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Improving insight and non-insight problem solving with brief interventions

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Developing brief training interventions that benefit different forms of problem solving is challenging. In earlier research, Chrysikou (2006) showed that engaging in a task requiring generation of alternative uses of common objects improved subsequent insight problem solving. These benefits were attributed to a form of implicit transfer of processing involving enhanced construction of impromptu, on-the-spot or 'ad hoc' goal-directed categorizations of the problem elements. Following this, it is predicted that the alternative uses exercise should benefit abilities that govern goal-directed behaviour, such as fluid intelligence and executive functions. Similarly, an indirect intervention – self-affirmation (SA) – that has been shown to enhance cognitive and executive performance after self-regulation challenge and when under stereotype threat, may also increase adaptive goal-directed thinking and likewise should bolster problem-solving performance. In Experiment 1, brief single-session interventions, involving either alternative uses generation or SA, significantly enhanced both subsequent insight and visual–spatial fluid reasoning problem solving. In Experiment 2, we replicated the finding of benefits of both alternative uses generation and SA on subsequent insight problem-solving performance, and demonstrated that the underlying mechanism likely involves improved executive functioning. Even brief cognitive– and social–psychological interventions may substantially bolster different types of problem solving and may exert largely similar facilitatory effects on goal-directed behaviours.

We encounter a wide variety of problems and problematic situations daily, of varying levels of complexity and importance. Although focused and specialized, training in how to approach particular types of problems within a given domain (e.g., problems in algebra, or physics) is essential, developing interventions that can enhance the effectiveness with which we approach problem solving more generally is also important. In this report we provide evidence that two brief interventions, one taken from cognitive psychology and the other from social psychology, that have previously been examined separately, and each in more limited (restricted) problem-solving contexts, may enhance

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flexible on-the-spot problem solving across quite different problem types. We also begin to examine possible mechanisms supporting those beneficial effects.

Problem solving, goals, and executive function

A problem can be broadly defined as a situation in which a gap exists between one's current state and a hoped-for goal state. Thus, problem solving refers to a process by which the solver develops and implements plans (operators) within a range of constraints in the attempt to move from the current state towards the goal state (Newell & Simon, 1972) or, more generally, to a goal-directed sequence of cognitive operations (Anderson, 1980).

Although sometimes the problems we face are *well defined*, such that the initial state of the presented problem, the desirable goal state, and the operators to implement the necessary steps to achieve the goal state are clear, often problems are *ill defined.* When confronted with ill-defined problems, such as problems that require 'insight', there is a lack of clarity regarding the goal state and the steps to be taken, and the solver frequently reaches an impasse in which he or she is very uncertain just how to proceed in approaching the problem. For insight-type problems, the would-be solver is easily misled by the initial interpretation of the problem situation leading to poor organization of goal-directed behaviours (Fleck, 2008); success thus may require the solver to adaptively restructure the problem, such as reinterpreting the initial problem situation, resetting the goal state, and newly searching for effective operations to reach the new goal state. Chrysikou (2006) also proposed that successfully solving insight problems relies on goal-directed processes, particularly an implicit process termed 'goal-derived categorization' in which one generates *ad hoc*, on-the-spot combinations of various elements existing in one's memory 'to instantiate relevant properties of various problem elements and dynamically organize those elements in goal-derived categories [. . .] so as to satisfy the given goal' (Chrysikou, 2006, p. 936). As developed next, the generation, sustained representation, and coordination of goals is central to both fluid reasoning and executive function.

Fluid intelligence is critical to goal-directed behaviours (Duncan, 2010; Duncan, Emslie, Willis, Johnson, & Freer, 1996). In a series of experiments, Duncan *et al.* (1996) found that goal neglect – involving a failure to act in accordance with one or more of the requirements of a task – was more frequent in individuals who scored in the lower than in the upper range of the Cattell Culture Fair (CCF) Test (Institute for Personality and Ability Testing, 1973) of fluid intelligence. In contrast to crystallized intelligence, which primarily reflects acquired skills and knowledge, fluid intelligence particularly taps an individual's ability to adapt to novel situations (e.g., Horn, 1982; Sternberg, 2008), and measures of fluid intelligence thus feature problems requiring on-the-spot reasoning, abstracting, and analogical problem solving. Although the CCF includes non-insight problems, such as visual–spatial series completion, or identifying an 'odd one out', that are comparatively well defined with respect to the initial state and goal state, successful performance on this and similar fluid reasoning measures requires organization of goal-directed cognitive processes. Patients with frontal lobe lesions had pronounced difficulty in maintaining goals as instructed, and were especially vulnerable to goal neglect, suggesting that frontal functions, particularly executive function, may be central to fluid intelligence and adaptive responding to novel problems (e.g., Duncan *et al.*, 1996).

Executive function, the centre of organization of goal-directed behaviour (Duncan *et al.*, 1996), is an umbrella term encompassing various cognitive functions, such as reasoning, problem solving, planning, sequencing, sustaining attention, resistance to interference, and the ability to deal with novel stimuli (see Chan, Shum, Toulopoulou, & Chen, 2008). Executive functions are crucial in enabling the achievement of intended goals by maintaining action plans, goal states, and task-relevant stimuli in a highly active state and inhibiting sources of interference (Duncan, 2010; Kane & Engle, 2002). Additionally, as both insight and non-insight problem solving (and especially problems demanding on-the-spot fluid reasoning) can be considered goal-directed behaviours, improvements in executive function might thus be expected to enhance problem-solving performance regardless of problem type (ill-defined insight problems or non-insight, analytical problems). Task or training interventions that might act to enhance executive function could, then, be predicted to bolster both forms of problem solving.

The two experiments reported here aim to test this prediction. Specifically, in Experiment 1, we examined whether two quite different interventions that previous research has suggested were beneficial for particular subtypes of problem solving, might facilitate *both* insight problem solving and fluid reasoning (as assessed by the CCF). The two potential intervention approaches – the Alternative Uses Task (AUT) and self-affirmation (SA), grounded in cognitive psychology and social psychology, respectively – themselves share no seeming similarity to either insight problems or fluid intelligence. Nonetheless, as developed below, both the AUT and SA may act to alter aspects of goal-related processing. In Experiment 2, we examined whether the facilitation of problem solving derived from these interventions is attributable to changes in one or more aspects of executive function. We next provide an overview of the two interventions.

