and the number of dwells in the target region in the blunder move Einstellung problems (i.e., Problems 2, 3, and 4), as a function of time, for all expert and novice chess players. See text for further details.
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Retrospective Responses

To further explore the chess player's problem-solving strategies, we also examined the expert and novice players' retrospective responses for both types of Einstellung problem (i.e., suboptimal versus blunder). For both types of problems, the majority of the chess players stated that they considered the Einstellung move first, which coincides with our findings of rapid times to the first fixation on the target region (see Table 1). However, consistent with the pattern of results for the accuracy and eye tracking measures, both the expert and novice chess players had more difficulty ruling out the Einstellung solution when it was a suboptimal move rather than a blunder move. In fact, out of the eight expert and eight novice players who selected the suboptimal Einstellung move (i.e., "Ba7"), two of the experts and four of the novices did not rule out checkmate (Sample expert comment: "I was actually wrong to think that Ba7 leads to checkmate in this position"; Sample novice comment: "By moving the bishop in, it is a checkmate"). The remaining players thought that the suboptimal Einstellung move would improve white's position (Sample expert comment: "No forced checkmate that I can see…After Ba7 Na7 Qa7 Kc8 Qc5 white looks to have improved its position [by] giving the queen more mobility …."; Sample novice comment: "I chose to move bishop to a7 because….white can continue attacking with black having less defenders"), although several of the experts were unsure if it was the best move (e.g., "I'm unclear as to if Ba7 is best but it looks promising"). In contrast, the nine experts who chose the optimal move stated that they ruled out checkmate in the target region, and then considered the optimal move outside of the target region (e.g., "I didn't see the mate on a7, so I looked at the other side of the board…"). Some of these experts considered the long-term consequences of the optimal move for the pieces within the target region (e.g., "The only piece missing in action was N on e3, so I wanted to bring it in by Nc2-b4 then possibly Na6"), which might account for why the experts who chose the optimal move showed an increase in the number of dwells in the target region, relative to the experts and novices who selected the Einstellung move. Finally, unlike the suboptimal move Einstellung problem, the retrospective responses for the blunder move Einstellung problems revealed that all of the experts and the majority of the novice players ruled out the Einstellung moves as a viable option (Sample expert comment: "Though it looks like white has an attack, Black is defending it well"; Sample novice comment: "I was not able to find a good move in the dotted region of the board").

Discussion

The present findings revealed new insights concerning the processes underlying the Einstellung (mental set) effect, in which a familiar solution blocks the discovery of a better solution [1]. Most importantly, the subset of expert and novice chess players who chose the familiar but suboptimal Einstellung move continued to look at this move throughout the trial – even though there was an optimal move located in a different region of the board – whereas the experts who discovered the optimal move were able to gradually disengage their attention from the Einstellung move. This pattern of results replicates [7], using a choose-a-move task that employed a single problem to elicit both the optimal and suboptimal move choices, rather than requiring two different versions of the problem as in [7]. Thus, our findings provide convergent evidence for [7]'s conclusion that the Einstellung effect operates by biasing the problem-solvers' attention towards problem features that are associated with the familiar solution, thereby preventing the discovery of new solutions. In the present study, this bias in attention towards the familiar solution was evident for both the experts and the novices who chose the Einstellung move, which underscores prior findings that the Einstellung effect is pervasive across a wide range of levels of expertise [8].

Extending [7–8], we also uncovered a key boundary condition of the Einstellung effect, by showing that the magnitude of the Einstellung effect was severely reduced when we introduced a new type of Einstellung move that was a clear blunder rather than an advantageous (but suboptimal) move. Specifically, unlike the suboptimal Einstellung move in Problem 1, all of the experts and the majority of the novices were able to avoid choosing the blunder moves in Problems 2, 3, and 4, and both the expert and novice chess players were able to gradually disengage their attention from the target region containing the blunder move. These findings shed light on the boundary conditions of the Einstellung effect, by revealing that the outcome of the Einstellung move (suboptimal versus blunder) plays a critical role.

One possible explanation for why the blunder moves reduced the Einstellung effect is that the blunder moves provided feedback that the familiar solution was not viable. This type of feedback may have improved performance on the blunder move Einstellung problems by providing the chess players with increased motivation to search for a new solution. In contrast, such feedback was not available for the suboptimal move Einstellung problem, because the suboptimal move was advantageous for white. Moreover, similar to the suboptimal move, the longer checkmate solution in [7] might have given chess players the impression that the problem was already solved, which could have reduced their motivation to find a new solution. Thus, the Einstellung effect may be especially pernicious when problem-solvers are not given feedback that they are using a suboptimal strategy (for a related discussion, see [13,25]).

In addition, another implication of the present findings is that the percentage of looking time measure employed by [7] is not always sufficient, and should be supplemented with additional measures, such as the number of dwells measure. This is because the percentage of looking time measure alone cannot reveal whether target region fixations were due to an inability to rule out the Einstellung move, or due to long-term strategizing concerning how the optimal move would impact the pieces within the target region. To the extent that the chess players were returning to the target region to strategize about the impact of the optimal move, then the percentage of looking time measure could be over-estimating the chess players' inability to disengage from the Einstellung move. In the present study, the number of dwells measure seemed to provide a good index that this type of optimal move strategizing was occurring, because the experts who discovered the optimal move displayed shorter and more frequent dwells in the target region, relative to the experts and novices who remained fixated on the suboptimal Einstellung move. Moreover, for the blunder Einstellung problems, the experts showed shorter and more frequent dwells than the novices, even though the blunder move problems did not reveal any expertise differences for the percentage of looking time measure. This pattern of results underscores the importance of supplementing the percentage of looking time measure with additional measures, to provide a more complete understanding of why chess players are fixating on a particular region of the board.

Finally, future work could investigate the extent to which the mechanisms underlying the Einstellung effect in chess are related to other thinking errors beyond the chess domain. More specifically, as discussed by [6–8], the chess players' bias in attention towards the familiar checkmate solution might reflect a more general cognitive tendency to selectively focus attention on information that is associated with an already activated knowledge schema. To give an example, this mechanism could be contributing to the satisfaction of search (SOS) effect that has been studied extensively in the domain of medical expertise [26–29]. The SOS effect refers to the finding that the discovery of one abnormality can prevent expert radiologists from discovering additional abnormalities. Although the mechanisms underlying SOS are controversial, one possibility is that the discovery of an obvious abnormality could subsequently bias attention towards visual features that are related to this type of abnormality, rather than towards features that are associated with more subtle abnormalities [30]. Moreover, beyond the domain of visual expertise, this bias in attention towards already activated knowledge schemas could be contributing to the tendency of political experts and scientists to ignore evidence that does not fit with their existing theories [31–32], as well as memory findings that it is difficult to recall details that do not fit with already-activated knowledge schemas (i.e., the part-set cuing phenomena: [33–34]). Future work could continue to explore the extent to which thinking errors in different domains and tasks are potentially driven by common mechanisms.

Supporting Information

Appendix S1 For each of the four experimental problems (1,2,3,4), Appendix S1 contains the move quality ratings (averaged across the five expert raters), the program scores (averaged across the two programs), the location of each move on the board (1 = inside the target region, 0 = outside the target region), and the frequency with which each move was selected by the expert and novice players. See text for further details.
(DOCX)

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Author Contributions

Conceived and designed the experiments: HS EMR. Performed the experiments: HS. Analyzed the data: HS EMR. Contributed reagents/materials/analysis tools: HS EMR. Wrote the paper: HS EMR.

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Forgetting as a Consequence and Enabler of Creative Thinking

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Four experiments examined the interplay of memory and creative cognition, showing that attempting to think of new uses for an object can cause the forgetting of old uses. Specifically, using an adapted version of the Alternative Uses Task (Guilford, 1957), participants studied several uses for a variety of common household objects before attempting to generate new uses for half of those objects. As revealed by performance on a final cued-recall task, attempting to generate new uses caused participants to forget the studied uses. This thinking-induced forgetting effect was observed regardless of whether participants attempted to generate unusual uses or common uses, but failed to emerge when participants used the studied uses as hints to guide their generation of new uses. Additionally, the forgetting effect correlated with individual differences in creativity such that participants who exhibited more forgetting generated more creative uses than participants who exhibited less forgetting. These findings indicate that thinking can cause forgetting and that such forgetting may contribute to the ability to think creatively.