The AUT intervention

Chrysikou (2006) demonstrated that brief prior training on two variations of the AUT developed by Guilford, Christensen, Merrifield, and Wilson (1978), significantly improved subsequent insight problem solving. In a variant of this task used by Chrysikou (2006), called the Alternative Categories Task (ACT), participants were asked to generate other *categories* to which each of several common objects (e.g., shoe, fork) might also belong (e.g., a shoe might also be used as a hammer). A further variant of this task, called the Alternative Categories with Critical Items Task (ACT-C), was very similar, except that it included items that themselves were also part of the subsequent insight problems (e.g., 'box', where one of the insight problems involved the 'Candle problem' and where using the box in a different way is essential to finding the problem solution). Notably, beneficial effects of earlier performance of the ACT task on insight problem solving were obtained even under conditions where participants were not explicitly informed of the potential relevance of the training intervention to insight problem solving. The benefits for insight problem solving were also found regardless of whether or not the alternative categories included critical items from the insight problems, and were observed relative to two different control conditions, including a Word Association control condition, and an Embedded Figures Test control condition.

Given these findings, Chrysikou (2006, p. 938) suggested that the benefits of the ACT and ACT-C interventions could not be attributed to 'a general training to "think flexibly," but rather to a specialised training in goal-derived category construction'. More specifically, and also partially based on an analysis of participants' think-aloud protocols, she theorized that, following the ACT task, participants were 'more likely to construct and instantiate goal-derived categories regarding problem elements' (p. 940) and that this may have accounted for their enhanced problem-solving performance. Thus, goal-derived categorization, particularly *ad hoc*, secondary categorization, was proposed as the underlying mechanism for the beneficial effects of the ACT intervention on insight problems. Furthermore, Gilhooly, Fioratou, Anthony, and Wynn (2007) found that producing alternative uses is positively correlated with executive function, especially during the generation of new alternative uses (i.e., *ad hoc* secondary categorization), suggesting that the goal-derived categorization mechanism triggered during the alternative uses exercise itself involves executive function.

The self-affirmation (SA) intervention

Comparing the effects of different interventions without explicit and direct training on the targeted problem-solving tasks might further help to illuminate the cognitive processes involved, and how they may enable changes in adaptively flexible goal-related problem-solving performance. Thus, we also consider a quite different intervention – the SA intervention, derived from social psychology – that current evidence likewise suggests might also act to promote successful problem solving. According to SA theory (Steele, 1988), a fundamental goal of the self-system is to protect an image of its integrity and of its moral and adaptive adequacy. That is, individuals strive to see themselves as 'competent, good, coherent, unitary, stable, capable of free choice, capable of controlling important outcomes, and so on' (p. 262). Self-affirming processes may be elicited when one receives positive feedback from others and reflects upon positive aspects of oneself (Sherman & Cohen, 2006). One of the most important avenues to affirming the self is to explore one's core values that may, in turn, lead to changes in attitude, cognitive performance, and behaviours.

Studies have shown that SA can offset the impact of negative stereotypes or stereotype threat on cognitive performance, enabling appropriate goal-directed cognitive and behavioural competencies. Cohen, Garcia, Apfel, & Master (2006) found that an SA intervention significantly improved African-American students' grades and reduced the racial achievement gap linked to negative intellectual stereotypes. Similarly, Martens, Johns, Greenberg, & Schimel (2006) and Miyake *et al.* (2010) demonstrated that although women are often stereotyped as having inferior abilities in particular task domains, such as mathematics, spatial rotation, and physics, an SA intervention significantly improved their performance on tasks in these domains and reduced the gender achievement gap.

What cognitive processes might underlie these positive effects of SA? Based on the observation that SA countered the detrimental effects on performance that often follow sustained efforts at self-regulation, Vohs and Baumeister (2004) proposed that SA freed self-regulatory resources from ego-defensive concerns so that these resources were preserved for effective executive functioning. These researchers found that self-affirmed participants after performing an initial resource-demanding task, namely the Stroop colour-word interference task, could still perform well on a subsequent high resource-demanding executive task – the Tower of Hanoi task. Schmeichel and Vohs (2009) similarly found that SA enhanced self-regulatory control across successive tasks. Therefore, it seems that SA holds the promise of facilitating adaptive goal-directed cognitive processes. Nevertheless, whether SA as an intervention can improve ill-defined insight problem solving and/or fluid reasoning problem solving is unknown.

EXPERIMENT 1

The first, and primary, purpose of Experiment 1 is to investigate whether the AUT and SA interventions can act to facilitate *both* ill-defined and non-ill-defined problem solving, as assessed by insight-problem solving and visual–spatial fluid reasoning tasks, respectively. Demonstration of intervention-based improvements on both insight and fluid reasoning tasks for the AUT and/or SA task would provide key evidence that, as hypothesized, these interventions are influencing goal-directed cognition in a quite general (across-domain) manner.

A second purpose of this experiment is to examine the influence of the Word Association Task as the control task on subsequent problem solving. As noted earlier, Chrysikou (2006) included two different control comparison tasks (Word Association and Embedded Figures) and demonstrated that performance of the 'ACT' significantly enhanced subsequent insight problem-solving performance compared to *both* of these comparison conditions. The appropriateness of using word association as the control task to compare with the alternative categories intervention condition thus appears to be clear. Nonetheless, both of these comparison tasks differ from the ACT in multiple ways (e.g., both require convergent rather than divergent thinking and a single rather than multiple responses) that might differentially influence subsequent processing. More importantly, whether word association can serve as a legitimate control task for the effects of the SA intervention has not been examined. It is possible that, relative to the SA task with its explicit focus on positive aspects of the self, the Word Association Task requiring participants only to provide the first word that comes to mind for a series of simple words is less interesting and may reduce participants' motivation for fully engaging with this task and following tasks. This, then, raises the possibility that, rather than the intervention condition facilitating performance, the control conditions may, in some manner, be impeding or undermining subsequent problem solving performance.

To address this possibility, we added a further 'Neutral Baseline' condition to the experiment – in which participants simply were given the problems to solve, with no initial or prior intervention task. By comparing insight performance in the Word Association and the Neutral Baseline conditions, it would be clear if the Word Association Task does cause any detrimental effect on subsequent problem solving and the legitimate role of the Word Association Task as a control task for both the AUT and SA manipulations could be ascertained.

A third purpose of this experiment was to examine if the interventions influenced participants' mood, and thereby exerted effects on problem solving. Research has shown that, compared with negative or neutral affect, mildly positive affect (such as that induced by a small gift, or a brief exposure to humorous material) may facilitate problem solving, including creative problem solving. Specifically, positive affect may enhance cognitive flexibility, which enables one to respond appropriately to the task or situation at hand (for reviews, see Hirt, McDonald, & Melton, 1996; Isen, 2004). Therefore, we also examined mood changes across the experiment to clarify whether the AUT and SA interventions involve mood enhancement.

The hypotheses of Experiment 1 are as follows: (1) both the AUT and SA interventions can improve ill-defined insight problem solving and fluid reasoning, (2) the Word Association Task as a control condition neither improves nor impedes insight problem solving and fluid reasoning, and (3) the intervention effects do not involve or reflect mood enhancement.

Method

Participants

A total of 160 undergraduate students were recruited from the University of Reading via the Department of Psychology Research Panel (132 females; 28 males; mean age = 20.04 years; $SD = 3.19$ years). Participants were pre-screened for depression using the Brief Symptom Inventory (BSI, Derogatis & Melisaratos, 1983) and also for visual and hearing difficulties. All participants were native or fluent English speakers with an average of 13.59 years of formal education ($SD = .96$ years). Participant age and educational level did not differ across the four conditions ($F < 1$ and $F = 2.40$, respectively, ps $> .05$).

Materials

Problem-solving intervention conditions

There were four problem-solving intervention conditions.

(1) *The Alternative Uses Task (AUT)*: This task was based on that developed by Guilford *et al.* (1978). Participants were asked to generate non-standard or alternative uses for 12 common objects (e.g., a chair) listed on two consecutive pages. The standard use for each item was stated (e.g., a newspaper is generally used for reading). For each object, the maximum requested number of generated uses was ten. Participants were instructed to proceed to the next object when ten uses had been generated or no further uses could be generated. Participants were also reminded that all of the uses they produced should be different from each other and from the stated common use listed beside each object.

(2) *The SA Task*: The SA was developed based on Steele's SA theory (1988), according to which individuals may reduce their defensiveness and be more open-minded towards counter-attitudinal perspectives after an intervention that promotes SA in a valued domain unrelated to that involving threats or challenges to one's self-esteem. In this task, participants were presented 12 pairs of values (e.g., thrifty and generous), shown on two pages, and were asked to write about personally significant experiences for one or both values in each item that was important to them and that also made them feel good about themselves.

(3) *The Word Association Task (control task)*: This task comprised 300 common words (e.g., 'fruit'). The words were presented on four consecutive pages, two columns per page. After reading each item, participants were asked to write down the very first word that came to their mind in the blank space beside the stimulus word. Before starting this task, participants were reminded that there were no right or wrong answers for items and that they just needed to do their best rather than rushing through all of the items.

(4) *The baseline condition*: In this condition, no intervention or control task was used. Participants simply proceeded straight to the problem-solving tasks.

Problem-solving phase

There were two problem-solving tasks as dependent measures.

(1) *Insight problems:* Six insight problems were used, including the Ancient Coin Dated 544 B.C. problem (Metcalfe, 1986), the Woman and Policeman, and the

Dead Charlie problems (Weisberg, 1995), and the 10-Coin Triangle, the Two Strings, and the Pyramid and £50 Note problems (Isaak & Just, 1995). All of these problems were drawn from published studies on insight problem solving and some were slightly modified to be suitable to the UK population. The order of the problems was randomized and presented on paper. For each problem, the time limit was 5 min. If participants solved the problem within 5 min or could not solve it in 5 min, they were instructed to proceed to the next problem. Data from participants who, on the post-experimental questionnaire, identified three, or more than three, of the six insight items as pre-experimentally familiar were excluded from analysis. In all, a total of two participants were replaced for this reason. There were no differences between conditions with regard to the number of insight problems identified as familiar, $\chi^2(3) = 2.04$, $p > .05$. The solution rate was the total number of solved unfamiliar items divided by the total number of unfamiliar items.

(2) *CCF Test*: This task is a non-verbal paper-and-pencil task and was designed by Cattell and Cattell (1963) to assess relatively culture-free potential for learning. It is considered a good measure of fluid intelligence (Duncan, Burgess, & Emslie, 1995), consisting of four types of visuo-spatial problems, namely, series, classifications, matrices, and conditions. For example, in the classifications subtest, participants are shown 14 problems of five abstract shapes and figures and are asked to select which, of five, does not match or belong with the others. The tasks required participants to inspect the relationship between shapes and figures and determine which of several possible alternatives was the correct solution. For each subtest, the time allocated for completion was 3, 4, 3, and 2.5 min, respectively. The sum of the four subtest scores provided a total score of 50.

Mood Evaluation: A single question regarding current mood state, shown on a 7-point Likert-type scale (1 = very unhappy; 7 = very happy), was used to measure participants' mood state at three time-points (see procedure below).

Design and Procedure

This study employed a between-subjects design. Participants were randomly assigned to one of three problem-solving intervention conditions (AUT, SA, Control, $N = 40$ for each condition); participants in the Neutral Baseline condition ($N = 40$) were recruited and tested separately, and were drawn from the same general student population as those in the main experiment.

Each participant was tested individually and provided written informed consent and demographic data after receiving the study information. Next, all participants were asked to report their current mood state (Time-1) followed by a 10-min intervention manipulation and a further evaluation of their current mood state (Time-2); participants in the baseline condition proceeded directly to the first of the two problem-solving tasks.

In the problem-solving phase, within each condition, half of the participants ($N = 20$) were assigned to a problem-solving order of insight task first and then the CCF, whereas the other half followed the opposite order (CCF then insight). Once participants finished the two problem-solving tasks, they were asked to identify which insight problem(s) they had previously encountered, if any. Finally they were asked to report their current mood state (Time-3), debriefed, and thanked for their participation. For the baseline condition, participants were asked to report their mood state only at Time-1 and Time-3.