Keywords: thinking, forgetting, inhibition, creative cognition, Alternative Uses Task

Isaac Newton is often quoted as saying that if he has "seen further it is by standing on the shoulders of giants," and in many ways he was right. There are many instances in which insight and achievement are accomplished by building off of what is already known. New ideas are born from old ideas, and without sufficient context or background it can be impossible to think of something new and truly groundbreaking (Holyoak & Thagard, 1995; Osborn, 1957; Simonton, 2012; Ward, 1994; Weisberg, 2006). In some contexts, however, existing knowledge can cause mental fixation, such as when counterproductive ideas impede the generation of new and better ideas. Whether in the context of art, engineering, or science, to achieve or to think of something new can sometimes require that we dismiss, or move beyond, what we already know (Smith, 2003, 2008; Smith & Ward, 2012; Ward, Smith, & Finke, 1999). One mechanism that may facilitate this process is that of forgetting. If old ideas are rendered less accessible, even if only temporarily, then it may become easier to think of new and creative ideas. We examined this possibility in the present research by showing how the act of thinking can cause forgetting, and that such forgetting can serve to enable creative thinking.

Mental Fixation in Memory, Problem Solving, and Idea Generation

Mental fixation is generally defined as something that blocks or impedes the successful completion of a cognitive operation, which can occur in contexts such as remembering, solving problems, or generating creative ideas (Smith, 1995, 2003, 2008). In memory research, for example, the strengthening of semantic, phonological, or episodic associations can cause fixation by interfering with, or otherwise preventing access to, target associations (e.g., McGeoch, 1942; Raaijmakers & Shiffrin, 1981; Roediger, 1973; Rundus, 1973; Watkins & Watkins, 1975). Other examples of fixation come from the problem-solving literature. Functional fixedness and Einstellung, for example, provide apt examples of how old ways of thinking can interfere with new ways of thinking. Functional fixedness refers to the tendency for people to become fixated by the traditional use of an item (Duncker, 1945; Maier, 1931), and Einstellung refers to the tendency for people to continue to solve a problem the same way. As an example of Einstellung, Luchins and Luchins (1959) gave participants three jugs of different capacities and asked them to use the jugs to measure a specific quantity of water. In solving the first few problems, participants quickly learned they could calculate the quantity using a certain algorithm. After learning this approach, however, participants continued to use it even when it was no longer the most efficient means of finding a solution.

In more recent work, Steve Smith and colleagues have employed a variety of experimental tasks to demonstrate the pervasiveness of mental fixation in cognition. Smith and Tindell (1997), for example, showed that the ability to solve a given word fragment (e.g., *a _ _ l _ g y*) is impaired if participants are exposed to orthographically similar words, or negative primes, such as *allergy*. This memory blocking effect was observed regardless of whether participants were aware of the connection between the negative primes and word fragments, and it was even observed when participants were explicitly warned that the negative primes would interfere with solving the fragments. In this context, as in many others, fixation does its damage implicitly, or outside the person's awareness (see also Kinoshita & Towgood, 2001; Koppel & Storm, 2012; Kozak, Sternglanz, Viswanathan, & Wegner,

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2008; Leynes, Rass, & Landau, 2008; J. M. Logan & Balota, 2003).

In other work, Smith and Blankenship (1989) found evidence of fixation in rebus problem solving. To solve a given rebus problem, participants must identify associations between representations of words in the form of pictures, symbols, and common phrases (e.g., *fly night*; solution: *fly by night*). Similar to research on memory blocking, participants are less likely to solve problems if they are provided with unhelpful clues such as "paper over" than if they are given either helpful clues or no clues. Similar fixation effects have been observed using the Remote Associates Test (RAT; Mednick, 1962; e.g., Kohn & Smith, 2009; Smith & Blankenship, 1991; Storm & Angello, 2010; Vul & Pashler, 2007; Wiley, 1998). In the RAT, participants are given three cue words, such as *mouse*, *sharp*, and *blue*, and asked to think of a target word that is associated with all three (solution: *cheese*). Fixation in the RAT is demonstrated by showing that performance is impaired by exposure to unhelpful associates, such as *mouse–cat*, *sharp–point*, and *blue–sky*, or by the activation of unhelpful associates from long-term memory.

Mental fixation has also been shown in idea-generation tasks such as inventing new toys, drawing alien creatures (Smith, Ward, & Schumacher, 1993), designing spill-proof coffee cups (Jansson & Smith, 1991), and brainstorming (Kohn & Smith, 2010). Smith et al. (1993), for example, found that participants were unable to deviate from the characteristics of examples of alien creatures when told to imagine completely new and different alien creatures. In fact, in this and other work, participants conform to existing knowledge and examples even when they are explicitly instructed to avoid doing so (e.g., Landau & Leynes, 2006; R. L. Marsh, Landau, & Hicks, 1997; R. L. Marsh, Ward, & Landau, 1999). Taken together, the work on mental fixation suggests that making nontarget information more accessible—such as through exposure to an example or by providing a seemingly innocuous hint—can constrain cognition and interfere with one's ability to think creatively.

Researchers have identified several ways in which fixation can be overcome. Depending on the nature of the task and the type of fixation encountered, potentially effective strategies include focusing on abstract representations of the task (e.g., McCaffrey, 2012), training new and more effective heuristics (e.g., Ansburg & Dominowski, 2000), restructuring the problem space (e.g., Ohlsson, 1984), providing incidental hints (e.g., Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995), and taking advantage of a break, or incubation period (e.g., Smith & Blankenship, 1989). In the latter example, simply allowing time to pass after exposure to a fixating stimulus, or an initial attempt to complete the task, can alleviate the effects of fixation. Leynes et al. (2008), for example, found that the memory blocking effect disappeared after a 72-hr delay. Similarly, Smith and Blankenship (1989, 1991) had participants attempt to solve previously unsolved rebus and RAT problems after a delay. In both cases, taking time away from the task allowed participants to forget the associations causing fixation, thus making participants more likely to generate the target solutions (see also Kohn & Smith, 2009, 2010; Koppel & Storm, 2014; Vul & Pashler, 2007). Smith and colleagues have referred to the benefits of incubation as evidence for the forgetting-fixation hypothesis—that one way we are able to overcome mental blocks is by taking a break from thinking and problem solving, thus allowing the fixation-inducing associations to be forgotten.

Inhibition and Retrieval-Induced Forgetting

Unfortunately, people do not always have the luxury of time necessary to benefit from an incubation period. Often people must generate a new idea or solve a problem in the current context and without delay. Thus, when existing information and associations cause fixation, it would be useful to have some mechanism by which to cause that information and those associations to become less accessible, without having to wait for them to be forgotten. One such mechanism may be that of inhibition. Researchers from a variety of perspectives have argued that inhibition, and related processes of executive control, are essential for the goal-directed control of thought and behavior (e.g., M. C. Anderson, 2003; Aron, Robbins, & Poldrack, 2004; R. A. Bjork, 1989; Dempster & Brainerd, 1995; Diamond, Balvin, & Diamond, 1963; Friedman & Miyake, 2004; Hasher & Zacks, 1988; G. D. Logan & Cowan, 1984; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). In the context of creative thinking, inhibition may provide a means by which to select against the information and associations causing fixation, rendering them less accessible in memory and thus less likely to interfere with the generation of creative thoughts and insights.

Primary evidence for the role of inhibition in memory—and more specifically, memory retrieval—has come from work on retrieval-induced forgetting (M. C. Anderson, Bjork, & Bjork, 1994), which has shown that retrieving a subset of items related to a cue can cause the forgetting of other items related to that cue. According to the inhibitory account of retrieval-induced forgetting, nontarget items interfere with the retrieval of a target item, and inhibition is recruited to resolve this interference, inhibiting the nontarget items and rendering them less recallable in the future than they would have been otherwise (for reviews of the phenomenon and various theoretical accounts, see, e.g., M. C. Anderson, 2003; Bäuml, Pastötter, & Hanslmayr, 2010; Jonker, Seli, & MacLeod, 2013; Levy & Anderson, 2002; C. M. MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; M. D. MacLeod & Saunders, 2008; Norman, Newman, & Detre, 2007; Perfect et al., 2004; Raaijmakers & Jakab, 2013; Storm & Levy, 2012; Verde, 2012).

There is now good evidence that inhibition contributes to observations of retrieval-induced forgetting (Storm & Levy, 2012). For example, there is evidence that retrieval-induced forgetting is largely independent of the degree to which retrieved items are strengthened (e.g., M. C. Anderson, Bjork, & Bjork, 2000; Bäuml, 2002; Saunders, Fernandes, & Kosnes, 2009; Storm, Bjork, Bjork, & Nestojko, 2006; Storm & Nestojko, 2010), that it is contingent on nontarget items causing competition during retrieval (e.g., M. C. Anderson, Bjork, & Bjork, 2000; M. C. Anderson et al., 1994; Levy, McVeigh, Marful, & Anderson, 2007; Storm, Bjork, & Bjork, 2007), and that it is reduced or eliminated if the executive processes presumed to underlie inhibition are impaired or disrupted (e.g., Aslan & Bäuml, 2010; Román, Soriano, Gómez-Ariza, & Bajo, 2009; Soriano, Jiménez, Román, & Bajo, 2009; Storm & White, 2010). There is also evidence that retrieval-induced forgetting can be observed on cue-independent final tests that are designed to be less susceptible to other sources of forgetting, such as associative interference (e.g., M. C. Anderson & Spellman, 1995; Johnson & Anderson, 2004; M. D. MacLeod & Saunders, 2005; Radvansky, 1999), and recent cognitive neuroscience research has revealed an association between retrieval-induced forgetting and activity in the prefrontal cortex, a region known to be critical for inhibition and executive functioning (Hanslmayr, Staudigl, Aslan, & Bäuml, 2010; Johansson, Aslan, Bäuml, Gäbel, & Mecklinger, 2007; Kuhl, Dudukovic, Kahn, & Wagner, 2007).

According to proponents of the inhibitory account, our ability to retrieve the item we want to retrieve at a given point in time is made possible, at least in part, by the ability to inhibit, and thus forget, contextually inappropriate items that interfere. This sort of goal-directed forgetting should be important in other contexts as well. As argued by Storm (2011), the inhibitory process believed to underlie retrieval-induced forgetting should have the potential to facilitate any act of remembering, thinking, or problem solving that suffers from old or inappropriate information being too accessible. Consistent with this idea, retrieval-induced forgetting has been shown to correlate positively with working memory capacity (Aslan & Bäuml, 2011) and having better access to positive, as opposed to negative, autobiographical memories (Storm & Jobe, 2012b). Moreover, there is evidence that other forms of selective practice, such as solving word fragments (Healey, Campbell, Hasher, & Ossher, 2010) and using a second language (Levy et al., 2007), can also cause forgetting. In each of these examples, there is presumed to be some processing objective that stands to benefit from making nontarget information less accessible. When learning and using a second language, for example, forgetting a word in the first language, even if only temporarily, can facilitate access to the word in the second language.

Overcoming Fixation via Inhibition

Inspired by the above arguments, Storm and Angello (2010) investigated whether retrieval-induced forgetting could predict a person's ability to overcome fixation in creative problem solving. Retrieval-induced forgetting was measured first with a close variant of the standard task (M. C. Anderson et al., 1994). Then, in a separate task, participants attempted to solve 20 RAT problems. As discussed above, each problem consisted of three cue words (e.g., *mouse–sharp–blue*) and participants were asked to think of a fourth word related to each of them (e.g., *cheese*). Critically, half of the participants attempted to solve the RAT problems after studying fixation-inducing associates (fixation condition), such as *mouse–cat*, *sharp–point*, and *blue–sky*, and the other half attempted to solve the problems without studying the fixation-inducing associates (baseline condition). Not surprisingly, participants in the fixation condition performed significantly worse than participants in the baseline condition, thus replicating the effects of mental fixation observed by Smith and Blankenship (1991). The more surprising and important finding was that the extent to which participants suffered fixation was predicted by individual differences in retrieval-induced forgetting. Whereas participants exhibiting low amounts of retrieval-induced forgetting suffered massive fixation, performing substantially worse in the fixation condition than in the baseline condition, participants exhibiting high amounts of retrieval-induced forgetting suffered significantly less fixation.

In the study by Storm and Angello (2010) it was the ability to forget, not the ability to remember, that appeared to facilitate RAT performance. Critically, however, this was only true for problems fixated by exposure to inappropriate associates. When problems were not fixated, participants exhibiting low levels of retrieval-induced forgetting performed just as well as participants exhibiting high levels of retrieval-induced forgetting. Koppel and Storm (2014) observed a similar pattern of results, showing once again that retrieval-induced forgetting correlates with problem-solving success for fixated RAT problems, but that the correlation is eliminated when participants are given an incubation period after an initial problem-solving attempt, thus allowing fixation to dissipate on its own and presumably obviating the need for inhibition during the subsequent problem-solving attempt.

If inhibition can help participants solve fixated RAT problems, then there should be evidence of fixating items being forgotten as a consequence of RAT problem solving. Storm, Angello, and Bjork (2011) tested this hypothesis by having participants study a series of cue–response pairs (e.g., *mouse–cat*, *bite–dog*, *monkey–ape*, *sharp–point*, *blue–sky*, *widow–sad*) before attempting to solve RAT problems consisting of a subset of the cues (e.g., *mouse–sharp–blue*, but not *bite–monkey–widow*). Later, in a surprise final test, participants were provided the cues and asked to retrieve the associated responses. Responses associated with cues used in the RAT (*cat*, *point*, *sky*) were recalled significantly less well than responses associated with cues that were not used in the RAT (*dog*, *ape*, *sad*). This result, dubbed problem-solving-induced forgetting, provided additional evidence that inhibition can help problem solvers overcome fixation, and demonstrated that the act of problem solving can cause the fixating information to be forgotten.

In subsequent experiments, Storm et al. (2011) showed problem-solving-induced forgetting to be a reliable phenomenon, increasing with the amount of time participants spent attempting to solve a given problem and emerging even when participants failed to generate a correct solution. Moreover, individual differences in problem-solving-induced forgetting were shown to predict performance on a separate set of fixated RAT problems. That is, participants who exhibited greater levels of problem-solving-induced forgetting were more likely to solve another set of problems than participants who exhibited reduced levels of problem-solving-induced forgetting. This finding suggests that the forgetting caused by problem solving is adaptive in nature, allowing participants to reach solutions they might have otherwise been unable to reach.

Forgetting as a Consequence and Enabler of Creative Thinking

If attempting to solve a RAT problem can cause fixating associates to be forgotten, then one might wonder whether similar dynamics might occur more broadly across all of creative cognition. Fixation is encountered in many contexts, and forgetting may play a very general and important role by helping people to overcome such fixation. Just as the act of retrieval has been argued to modify memory (R. A. Bjork, 1975), so might the act of thinking. Specifically, whenever information in memory interferes with some thinking process, such as the generation of a new idea or access to the solution of a problem, that information may be targeted by an inhibitory process that acts to render it less accessible. In this way, thinking may serve to update our memories in the same way that retrieval does, making information that is no longer useful less recallable, and thus potentiating access to information that is more likely to be useful.

We explored this potential role for forgetting in creative thinking using an adapted version of the Alternative Uses Task (AUT;

Guilford, 1957, 1967; see also Plucker & Renzulli, 1999; Quellmalz, 1985; Weisberg, 2006). In the AUT, which is commonly used to measure creative and divergent thinking, participants are provided with the name of an object (e.g., *brick*) and asked to think of as many uses for that object as possible. Performance can be measured in a variety of ways, but typically by recording the number of uses generated (fluency) or the distinctiveness or uncommonness of the uses (originality). Presumably, to perform well on the task, participants must have some way of inhibiting or forgetting old and noncreative uses. The most obvious and recently encountered uses for an object can cause fixation, for example, interfering with the generation of less obvious and rarely encountered uses. Even generating initial uses can be problematic because those initial uses can then interfere with the generation of subsequent uses, as has been routinely observed in demonstrations of output interference (e.g., Tulving & Arbuckle, 1963). In the present work, we increased the likelihood of participants experienced fixation in the AUT by borrowing from work on part-set cuing (e.g., Brown, 1968; Roediger, 1973; Slamecka, 1968). Specifically, we exposed participants to several uses for each object before asking them to generate new uses, a manipulation that should increase competition and make new uses more difficult to generate than they would have been otherwise (Rundus, 1973; see also E. J. Marsh, Dolan, Balota, & Roediger, 2004; Roediger, Stellon, & Tulving, 1977). This procedure also allowed us to measure the extent to which the studied uses would be forgotten as a consequence of trying to think of new uses.

There is some evidence that performance on creative thinking tasks such as the AUT can benefit from inhibition (Benedek, Franz, Heene, & Neubauer, 2012; Benedek, Könen, & Neubauer, 2012; Gilhooly, Fioratou, Anthony, & Wynn, 2007; Golden, 1975; Groborz & Nęcka, 2003; Martin, Wiggs, Lalonde, & Mack, 1994). Gilhooly et al. (2007), for example, found that performance on a task requiring flexible responding and executive control predicted the production of new uses on the AUT—that is, uses that participants had not thought of prior to the experiment. Similarly, Golden (1975) and Groborz and Nęcka (2003) found positive correlations between divergent thinking and performance on tasks like the Stroop and the Navon, and Eslinger and Grattan (1993) found that individuals with frontal lobe damage were impaired on the AUT.