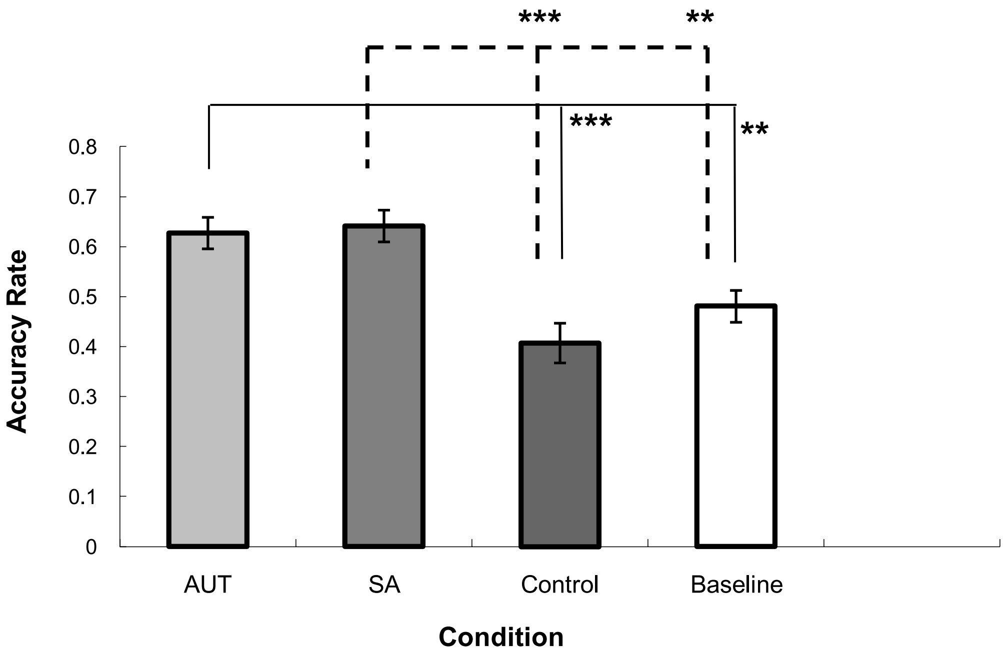

Figure 1. Insight problem-solving task performance. Mean accuracy rate on the insight problem-solving task for the Alternative Uses Task (AUT), self-affirmation (SA), control, and baseline conditions. Error bars represent standard errors of the means. Asterisks indicate significant differences compared to the control and baseline conditions, $^{**}p < .01$; $^{***}p < .001$.

Results

We first examined if there was an effect of the two orders of the dependent tasks (insight problems first or CCF first) and found no significant differences between the two orders, $ts\,(158) < 1$. Therefore, for each condition, the data from the two orders were collapsed for analyses.

Figures 1 and 2 present the key findings from the insight problem solving and CCF dependent measures, respectively. One-way analyses of variance (ANOVA) with condition as a between-subjects factor revealed a significant main effect of condition on the insight problem-solving task ($F[3, 156] = 11.72, p < .001$) and also on the CCF ($F[3, 156] = 6.71, p < .001$). For the insight problem-solving task, Tukey's honestly significant difference (HSD) *post hoc* analyses were employed given no violation of assumptions of ANOVA and revealed that participants in the AUT condition performed significantly better than those in the control condition ($p < .001$, Cohen's $d = 0.97$) and baseline condition ($p < .01$, Cohen's $d = 0.79$); also, participants in the SA showed significantly better performance on this task than in the control and baseline conditions ($p < .001$ and $<.01$, Cohen's $d = 1.03$ and 0.85, respectively).

For the CCF, the Levene's test was significant ($p < .05$) indicating that the assumption of homogeneity of variance was violated, so Games–Howell *post hoc* analyses were conducted. These analyses showed that performance on the CCF in the AUT condition

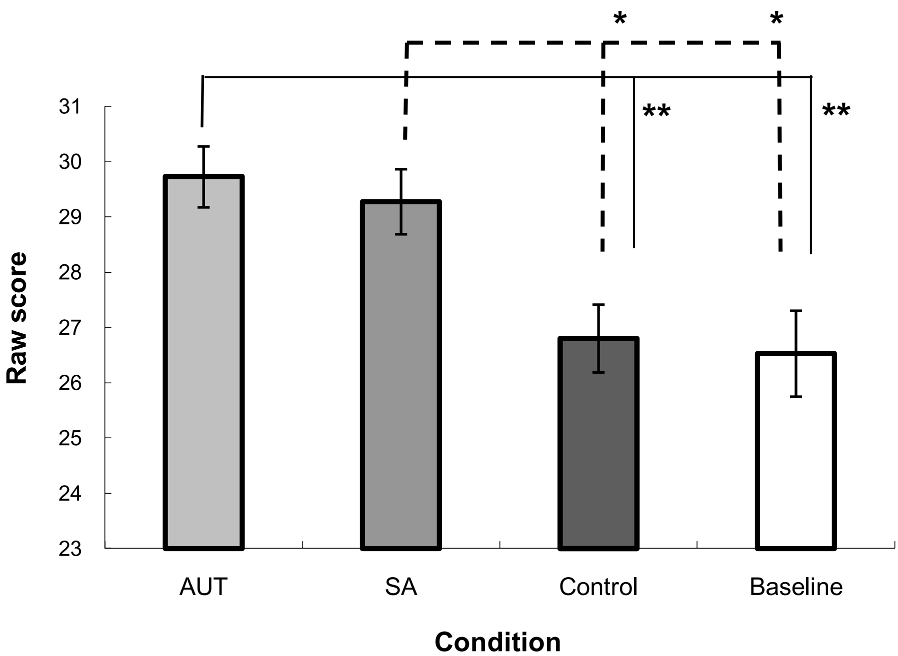

Figure 2. Cattell Culture Fair (CCF) Test performance. Mean score (of 50) on the CCF test of fluid visual–spatial reasoning for the Alternative Uses Task (AUT), self-affirmation (SA), control, and baseline conditions. Error bars represent standard errors of the means. Asterisks indicate significant differences compared to the control and baseline conditions, $^{*}p < .05$; $^{**}p < .01$.

significantly exceeded that in the control and baseline conditions (ps < .01, Cohen's $d =$ 0.79 and 0.75, respectively); likewise, participants in the SA condition also significantly outperformed those in the control and baseline conditions, ps < .05, Cohen's $d = 0.65$ and 0.63, respectively.