However, there is also evidence that creativity and inhibition are inversely correlated, that individuals with greater inhibitory abilities tend to perform worse on creative thinking tasks than those with more limited inhibitory abilities (e.g., Carson, Peterson, & Higgins, 2003; Chrysikou et al., 2013; Jarosz, Colflesh, & Wiley, 2012; White & Shah, 2006; see also Eysenck, 1995; Martindale, 1999). One interpretation of these seemingly inconsistent results is that the relationship between inhibition and creativity may be more nuanced and dynamic than can be represented by a single correlation, and that depending on the demands of a given task, inhibition can serve to enhance creative thinking in some instances while impairing it in others (cf. Bristol & Viskontas, 2006). For example, the benefits of inhibition may be particularly powerful when one must overcome fixation, such as in the RAT when one must bypass inappropriate associates (Koppel & Storm, 2014; Storm & Angello, 2010; Storm et al., 2011), or in the AUT when one must move beyond the most typical uses and avoid perseverating on the uses that have already been generated. In other words, inhibition may be useful in situations that require fixating information to be forgotten. The question we explore here, then, is not simply whether inhibition is associated with creativity, but rather how does inhibition act to promote creativity? Can we create a situation in which creative thinking would presumably benefit from certain information being forgotten, and if so, will thinking induce forgetting? And finally, if thinking does induce forgetting, will individuals who exhibit greater levels of such forgetting be more capable of thinking creatively?

Experiment 1

We adapted the AUT to create a context in which to induce the need to overcome fixation and then measure thinking-induced forgetting. The experiment consisted of eight study/thinking trials and a subsequent final test. At the beginning of each study/thinking trial, several uses for a common household object were presented simultaneously on the screen for participants to study (e.g., *newspaper*: *paper mâché*, *gift wrapping*, *start a fire*, *table cloth*). On half of the trials, participants simply studied the uses for 12 s. On the other half of the trials, participants studied the uses for 12 s and then had 60 s to attempt to generate new uses for the object.

This procedure created two types of items: studied uses associated with objects that participants attempted to generate new uses for (i.e., items in the thinking condition) and studied uses associated with objects that participants did not attempt to generate new uses for (i.e., items in the baseline condition). Because the four studied uses were designed to fixate thinking and interfere with the participants' ability to generate new uses, we predicted that these uses would be susceptible to thinking-induced forgetting. Specifically, we predicted that when participants were given a final test asking them to recall the original studied uses associated with each of the objects, uses in the thinking condition would be less recallable than uses in the baseline condition. Moreover, because thinking-induced forgetting is presumed to reduce mental fixation from the studied uses, we predicted that individuals exhibiting more forgetting would be at an advantage in the AUT, perhaps leading them to generate more creative and divergent uses in their responses than individuals exhibiting less forgetting.

In a separate manipulation, we also examined whether certain types of thinking are more likely to cause forgetting than others. Specifically, when coming up with new uses, we instructed half of the participants to think of highly unusual and creative uses, while instructing the other half to think of common and mundane uses. We predicted that both forms of thinking would cause significant forgetting, but we were interested in seeing whether one form of thinking might lead to more forgetting than the other. On the one hand, forgetting might be greater in the unusual condition because of the relatively greater need to think "outside the box" and thus inhibit the more typical studied uses. On the other hand, forgetting might be greater in the common condition because thinking of several common uses for an object is much more difficult than one might think, especially when four common uses have already been provided. Moreover, in work on retrieval-induced forgetting, there is evidence that the extent to which an item is susceptible to forgetting depends on the extent to which it causes competition (e.g., M. C. Anderson et al., 1994; Storm et al., 2007; but see Jakab & Raaijmakers, 2009). Thus, if studied uses are more likely to compete with the generation of common uses than unusual uses, we might expect more forgetting to be observed in the common condition than in the unusual condition. Regardless of whether one condition leads to more forgetting than the other, our overall goal was to demonstrate that both types of thinking are capable of causing forgetting.

Method

Participants. Sixty-eight undergraduate students (M_{age} = 20.5 years) from the University of California, Santa Cruz (UCSC) participated for partial credit in a psychology course. All participants were fluent in English. Under random assignment, 34 participants were assigned to the unusual thinking condition, and 34 participants were assigned to the common thinking condition.

Materials. Eight objects were selected from those typically used in the AUT (i.e., brick, spoon, newspaper, bucket, paperclip, rubber band, coat hanger, and screwdriver). Fifteen volunteer undergraduates, none of whom would participate in any of the experiments, were given 1 min to generate as many uses for each object as possible. From these responses, four of the most frequently generated uses were selected for use in the experiment, all of which are shown in the Appendix. Importantly, we did not include the most frequent or obvious use for each object (e.g., newspaper: to read). This was done to ensure that participants studied and attempted to recall the uses provided for each object and did not simply guess them during final recall. In total, the materials consisted of eight objects and four associated uses. We decided to have participants study relatively common uses over highly unusual uses to increase the likelihood of participants becoming fixated by traditional ways of thinking about the objects.

Procedure. The experiment consisted of two phases: a study/thinking phase and a final recall phase. First, during the study/thinking phase, participants studied each of the objects and their associated uses. Each object was presented on the computer screen for 12 s along with the four to-be-studied uses (listed vertically below the object name). Participants were told that they would be tested on the uses later in the experiment and that they should try to remember them. For half of the objects, participants simply studied the uses for 12 s and then moved on to the next trial (baseline condition). For the other half of the objects, participants studied the uses for 12 s, and were then given an additional 60 s to attempt to generate new, distinct uses for the object (thinking condition). The order of the trials was randomized such that participants were unable to predict whether they would be asked to generate new uses on a given trial, thus ensuring that they studied each object and its uses the same way regardless of trial type. Whether an object served in the baseline or thinking condition was counterbalanced across participants such that every object was equally likely to serve in both conditions.

As a between-subjects manipulation, half of the participants were instructed to think of highly unusual and creative uses in the thinking portions of the study/thinking phase, whereas the other half were instructed to think of relatively common and routine uses. In the unusual condition, participants were told to think of atypical uses that one would almost never see the objects used for and given the example of using a balloon as a substitute for gum. In the common condition, participants were told to think of typical uses that one would frequently see the objects used for and given the example of using a balloon as a party favor.

In the second phase of the experiment, participants were presented with each of the eight objects on the computer screen for 16 s and asked to say out loud the four studied uses. The objects were shown one at a time and in the same order they had been studied. The experimenter marked off correct responses and wrote down any incorrect responses provided by the participant. At the conclusion of the experiment, participants were debriefed and thanked for their participation.

Results and Discussion

Uses generated. On average, participants generated 3.5 (SD = 1.1) uses per object. Although generation rates did not differ significantly between the two conditions, $t(66) = 0.97$, $p = .34$, $d = 0.23$, participants in the unusual condition ($M = 3.6$, $SE = 0.2$) did generate numerically more uses than participants in the common condition ($M = 3.4$, $SE = 0.2$).

Three independent raters, blind to experiment and experimental condition, coded the uses generated by participants based on their similarity to the studied uses, creativity, unusualness, novelty, and usefulness. Similarity was defined as how similar a use was to the studied uses, with a use being identified as similar if it had the same, or close to the same, meaning as one of the studied uses. If any of the three raters coded a use as being similar, then it was identified as such in all analyses reported below. The four other measures were rated on a 1–9 scale, with 1 indicating a low degree of creativeness, unusualness, novelty, and usefulness and 9 indicating a high degree of creativeness, unusualness, novelty, and usefulness. Raters were instructed to compare the uses to the types of uses for which the objects are generally used in everyday life. Composite scores were calculated by averaging scores across the three raters.

As shown in the top two rows of Table 1, participants instructed to think of unusual uses generated more unusual, novel, and creative uses than participants who were instructed to think of common uses (all $p < .001$). Usefulness was negatively correlated with the other three measures such that uses rated as being unusual, novel, and creative were generally rated as not being very useful, a finding that has also been observed in prior research. In terms of similarity, participants generated an average of 0.5 uses per object that were similar to one of the studied uses. The number of similar uses generated did not vary as a function of condition, $t(66) = 0.29$, $p = .77$, $d = 0.09$.

Final recall performance. A 2 (item type: thinking vs. baseline) $\times$ 2 (generation condition: unusual vs. common) analysis of variance was employed to analyze final recall performance. As can be seen in Figure 1, a main effect of item type was observed such that participants recalled fewer studied uses associated with thinking trials than baseline trials, $F(1, 66) = 36.56$, $MSE = .01$, $p < .001$, thus demonstrating evidence of thinking-induced forgetting. A main effect of generation condition was also observed such that recall performance was lower in the unusual condition than in the common condition, $F(1, 66) = 6.30$, $MSE = .04$, $p = .02$. We will return to this finding in the general discussion. No evidence of an interaction was observed, $F(1, 66) = 0.15$, $MSE = .01$, $p = .70$, with participants exhibiting similar amounts of thinking-induced forgetting in the two conditions. Whereas participants in the unusual condition exhibited a mean forgetting effect of 0.10, $t(33) = 4.23$, $p < .001$, $d = 0.73$, participants in the common condition

Table 1
Mean Ratings of Uses Generated and Mean Number of Similar, Creative, and Noncreative Uses Generated Per Object in Experiments 1, 2A, 2B, and 3

Procedure	Ratings of uses generated: Unusual	Novel	Creative	Useful	No. of responses: Similar	New: Creative	New: Noncreative
Experiment 1							
Unusual uses	4.1	3.4	3.5	5.3	0.5	2.2	1.0
Common uses	2.5	2.1	2.2	6.7	0.4	0.9	2.1
Experiment 2A: New uses/hints	3.0	2.3	2.6	6.3	1.3	1.0	1.3
Experiment 2B: New uses/no hints	3.0	2.4	2.6	6.3	0.3	1.4	2.0
Experiment 3: Unusual uses/stem	3.7	3.1	3.3	5.9	0.5	1.8	1.3

Note. The left side of the table shows the mean ratings of unusualness, novelty, creativeness, and usefulness (on a scale of 1 to 9) of the uses generated by participants. The right side of the table shows the mean number of uses generated per object that were identified by the raters as being either similar (very similar to, or the same as, one of the studied uses), new creative (different from all studied uses and rated to be more creative than the average use), and new noncreative (different from all studied uses and rated to be less creative than the average use).

exhibited a mean forgetting effect of 0.11, $t(33) = 4.33$, $p < .001$, $d = 0.74$.

The size of the thinking-induced forgetting effect deserves some emphasis. With such large Cohen's *d* effect sizes in both conditions, it appears that thinking-induced forgetting may reflect a reliable and robust phenomenon. Perhaps most impressive, however, when looking at participants individually, eight times as many participants exhibited forgetting (48) than facilitation (six).

One concern might be that participants recalled their self-generated uses at test, thus blocking or occluding the recall of studied uses. That is, participants may have recalled fewer items in the thinking condition simply because they incorrectly recalled the items they had generated instead of those they had studied. We attempted to address this concern by removing any participant who recalled even a single self-generated use, yet the same pattern was observed, producing a significant effect of thinking-induced forgetting, $F(1, 54) = 34.92$, $MSE = .01$, $p < .001$; a marginal effect of generation condition, $F(1, 54) = 3.67$, $MSE = .04$, $p = .06$; and no evidence of an interaction, $F(1, 54) = 0.19$, $MSE = .01$, $p = .67$. Furthermore, to provide additional evidence against this concern, we reanalyzed the data after counting each use recalled on the final test as correct regardless of whether it was from the study list or self-generated (completely new uses were not counted as correct). Even under these conditions, with the recall of uses in the thinking condition being exaggeratedly increased, significant thinking-induced forgetting was observed, $t(67) = 4.47$, $p < .001$, $d = 0.54$.

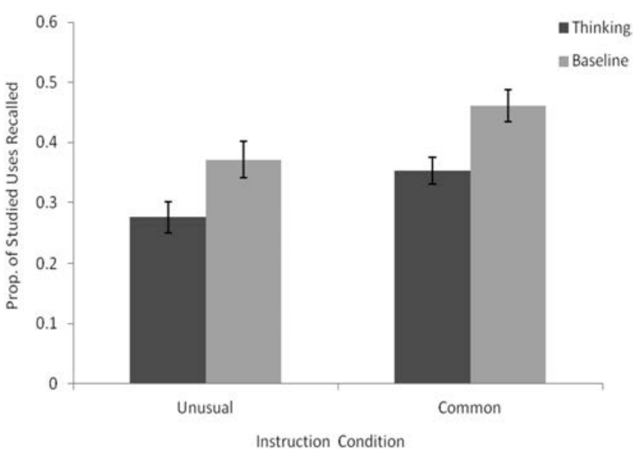

Figure 1. Final recall performance as a function of item type (thinking vs. baseline) and experimental condition in Experiment 1. The left and right columns show performance when participants were asked to generate unusual and common uses, respectively. Error bars represent standard error of the mean. Prop. = proportion.

Experiment 2A

We next sought to identify a boundary condition of the thinking-induced forgetting phenomenon. Specifically, if participants use the studied uses as hints to help them generate new uses—perhaps by using them as retrieval routes to think of similar or related uses—then the studied uses should not need to be inhibited and, as a consequence, they should not be susceptible to thinking-induced forgetting. In other words, it should only be information that interferes with new thinking that needs to be forgotten. If information is made to be relevant and useful, then there should be no need for a presumably goal-directed inhibitory mechanism to act against it. Indeed, research on retrieval-induced forgetting has shown that forgetting is not observed when target and nontarget items are well integrated or when nontarget items have the potential to mediate the retrieval of target items (e.g., M. C. Anderson, Green, & McCulloch, 2000; M. C. Anderson & McCulloch, 1999; Chan, 2009; Chan, McDermott, & Roediger, 2006; Goodmon & Anderson, 2011; Storm & Jobe, 2012a). We tested this hypothesis in Experiment 2A by instructing participants to use the studied uses as hints to help them think of related, but distinct, uses for the objects.

Method

Thirty-four UCSC undergraduates ($M_{age} = 19.9$ years) participated for course credit in a psychology course. The materials and procedures were identical to those of Experiment 1 except that participants were instructed to use the studied uses as hints to help them generate related uses. A second difference between Experiments 1 and 2A was that participants were not instructed to think of particular types of uses for the objects, such as unusual or common uses; they were simply asked to think of new uses. It was emphasized that participants could think of uses related to the studied uses, but that they should make sure that the uses they generate are distinct or different from the studied uses in some way.

Results

Uses generated. Participants generated 3.6 (SD = 1.3) uses per object, a rate nearly identical to that observed in Experiment 1. Not surprisingly, many of the generated uses were judged to be similar to those that had been studied. Specifically, participants generated an average of 1.3 similar uses per object, a rate significantly greater than that observed in Experiment 1, $t(100) = 5.09$, $p < .001$, $d = 0.95$. Another interesting point of comparison is that ratings of unusualness, novelty, creativity, and usefulness tended to be in between those observed in the unusual and common conditions of Experiment 1, with ratings trending closer to the common condition than the unusual condition.

Final recall performance. No evidence of thinking-induced forgetting was observed. As shown in the left-hand column of Figure 2, participants did not recall studied uses in the thinking condition any worse than they recalled them in the baseline condition, $t(33) = .14$, $p = .89$, $d = 0.02$. This finding suggests that it may only be trying to think of something completely new that causes the forgetting of something old. If existing ideas are helpful in facilitating the thinking of new ideas, then those ideas do not appear to be susceptible to thinking-induced forgetting. It should be noted that given the robust forgetting effects observed in Experiment 1—as well as those that will be observed in Experiments 2B and 3—an experiment with a sample size of 34 subjects should have had sufficient power (.99) to observe a significant effect if there was indeed one to be observed.

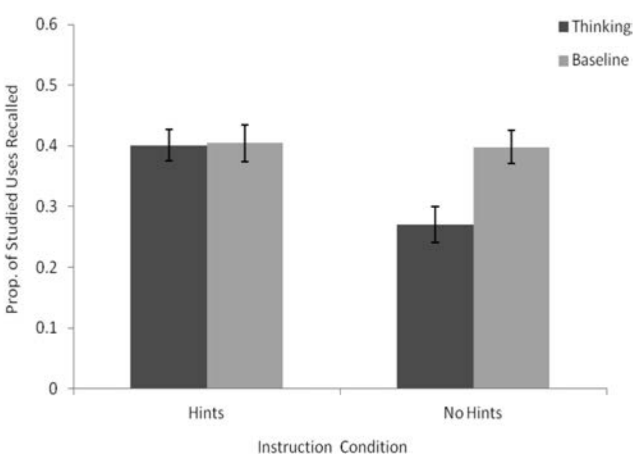

Figure 2. Final recall performance as a function of item type (thinking vs. baseline) and experimental condition. The left columns show performance when participants were asked to use the studied uses as hints (Experiment 2A); the right columns show performance when participants were not asked to use the studied uses as hints (Experiment 2B). Error bars represent standard error of the mean. Prop. = proportion.