Table 1 provides descriptive results for the mood evaluations in the four conditions. The effects of condition and time-point on mood were examined in a 3 (condition: AUT, SA, and Word Association control) × 3 (time-point) mixed-factor ANOVA. This analysis revealed that there was a significant difference in mood state between time-points, $F(1.67, 195.46) = 7.47$, $p < .001$. Contrast comparison analyses revealed that, averaging across conditions, mood state at Time-3 was significantly lower than at Time-1 ($p = .001$) and slightly lower than mood state at Time-2 ($p = .06$). Importantly

Table 1. Mean mood ratings across the three time-points (Experiment 1)

Time-point	AUT Mean (*SD*)	SA Mean (*SD*)	Control Mean (*SD*)	Baseline Mean (*SD*)
Time-1	5.20 (1.04)	5.10 (0.87)	5.03 (0.86)	5.25 (0.87)
Time-2	4.88 (0.97)	5.10 (0.90)	4.90 (0.87)	—[a]
Time-3	4.78 (1.12)	4.98 (1.00)	4.65 (1.31)	4.93 (0.94)

Note. AUT, Alternative Uses Task condition; SA, self-affirmation condition.[a]No mood rating was obtained at Time-2 for the Baseline condition because there was no intervening task for this condition.

though, this analysis also showed that there were no significant differences between conditions, and no interaction between condition and time-point (Fs < 1.10). Results from a 4 (condition) × 2 (time-point) ANOVA, examining mood states across all four conditions and including just the first and the last mood assessment (because mood in the Neutral Baseline condition was assessed only twice, as they had no intervening task) also indicated no difference in mood state across time between conditions and no condition × time-point interaction (Fs < 1).

Discussion

There were five main results from Experiment 1. First, ill-defined insight problem solving performance was significantly enhanced by briefly engaging in a task requiring the generation of alternative uses for common objects, thereby replicating the findings reported by Chrysikou (2006), and extending them to the original version of the Alternative Uses Task developed by Guilford and colleagues (rather than the 'ACT'). Second, an SA intervention drawn from social psychology, in which participants were asked to reflect upon and write about personally important values, also had a significant beneficial effect on insight problem solving. Third, for both the AUT and the SA interventions, these benefits were found against both a simple word association control and a no-task baseline condition, thereby confirming that the effects do reflect enhanced performance in the intervention conditions, rather than impeded performance in the control conditions. Fourth, and crucially, both the AUT and SA significantly promoted a different type of problem solving – that is, novel, on-the-spot visual–spatial fluid reasoning, as measured by the CCF, a well-accepted measure of *fluid intelligence* involving problems such as series completion and progressive matrices. These performance benefits were observed both when the fluid reasoning measure preceded the insight problems, and when it followed the insight problems. Fifth, analyses of the brief measure of participants' overall mood across time suggested that these outcomes were not attributable to differences in mood between the intervention conditions and the control conditions.

The finding that the AUT improved insight problem solving corresponds to Chrysikou's finding (2006). The AUT intervention creates a problem situation that requires one to think of alternative, novel strategies or solutions beyond one's typical or habitual responses (e.g., typical uses for common objects). As Chrysikou's account of goal-directed categorization suggests, engaging in the AUT encourages adaptively restructuring the problem stimuli and resetting the goal (*ad hoc*, on-the-spot categorization) in order to solve the given problem. For ill-defined insight problem solving, the first presented problem situations are usually unclear and misleading. However, to reach the goal state, one should not be misled, but should have flexible goal-directed thinking.

Similarly, successful problem solving on the CCF, a well-accepted measure of novel, on-the-spot fluid intelligence, requires substantial organization of goal-directed behaviour (e.g., Duncan *et al.*, 1996). The CCF at times requires the individual to focus on exceedingly concrete/item-specific details and at other times, asks for a shift of focus to abstract relations between stimuli (e.g., patterns of sameness, or difference) in order to achieve the goal state. The AUT exercise enables one to decompose the object, focus on the detailed parts, and use the parts or recombine the parts. Additionally, however, the AUT also may promote abstract thinking, such as generating broad classes or categories of objects (see Gilhooly *et al.*, 2007). Therefore, the flexible goal-directed processes elicited by the AUT may facilitate subsequent fluid reasoning.

Equally important, a brief SA intervention, asking participants to reflect on and to bring to mind personally important values, showed similar beneficial effects on both insight problem solving and fluid reasoning. Although previous research has demonstrated that SA may increase an individual's cognitive competencies in some social contexts (e.g., minority students' academic performance), to our knowledge, this is the first study broadly testing the *immediate-term* effects of SA on novel, on-the-spot, problem solving and reasoning, including a variety of insight problems and non-insight visual–spatial fluid reasoning problems (themselves of several types). The finding that a brief SA intervention, like the AUT, improved different types of problem solving suggests that SA may broadly facilitate goal-directed behaviour across a variety of complex problem-solving situations (e.g., Schmeichel & Zell, 2007).

Notably, neither the AUT nor the SA interventions share any similarities in terms of surface structure with either insight problems or with the CCF. Also, the further observation that the AUT and SA interventions boosted problem-solving performance regardless of whether the insight task preceded or followed the CCF may further demonstrate that the AUT and SA bolstered adaptively flexible goal-related problem solving generally, rather than only more narrow problem-specific strategies (e.g., remembering specific problem-solving steps or increasing familiarity with the problem structures).

A further important finding from this experiment was that the control Word Association Task neither improved nor impeded subsequent problem solving; rather, its effects were similar to the Neutral (no-intervention) Baseline condition. This outcome concurs with the results of Chrysikou (2006) indicating that the Word Association Task can be appropriately used as a control pre-problem-solving activity for the AUT task, and additionally shows that it also is an appropriate neutral comparison activity for the SA intervention.

This experiment revealed that the beneficial effects of the AUT and SA on insight problem solving and fluid reasoning did not involve mood enhancement given that there were no mood differences between conditions across time. These results suggest that the brief AUT and SA problem-solving interventions can genuinely improve insight problem solving and fluid reasoning in a manner that does not involve mood enhancement. Future research might consider a more finely gradated, multiple-item measure of mood to more firmly rule out a contribution from mood, while also, though, taking into account the possibility that extensive mood measurements may themselves change participants' processing or perceptions (e.g., eliciting greater attempts at the self-regulation of mood).