Experiment 2B

One concern in interpreting the null effect in the hint condition of Experiment 2A is that it differed from Experiment 1 in two important ways. Although participants were instructed to use the studied uses as hints to guide their generation of new uses, they were also not given any instruction to generate specific types of new uses (i.e., unusual vs. common). Thus, participants were free to generate whatever they wanted, and it may have been for this reason that thinking-induced forgetting failed to emerge. To rule out this alternative explanation, a new experiment was run replicating Experiment 1 using a nonconstrained generation task. Specifically, as in Experiment 2A, participants were not told to think of any specific type of uses in the generation task, but as in Experiment 1, they were also not told to use the studied uses as hints.

Method

Eighteen UCSC undergraduates (M_{age} = 20.3 years) participated for course credit in a psychology course. The materials and procedures were identical to those of Experiment 2A except that participants were not instructed to use the studied uses as hints to help them generate related uses. Once again, participants were simply instructed to generate new and distinct uses for the objects, with no mention made of the particular types of uses (unusual or common) that should be generated.

Results

Uses generated. Participants generated 3.7 (SD = 1.2) uses per object, a rate nearly identical to that observed in Experiment 2A. Importantly, participants generated only 0.3 uses per object judged to be similar to the uses they had studied. The difference between Experiments 2A and 2B in terms of similarity ratings was statistically significant, $t(50) = 3.53$, $p = .001$, $d = 1.15$. Interestingly, as can be seen in the third and fourth rows of Table 1, ratings of unusualness, novelty, creativity, and usefulness were nearly identical in Experiments 2A and 2B.

Final recall performance. As shown in the right-hand column of Figure 2, a significant effect of thinking-induced forgetting was observed, with uses in the thinking condition ($M = 0.27$, $SE = 0.03$) being recalled less well than uses in the baseline condition ($M = 0.41$, $SE = 0.03$), $t(17) = 4.49$, $p < .001$, $d = 1.06$. This finding suggests that it was not simply the lack of direction regarding the type of uses that subjects were to generate (common vs. unusual) in Experiment 2A that prevented thinking-induced forgetting from being observed.

Because the subjects in Experiment 2B were sampled from the same pool of undergraduate students as those in Experiment 2A—albeit at different times of the academic year—we felt it was appropriate to test for the interaction between item type and instruction condition. A 2 (item type: thinking vs. baseline) × 2 (instruction: hint vs. no hint) mixed-design analysis of variance revealed a significant interaction such that a stronger thinking-induced forgetting effect was observed in the no-hint condition than in the hint condition, $F(1, 50) = 10.09$, $MSE = .01$, $p = .003$. This result further confirms that thinking-induced forgetting can be significantly diminished when using something that is already known to try to think of something new.

Experiment 3

One potential limitation of the thinking-induced forgetting effects reported thus far is the nature of the final test used to measure them. Although we were able to show that forgetting was not caused by participants recalling generated uses instead of studied uses, it is possible that the generated uses still caused the studied uses to be less recallable through associative interference (e.g., McGeoch, 1942; Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Rundus, 1973; Watkins & Watkins, 1975). Indeed, in the context of retrieval-induced forgetting, studies employing nonspecific category-cued tests (e.g., recall each of the studied fruits) have been shown to be particularly vulnerable to interference dynamics at test (Murayama, Miyatsu, Buchli, & Storm, 2014; Storm & Levy, 2012), and because the above experiments employed a seemingly similar type of nonspecific object-cued test (e.g., recall each the studied uses associated with a brick), it seems possible that the thinking-induced forgetting effect could be largely attributed to interference dynamics at test as well.

The final test administered in the present research, however, differs in important ways from the typical category-cued tests employed in the study of retrieval-induced forgetting. Specifically, in the study of retrieval-induced forgetting, participants are provided with category cues and asked to simultaneously recall both practiced items and nonpracticed items. Not surprisingly, items strengthened by retrieval practice are often recalled first, thus leading to output interference effects for the items that were not strengthened by retrieval practice. In the present experiments, however, participants were provided with object cues and asked to recall only the uses they had studied, and not the items they had generated. Thus, the final tests used in present Experiments 1 and 2 would not have been susceptible to the output interference dynamics typically observed in the study of retrieval-induced forgetting.

Nevertheless, we felt it was important to replicate the thinking-induced forgetting effect using item-specific cues (i.e., object plus an identifying stem) at final test. Retrieval-induced forgetting has been reliably demonstrated using such cues (e.g., M. C. Anderson et al., 1994; Bäuml, 2002; Storm, Bjork, & Bjork, 2008; Storm et al., 2006), and perhaps more importantly, recent work suggests that the forgetting observed using such cues provides a particularly strong predictor of individual differences in factors related to inhibition and the ability to overcome interference (e.g., Aslan & Bäuml, 2010; Schilling, Storm, & Anderson, 2014; Soriano et al., 2009; Storm & White, 2010; for further discussion, see M. C. Anderson & Levy, 2007; Murayama et al., 2014; Storm & Levy, 2012). Thus, in Experiment 3, participants were provided with each object's name along with the first letter of each of the words of a given studied use (e.g., *newspaper*: *p__ m__*, for *paper mâché*). By uniquely identifying each of the studied uses, these conjoint cues should reduce interference from the previously generated nontarget uses by allowing participants to target each of the studied uses directly, consequently reducing the interference component of the forgetting effect. If the thinking-induced forgetting effects observed in the previous experiments were caused entirely by interference dynamics at test owing to the nonspecific nature of the test cues, then the forgetting effect observed in Experiment 3 should be greatly reduced, or even eliminated.

Method

Twenty-four UCSC undergraduates ($M_{age} = 20.6$ years) participated for partial credit in a psychology course. Except for the nature of the final test, the materials and procedures were identical to those employed in the unusual condition of Experiment 1. Specifically, the object-cued recall test (e.g., *newspaper*) was replaced by an object-plus-multiple-letter-stem-cued recall test (e.g., *newspaper*: *p__ m__*, for *paper mâché*). As in the previous experiments, the objects were tested in the same order as they were studied, but the uses associated with each object were tested individually. The test began by cuing the recall of the four uses studied with the first object (presented in a new random order), followed by cuing the recall of the four uses studied with the second object (presented in a new random order), and so forth, until all eight objects were tested.

Results

Uses generated. Participants generated 3.5 ($SD = 1.2$) uses per objects, a rate similar to that observed in the previous experiments. As shown in the bottom row of Table 1, participants generated uses that were comparable to those generated by participants in the unusual condition of Experiment 1.

Final recall performance. Despite using item-specific cues at final test, significant thinking-induced forgetting was observed, with participants recalling significantly fewer uses in the thinking condition ($M = 0.16$, $SE = 0.02$) than in the baseline condition ($M = 0.24$, $SE = 0.03$), $t(23) = 2.65$, $p = .01$, $d = 0.54$. The magnitude of the thinking-induced forgetting effect was nearly as large as that observed in the unusual condition of Experiment 1 (0.08 compared to 0.10). As expected, owing to the nature of the final test, none of the participants recalled any of the uses they had generated.

Analysis of Uses Generated

Similarity Ratings

As shown on the right side of Table 1, participants generated more similar uses per object in Experiment 2A than they did in the other three experiments. This finding is not surprising given that participants in Experiment 2A were specifically instructed to use the studied uses as hints to guide their generation of new uses. Naturally, what they generated would be highly similar to the uses they had studied. One question that arises, then, is whether it was the use of the studied uses as hints to guide the generation of new uses that prevented the studied uses from being forgotten, or whether it was actually the nature of the relationship between the studied and generated uses that prevented forgetting from being observed. Perhaps similarity is all it takes to prevent forgetting and that if we examined participants from Experiments 1, 2B, and 3 who also generated uses highly similar to those they had studied, that those participants would also have exhibited significantly reduced levels of thinking-induced forgetting. Indeed, a significant negative correlation was observed across the entire sample such that participants who generated uses that were less similar to the studied uses tended to exhibit less thinking-induced forgetting than participants who generated uses that were more similar to the studied uses ($r = -.25$, $p = .002$).