In summary, Experiment 1 has demonstrated first, that performance of the AUT *and* a quite different intervention – involving the SA manipulation from social psychology, can improve *both* ill-defined insight problem solving and clearly defined problem solving involving visual–spatial fluid reasoning, and second, that these beneficial effects do not appear to reflect changes in mood. Collectively, the findings from this experiment suggest the feasibility of adopting brief interventions that are ostensibly dissimilar to the dependent tasks to improve multiple forms of problem solving. In the next experiment, we examined whether the AUT and SA encourage a key function strongly related to goal-directed behaviour – executive function – to clarify the robustness of the AUT and SA effects on goal-directed problem solving.

EXPERIMENT 2

Problem solving regardless of the problem type involves a cluster of goal-directed actions. Previous studies have demonstrated that solving insight problems places demands on executive processing (Gilhooly & Murphy, 2005), particularly working memory (Ash & Wiley, 2006; Fleck, 2008; Gilhooly & Fioratou, 2009). In addition, the link between fluid reasoning and executive functions has also been well documented. For example, Kane and Engle (2002) found that fluid intelligence, as measured by matrix-reasoning tasks, involved executive attention to integrate multiple stimulus dimensions which in turn has close ties with executive functions in normal adults and patients with frontal lesions (e.g., Duncan *et al.*, 1996; Duncan, Johnson, Swales, & Freer, 1997; for review, see Kane & Engle, 2002). Specifically, fluid intelligence has been strongly linked to working memory (e.g., Kane *et al.*, 2004) and training on working memory and executive control has been shown to enhance fluid reasoning performance (Borella, Carretti, Riboldi, & De Beni, 2010; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Karbach & Kray, 2009).

Regarding the two interventions, first, the AUT has also been linked to executive functions. Using a near-infrared optical spectroscopy method, Folly and Park (2005) demonstrated that divergent thinking, measured by the AUT, was associated with bilateral prefrontal cortex activation across schizophrenic, schizotypal, and normal control groups. Given that the close relationship between frontal lobe function and executive function has been well documented (Baddeley, 1996; Lezak, 1995; Salthouse, Atkinson, & Berish, 2003), it appears conceivable that performing the AUT engages executive functions. More direct evidence of the association between the AUT and executive function comes from research by Gilhooly *et al.* (2007). They found that producing genuine novel, alternative uses that were not known previously to the individual but were newly generated for the first time during the task was positively associated with executive functions.

Second, for the SA intervention, there is some emerging evidence suggestive of a relationship between self-regulation and executive function. Baumeister and Vohs (2005) proposed that self-regulation refers to the process whereby individuals replace a highly prepotent or habitual response or behaviour with a less habitual but more desired response. Self-regulation is regarded as a core aspect of executive function, involving active and intentional self-monitoring and activation or inhibition of behaviour and cognition (Baumeister, Schmeichel, & Vohs, 2007). Furthermore, it has been demonstrated that SA may facilitate self-regulation (Schmeichel & Vohs, 2009; Vohs & Baumeister, 2004), similarly suggesting a positive relationship between SA and executive function.

Clearly, it is possible that the AUT and SA interventions operate through quite different mechanisms. However, the similarity of the outcomes for the two interventions – with both interventions broadly facilitating both insight and fluid reasoning problem solving – suggests that they may have a common basis. Following these lines, we reasoned that the AUT and SA interventions may likewise both improve executive function, which governs goal-directed behaviour, especially given the strong relation between executive function and fluid reasoning (Duncan *et al.*, 1996; Shamosh & Gray, 2007). Because executive function *per se* is a complex system, entailing a wide range of cognitive domains (Baddeley, 1996; Lehto, 1996), here we adopted the factor model of executive function developed by Miyake *et al.* (2000) to examine which component(s) of executive function may be particularly influenced by the two interventions.

Miyake *et al.* (2000) extracted three latent factors of executive functions including (1) shifting between tasks or mental sets (named '*shifting*'), (2) updating and monitoring of working memory representations (named '*updating*', closely linked to the construct of working memory), and (3) inhibition of dominant or prepotent responses (named '*inhibition*'). Support for this three-factor model has been provided by several studies (e.g., Collette *et al.*, 2005; Friedman *et al.*, 2006; Quinette *et al.*, 2003; Reay, Hamilton, Kennedy, & Schole, 2006).

The main purpose of Experiment 2 is to examine whether the AUT and SA interventions improve performance on tasks that tap executive function and, if so, to determine which particular aspect(s) of executive function are improved by each intervention. As reviewed previously, both insight problem solving and fluid intelligence are associated with updating; we therefore hypothesized that both the AUT and SA may improve updating ability. Given the inclusion of three additional measures of executive function within the experimental session, we now focused on insight problem-solving performance as our main measure of intervention effectiveness on problem solving. Additionally, to further test the generalizability of our finding that SA facilitated insight problem solving, we adopted an alternative version of the SA task.

Method

Participants

A total of 75 undergraduate students were recruited from the University of Reading via the Department of Psychology Research Panel (65 females; 10 males; mean age = 20.27 years; *SD* = 4.17 years). Participants were pre-screened for depression using the BSI (Derogatis & Melisaratos, 1983) and also for visual and hearing difficulties. All participants were native or fluent English speakers with an average of 14.13 years of formal education (*SD* = 1.22 years). One-way ANOVA analyses showed no significant differences in age or education between conditions (Fs[2, 72] < 1.4).

Materials

Problem-solving intervention conditions

There were three problem-solving intervention conditions.

(1) *The Alternative Uses Task (AUT):* The same task as used in Experiment 1.
(2) *The SA Task*: Previous research on SA has used various methods to elicit SA effects (for review, see McQueen & Klein, 2006). In order to assess the generalizability of our findings from Experiment 1, in this experiment we adopted a different SA intervention task developed by Napper, Harris, and Epton (2009). This SA task consisted of two parts: first, a questionnaire with 32 items (possible character strengths) presented on 5-point Likert-type scales, and second, a section where participants were asked to list two of their most important personal strengths and then to complete a brief essay explaining why these two personal strengths were important to them, and how the strengths had influenced their behaviours and attitude. This task has previously been shown to produce similar patterns of effects to other existing SA manipulations.
(3) *The Word Association Task (control task):* The same task as used in Experiment 1.

As we demonstrated the appropriateness of the current control task in Experiment 1, we did not include a Neutral Baseline condition in Experiment 2.