To investigate this issue further, a subset of the participants who were not instructed to use the studied uses as hints (i.e., participants from Experiments 1, 2B, and 3) were placed in two subsamples: lowest similarity and highest similarity. Participants in the lowest similarity sample did not generate a single use that was later identified as being similar to any of the studied uses, whereas participants in the highest similarity sample generated at least four uses that were identified as being similar to the studied uses. The split was done in this way to create a sample of participants that generated as many similar uses as participants in the hint condition (and in this case, slightly more). As shown in Table 2, significant forgetting was observed in the lowest similarity sample, $t(29) = 5.36$, $p < .001$, $d = 0.98$, but more importantly, significant forgetting was also observed in the highest similarity sample, $t(14) = 3.62$, $p < .01$, $d = 0.93$. This finding suggests that generating similar uses does not in itself prevent thinking-induced forgetting from being observed; rather, it seems to be the strategy that participants employ in generating new uses—namely, using the studied uses as hints to guide thinking—that prevents forgetting from being observed.

Creativity Ratings

We next analyzed the relationship between creativity ratings and thinking-induced forgetting. To control for variability between conditions and counterbalancing, creativity ratings and forgetting scores were Z-normalized relative to the means and standard deviations of all other participants in the matched experimental and counterbalancing conditions. This method of analysis was important to ensure that individual differences in ratings and forgetting would not be confounded by experimental condition or by item differences owing to counterbalancing, thus providing a more accurate measure of how much a given participant deviated from the rest of the sample (either in the positive or negative direction, relative to the mean of participants in the same condition who came up with uses for the same objects). A significant correlation was observed such that participants who exhibited greater levels of thinking-induced forgetting generated uses that were rated to be significantly more creative than participants who exhibited reduced levels of thinking-induced forgetting ($r = .19$, $p = .03$). Similar results were observed with regard to unusualness ($r = .14$, $p = .09$) and novelty ($r = .13$, $p = .11$), and a trend in the opposite direction was observed for usefulness ($r = -.14$, $p = .10$), though these latter relationships failed to reach statistical significance.

To further explore the relationship between forgetting and creativity, we counted the number of uses each participant generated that were rated as being either above or below average in creativity across the entire sample. That is, we calculated the mean creativity score for all uses generated and then identified any use rated as more creative than that mean score as being creative and any use rated as less creative than that mean score as being noncreative (descriptive statistics as a function of experiment and condition are shown in the two right-hand columns of Table 1). Uses identified as similar to studied uses were excluded, and once again scores were Z-normalized to account for differences between experimental and counterbalancing conditions. Two scatterplots are shown in Figure 3 indicating the relationship between the generation of uses and thinking-induced forgetting. Critically, a significant positive correlation was observed, but only for creative uses. Whereas no evidence of a correlation was observed between the number of noncreative uses and thinking-induced forgetting ($r = .03$, $p = .74$), a reliable correlation was observed between the number of creative uses and thinking-induced forgetting ($r = .26$, $p = .003$), with the

Table 2
Mean Proportion of Uses Recalled in the Thinking and Baseline Conditions as a Function of Subject Group

		Item type				Effect		
		Thinking		Baseline				
Subject group	No. similar	*M*	*SD*	*M*	*SD*	Forget	*d*	*p*
Not instructed to use as hints								
Lowest similarity	0.0	0.30	0.03	0.45	0.03	0.14	0.98	<.001
Highest similarity	1.4	0.30	0.04	0.40	0.04	0.10	0.93	.003
Instructed to use as hints								
All subjects	1.3	0.40	0.03	0.40	0.03	0.00	0.02	.89

Note. The mean number of generated uses per object identified as being similar to the studied uses, final recall performance, and thinking-induced forgetting effect sizes are shown for three samples of participants. The first sample—lowest similarity with no instruction to use the studied uses as hints—consists of participants from Experiments 1, 2B, and 3 who did not generate a single use that was later identified as being similar to any of the studied uses. The second sample—highest similarity with no instruction to use the studied uses as hints—consists of participants from Experiments 1, 2B, and 3 who generated at least four uses (across all four objects) that were later identified as being similar to any of the studied uses. The third sample—all participants instructed to use hints—consists of all participants from Experiment 2A. These data show that differences in thinking-induced forgetting were not necessarily a function of the similarity between studied and generated uses, but rather the strategy participants used to generate the new uses.

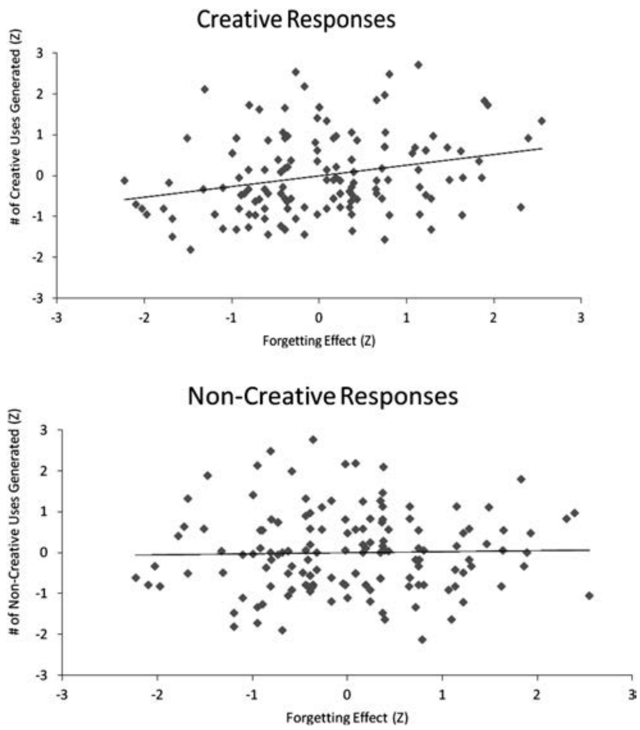

Figure 3. The top scatterplot shows the relationship between thinking-induced forgetting (positive values indicate more forgetting) and the number of creative uses generated per object by each participant ($r = .26$, $p = .003$). A generated use was identified as being creative if the three independent raters rated the use to be more creative than the average of the uses generated across the entire sample. The bottom scatterplot shows the relationship between thinking-induced forgetting and the number of non-creative uses generated per object by each participant ($r = .03$, *ns*). Data are collapsed across all four experiments.

difference between the coefficients reaching statistical significance ($Z = 1.99$, $p < .05$). Interestingly, when analyzed separately, the correlation between forgetting and the number of creative uses generated was stronger in Experiment 3 ($r = .56$, $p = .004$) than in any of the previous experiments, an observation we will return to in the general discussion.

One interesting aspect of the correlation between thinking-induced forgetting and creativity was that it was observed in terms of both fluency and creativeness. The logic for why forgetting might enhance fluency is relatively straightforward: Participants who were able to forget the studied uses presumably found themselves less constrained in their thinking and thus more capable of generating new uses. What is somewhat more surprising is that a significant correlation was observed between thinking-induced forgetting and ratings of creativity. One possibility is that participants who generated more uses tended to generate more creative uses because, on average, those participants had simply already exhausted the less creative uses in their initial output, thus leaving nothing but creative uses to generate in their subsequent output. Arguing against this possibility, however, is the fact that the correlation between forgetting and creativity remained significant even after controlling for variance in the total number of uses that participants generated (*partial* $r = .25$, $p = .003$). This observation suggests that the benefit of forgetting in thinking creatively cannot be explained by differences in the number of uses outputted. Instead, it may be that by inhibiting or in some way setting aside the studied uses, participants were able to explore a more diverse and original search space, leading them to generate more creative uses.

Of course, the correlation between thinking-induced forgetting and the generation of creative uses can be interpreted in multiple ways. On one hand, it may have been by forgetting the studied uses that participants were able to generate more divergent and creative uses. On the other hand, it may have been that generating more divergent and creative uses simply caused more forgetting. One consideration that leads us to endorse the first alternative is that if it was simply the act of generating creative uses that caused additional forgetting, then a difference in forgetting should have been observed in Experiment 1 when it was directly manipulated whether participants would generate creative or noncreative uses. Thus, it seems more likely that it was the participants' ability to forget the studied uses, or the fact that they actually did so, that enabled them to generate more creative uses.

General Discussion

The results of the present research suggest that thinking and forgetting are intrinsically connected—that to think of new ideas can cause the forgetting of old ideas, and that such forgetting may play an essential role in promoting the ability to think creatively. More specifically, the results show that trying to think of new uses for a given object can cause the forgetting of other uses for that object. This thinking-induced forgetting effect was observed regardless of whether participants tried to think of unusual or common uses, and was observed even when item-specific cues were employed at final test. The only time forgetting was not observed was in Experiment 2A, when participants were instructed to use the studied uses as hints to guide their generation of new uses. Subsequent analysis suggested that the absence of thinking-induced forgetting in this condition was not a by-product of participants simply generating uses that were similar to the old uses. Finally, individuals who exhibited greater levels of thinking-induced forgetting generated significantly more creative uses than did participants who exhibited reduced levels of thinking-induced forgetting—a finding that suggests that forgetting may serve the goal-directed purpose of enabling people to think creatively.

Notwithstanding the theoretical rationale presented in the introduction, there are reasons to be somewhat surprised by the present results. That is, there are reasons to think that generating new uses for an object might not cause the forgetting of other uses for that object. For example, associative theories of memory, such as spreading activation (Collins & Loftus, 1975) and the Adaptive Control of Thought–Rational (J. R. Anderson, 1996), assume that when information is activated, related information should also become activated. Generating new uses might have also improved the recall of studied uses by providing additional retrieval routes at test. Finally, even without explicit instructions to do so, participants might have taken advantage of the studied uses to facilitate their generation of new uses. That is, they might have employed the studied uses as hints or mediators in their generation attempts, in which case the studied uses would have been protected from forgetting. It seems that participants do not engage in this strategy unless explicitly instructed to do so.

At a general level, the present findings are consistent with the idea that forgetting plays an integral role in adaptively updating long-term memory (e.g., J. R. Anderson, 1990; J. R. Anderson & Schooler, 1991; E. L. Bjork & Bjork, 1988; R. A. Bjork, 1978). As conditions in the environment change, the particular information that is accessible in memory must be updated. Forgetting may be one mechanism by which to facilitate this process; specifically, by increasing the probability that information that is less likely to be useful does not interfere with access to information that is more likely to be useful. This idea fits well with arguments that forgetting, and memory failures more broadly, play an essential role in the general functioning of cognition (Bartlett, 1932; R. A. Bjork & Bjork, 1992; Schacter, 2001). If we did not have the ability to forget information that is no longer useful, or that stands in the way of information that would be useful, we would likely suffer for it.

Forgetting may play a much more general role in promoting the ability to think creatively and divergently than previously appreciated. Although empirical evidence of mental fixation as an impediment to creativity is abound (e.g., Duncker, 1945; Jansson & Smith, 1991; Kohn & Smith, 2010; Luchins & Luchins, 1959; Maier, 1931; Smith & Blankenship, 1989, 1991; Smith & Tindell, 1997; Smith et al., 1993), there have been far fewer demonstrations that the information causing fixation suffers forgetting as a consequence of attempting to overcome it (e.g., Healey et al., 2010; Smith & Blankenship, 1989; Storm et al., 2011). This idea has been explored most thoroughly in the memory literature, with proponents of the inhibitory account of retrieval-induced forgetting arguing that one way we are able to improve our chances of retrieving a target item is by inhibiting, and thus forgetting, interfering nontarget items (M. C. Anderson, 2003; Storm & Levy, 2012). It is possible however, that inhibition has the potential to enhance cognition in any context that requires fixating information to be forgotten. According to this perspective, forgetting may not simply be a side effect of thinking—it may be the consequence of a goal-directed inhibitory process, one that is similar to the type of inhibition that serves our more general goal of controlling inappropriate actions and behaviors. When information interferes with some cognitive process, whether it is in the context of memory, thinking, or problem solving, inhibition may be recruited in a top-down fashion to target that information, reducing its accessibility, and thus reducing the extent to which it causes fixation. One advantage of inhibition as a mechanism for overcoming fixation is that it can be recruited automatically in response to experiencing competition. Thus, unlike other mechanisms for overcoming fixation, people do not necessarily need to be consciously aware of the source of fixation for inhibition to act to help them overcome it.

Admittedly, it is still a bit speculative to conclude that the thinking-induced forgetting observed here was caused by inhibition. Considered in conjunction with work on retrieval-induced forgetting and problem-solving-induced forgetting, however, a case can be made. The most cited counterargument to inhibition is that of associative interference. In the context of the current paradigm, generating new uses for an object may have caused participants to forget the studied uses because of the strengthening caused by the generation of those uses. This form of interference contributes to forgetting in many contexts, and almost certainly contributes to thinking-induced forgetting as well. Several considerations, however, lead us to think that it is unlikely to be the sole explanation.

First, the forgetting effect was not the consequence of generated items occluding the recall of studied items through some sort of source confusion in which participants erroneously recalled the items they generated instead of the items they studied. In fact, significant forgetting was observed even when the analysis was restricted to participants who did not make such errors, and it was even observed when we counted as correct instances in which participants recalled their own generated uses. Second, by not having participants repeatedly think of a subset of items from the studied list, we were able to circumvent a problem recently proposed in the retrieval-induced forgetting literature; namely, that of contextual cuing (Jonker et al., 2013). Because participants were directed to recall the studied uses from a list context that was at least partially distinct from the uses they generated (i.e., the uses they studied, not the uses they generated), this more targeted retrieval search should have reduced the extent to which the generated items interfered with the recall of studied items. Third, significant forgetting was observed even when item-specific cues were employed at test, a practice that has been shown to greatly reduce the blocking component of retrieval-induced forgetting. Specifically, the item-specific cues should have allowed participants to more easily bypass the items strengthened by the thinking task, thus allowing them to recall the items they had studied.

Another reason we hesitate to endorse a purely interference-based account is the relationship between forgetting and uses generated. Thinking-induced forgetting was only predicted by the number of creative uses generated, not by the number of noncreative uses generated. Moreover, if generating creative uses caused forgetting via interference, then we would have expected the relationship between generating greater amounts of creative uses and thinking-induced forgetting to be weakest in the experiment that was least vulnerable to interference at test—specifically, Experiment 3. Yet, the opposite pattern was observed, with the relationship being stronger in that experiment than in any of the prior experiments, a finding that is generally in line with recent work on individual differences in retrieval-induced forgetting (see, e.g., Murayama et al., 2014; Storm & Levy, 2012).

These arguments aside, it is important to emphasize that it is highly unlikely that any one mechanism is going to be responsible for all effects of thinking-induced forgetting. Thinking of something new may have the power to cause forgetting in many ways, and the particular causes of forgetting in a given context will likely differ depending on factors such as the nature of the materials, the type of thinking task, the goals and strategies of the thinker, etc. Indeed, we see no reason why interference should not be responsible for causing substantial effects of thinking-induced forgetting, especially over extended periods as new ideas are repeatedly retrieved, strengthened, and elaborated.

Another mechanism by which thinking is likely to cause forgetting is by changing the way in which an item or problem is represented. In the AUT, for example, thinking of new uses of a given object may alter the way in which that object is perceived, thus making the object as a cue less appropriate for eliciting the recall of the initial studied uses. Similar arguments have a long-standing history in memory research, such as in Estes's stimulus fluctuation model (Estes, 1955a, 1955b; see also Bower, 1972; Bower & Hilgard, 1981). In this case, thinking of new and creative uses for an object may have reshuffled the stimulating features in such a way that the original studied responses were no longer accessible, thus reducing the probability of them being recalled. Similar dynamics may also have led to the main effect of condition observed in Experiment 1. Participants instructed to think of unusual uses performed worse on the final test than participants instructed to think of common uses, perhaps because doing so led them to think of the objects in new and different ways, thus reducing the probability that they would have been able to recall the studied uses at test. The fact that performance was worse for all objects, and not just for objects associated with additional thinking, however, suggests that thinking divergently may have changed the participants' context in a general way (e.g., Sahakyan & Kelley, 2002), perhaps by making all of the relatively more common uses for the objects less accessible, a possibility that future research should explore.

Concluding Comment

If thinking-induced forgetting can alleviate the effects of mental fixation, then regardless of the specific mechanism by which it does so, such forgetting has the potential to enable and facilitate the creativeness of our thinking. Although creativity may be endowed with a sense of unpredictability and characterized by seemingly ineffable illuminations of insight (Schooler & Melcher, 1995), the processes that underlie creativity are no different than the processes that underlie cognition more broadly (see, e.g., Smith & Ward, 2012; Weisberg, 1993). Thus, to understand creativity we must attempt to understand the noncreative processes that support it, and the present findings suggest that forgetting may be one such process.

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(*Appendix continues*)

Appendix

Objects Typically Used in the Alternative Uses Task

Object	Studied uses
Brick	Weight plate, give as a gift, crush into powder, stepping stones
Spoon	Percussion instrument, spoon bending entertainment, measuring tool, part of an art piece
Newspaper	Paper mâché, gift wrapping paper, start a fire, table cloth
Bucket	Music amplifier, seat, wear as a hat, small bathtub
Paperclip	Lock pick, hair pin, toothpick, create a small hole
Rubber band	Hair tie, play hand games, bracelet, music instrument
Coat hanger	Break into a car, unbend wire, clean a drain, reach small spaces
Screwdriver	Chisel, stir items together, hole punch, part of a survival kit

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