Post-intervention problem-solving measures

(1) *The Number-Letter Task:* This task drawn from Miyake *et al.*'s study (2000) is a robust measure of shifting ability(e.g., Fournier-Vicente, Larigauderie, & Gaonac'h, 2008; Miyake *et al.*, 2000). A number-letter pair (e.g., 5B) was presented in one of the four quadrants on the computer screen (24-point font, black-on-white text, 1500 ms presentation, 500 ms inter-trial interval). Participants were required to indicate whether the number in the number-letter pair was odd or even when the pair was presented in either of the top two quadrants, and to indicate whether the letter was a consonant or a vowel when the pair was presented in either of the bottom two quadrants.

Participants first were given a practice phase and then were guided to the testing phase. The testing phase consisted of 84 trials, presented in the same sequential order as the practice phase, and included three blocks of 20, 20, and 44 trials, respectively. Block 1 had only 'number' trials (all stimuli presented in the top two quadrants, requiring the odd/even judgment); block 2 had only 'letter' trials (all stimuli presented in the bottom two quadrants, requiring the consonant/vowel judgment); block 3 had intermixed 'number' and 'letter' trials (stimuli presented in a clockwise rotation around all four quadrants), and thus required regular switching between the two types of judgments (e.g., beginning in the upper left quadrant: number–number–letter–letter–number–number–letter–letter ...). In this design, the shifting trials were given at the end of the task, following blocked practice on each of the subcomponent tasks, and in a predictable trial-by-trial manner, and participants showed an overall practice effect (increase in accuracy) across the three blocks. The dependent measure for this task therefore was shift cost or the difference between the reaction time for correct trials for the trials in the third block that required a mental shift (change in task set) and the reaction time for correct trials from the same block in which no shift was necessary. Lower scores on this measure represented lower shifting cost.

(2) *The Stroop Task*: This task, modified from Miyake *et al.*'s study (2000), is a robust measure of inhibition ability (e.g., Hull, Martin, Beier, Lane, & Hamilton, 2008; Miyake *et al.*, 2000; Salthouse *et al.*, 2003; St Clair-Thompson & Gathercole, 2006). Participants were presented words and strings composed of four Xs in four different colours (24-point font, 1,000 ms per trial). They were instructed to press designated buttons based on the colour of the text of the presented word or strings (but not the meaning of the word) as quickly and accurately as possible.

After an initial practice phase, participants were given the test phase, comprised 144 randomly intermixed trials: 48 neutral (the stimulus was composed of four Xs printed in one of four different coloured fonts), 48 congruent (i.e., the stimulus colour was the same as the meaning of the stimulus word), and 48 incongruent (i.e., the stimulus colour was different from the meaning of the stimulus word). The improvement in inhibition ability (also the dependent measure) was measured in this way: the reaction time of correct responses to incongruent trials minus the reaction time to correct responses for neutral and congruent stimuli. Therefore, lower scores indicate better inhibition ability.

(3) *The Letter-Memory Task*: This task from Miyake *et al.*'s study (2000) strongly loaded onto updating ability (Friedman *et al.*, 2008; Miyake *et al.*, 2000; St Clair-Thompson & Gathercole, 2006) and simply required participants to recall the latest four letters occurring in an ongoing sequence of presented letters. Individual letters were sequentially presented (18-point font, black-on-white text) for 2,000 ms in the centre

of the computer screen. Participants were required to rehearse out loud the last four letters by mentally adding the most recent letter and dropping the fifth letter back and then saying the new string of four letters out loud to ensure the involvement of continuous updating.

Participants were first given practice trials and then continued to 10 test trials involving the sequential presentation of 5, 7, 9, 11, 7, 9, 5, 11, 5, 9 letters, respectively. The proportion of trials recalled correctly across all of the test trials was the dependent measure.

(4) *Insight problems*: The same items as used in Experiment 1.

Design and Procedure

This study employed a between-subjects design. Participants were randomly assigned to one of the three conditions: AUT, SA, or control condition ($N = 25$ for each condition). Participants were tested individually and provided written informed consent and demographic data after receiving the study information. Next, participants received one of the 10-min intervention or control tasks. Subsequently, participants received a further battery of tests comprising the post-intervention executive measures followed by insight problems. After completing the insight problems, participants completed a post-experimental assessment of their pre-experimental familiarity with the insight problems on which they were asked to indicate which, if any, of the insight problems they had previously encountered. Participants who identified three or more of the problems as pre-experimentally familiar were replaced (no participants were replaced for this reason though). Finally participants were debriefed and thanked.

Results

Figure 3 presents the results for the three post-intervention central executive measures and for the insight problem-solving measure. One-way ANOVA analyses indicated that there were no effects of experimental condition (AUT, SA, or control) on the measures of shifting or inhibition (ps $> .05$), whereas the differences in updating and insight problem solving were significant (Fs$[2, 72] = 9.47$ and 9.06, respectively, ps $< .001$). Tukey's HSD *post hoc* analyses revealed that for updating, participants in the AUT and SA conditions outperformed those in the control condition ($p < .001$ and $< .01$, respectively; Cohen's $d = 1.17$ and .90, respectively). For insight problem solving, replicating the finding in Experiment 1, participants in both the AUT and SA conditions outperformed those in the control condition (ps $= .001$; Cohen's $d = 1.13$ and 1.10, respectively). Moreover, overall insight problem solving was positively correlated with updating ($r = .40$, $p < .001$, respectively), but not with shifting and inhibition (ps $> .05$).

To further examine the overall intervention effects on the solution rate of each insight problem, we combined the data of Experiments 1 and 2 for each problem, separately for the AUT, SA, and control conditions. As shown in Table 2, numerically higher solution rates were observed in the AUT and SA conditions than in the control condition for all six problems. Binary logistic regression analyses revealed significant effects of condition on the solution rate for four of the six insight problems, including the Woman and Policeman problem, the Ancient Coin Dated 544 B.C. problem, the Dead Charlie problem, and the Pyramid and £50 Note problem. For each of these problems, contrast analyses (see

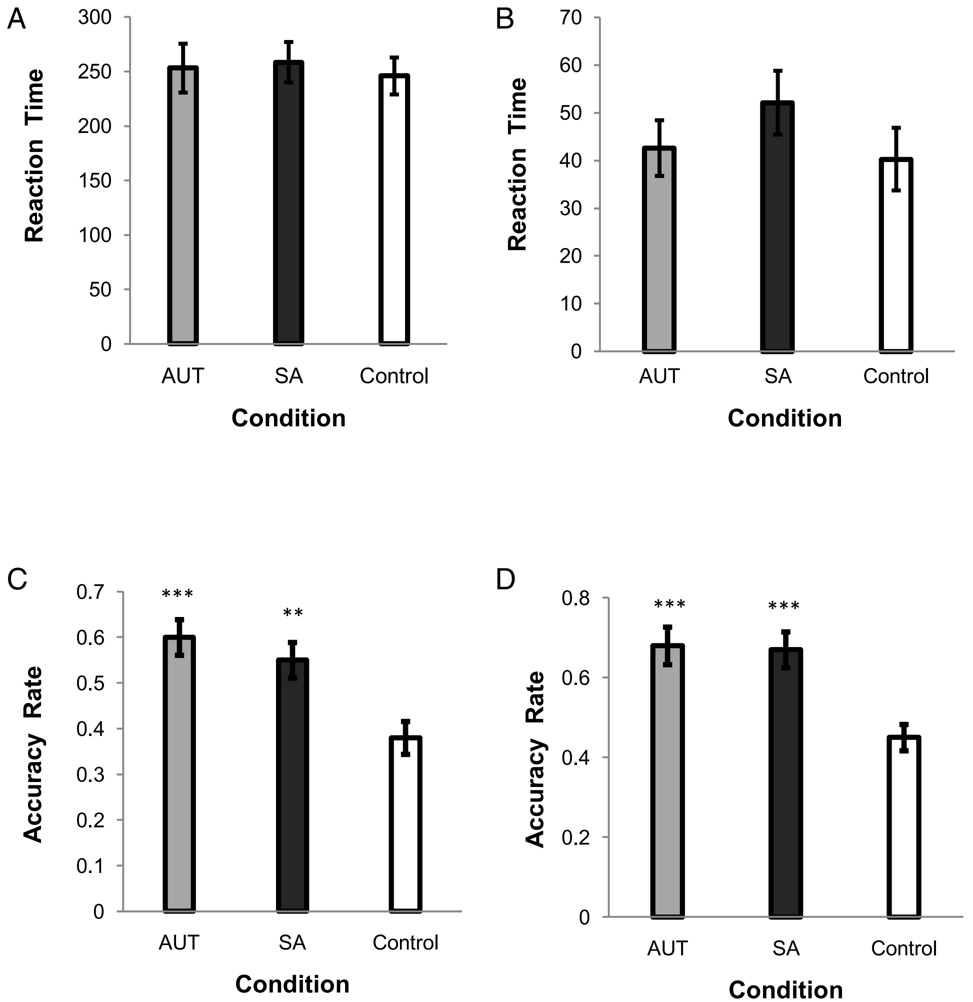

Figure 3. Executive and insight problem solving task performance. Correct reaction time on (a) the Number-Letter Task and (b) the Stroop Task, and accuracy rate on (c) the Letter-Memory Task and (d) insight problem-solving task for the Alternative Uses Task (AUT), self-affirmation (SA), and control conditions. Error bars represent standard errors of the means. Asterisks indicate significant differences compared to the control condition, $^{**}p < .01$; $^{***}p \leq .001$.

Table 2) further revealed that both the AUT and SA conditions significantly outperformed the control condition.

Discussion

The current experiment yielded two main findings. First, consistent with our hypothesis, both the AUT and SA yielded beneficial effects on the 'updating' component of executive function relative to the control condition. Second, both the AUT and SA interventions again significantly enhanced insight problem-solving performance. These outcomes conform to the correlation between insight problem solving and executive function

Table 2. Solution rate of insight problems for each condition and results of logistic regression analyses testing the association between condition and solution rate

Condition Insight problem	AUT	SA	Control	χ^2 (2)
Woman and Policeman	84.4	82.3	60.9	11.25**
10-Coin Triangle	63.8	68.9	55.7	2.28
Two Strings	34.5	42.6	25.4	3.75
Ancient Coin Dated 544 B.C.	59.4	54.8	27.7	15.62***
Dead Charlie	42.1	39.6	15.5	12.16**
Pyramid and £50 Note	95.1	95.3	66.1	26.88***

Note. Numbers represent percentage. $^{**}p < .01$; $^{***}p < .001$.
Contrast analyses showed that compared with the control condition, both the AUT and SA conditions produced significantly higher solution rates for the Woman and Policeman problem ($B = 1.24$, $SE = .43$, Wald = 8.37, $p < .01$ and $B = 1.09$, $SE = .42$, Wald = 6.74, $p < .01$, respectively), the Ancient Coin Dated 544 B.C. problem ($B = 1.34$, $SE = .38$, Wald = 12.67, $p < .001$ and $B = 1.15$, $SE = .38$, Wald = 9.38, $p < .01$, respectively), the Dead Charlie problem ($B = 1.38$, $SE = .45$, Wald = 9.31, $p < .01$ and $B = 1.27$, $SE = .46$, Wald = 7.71, $p < .01$, respectively), and the Pyramid and £50 Note problem ($B = 2.29$, $SE = .65$, Wald = 12.44, $p < .001$ and $B = 2.34$, $SE = .65$, Wald = 13.02, $p < .001$, respectively).

noted earlier. This may be because, as shown in previous studies (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Friedman *et al.*, 2006), working memory, strongly connected with fluid intelligence, reflects abilities that involve attentional control to keep relevant information (e.g., task goals) active in the face of interference and distraction. Although the AUT and SA interventions are drawn from two different theoretical grounds, both interventions produced similar improvement in updating (or working memory in some literature) and insight problem solving, implying different means to the same end.

Earlier research (Gilhooly *et al.*, 2007) demonstrated that the AUT involves executive processing. Our current work based on an already well-examined factor model of executive functioning, further indicates that generating alternative uses is associated with subsequently enhanced updating capacity. Neuroimaging research (Fink *et al.*, 2009) suggests that the AUT and updating may recruit a similar brain network, including left inferior frontal gyrus extending to anterior cingulate and supplementary motor area, consistent with our finding that the AUT improved updating. Additionally, a social–psychological intervention – SA has been shown to enhance self-regulation (Schmeichel & Vohs, 2009; Vohs & Baumeister, 2004) whose major elements are encapsulated by executive functions (Barkley, 2001). However, the particular aspect(s) of executive function that are affected by the process of SA, and that may facilitate self-regulation, has not previously been explored. The results from this experiment suggest that a key contributor to enhanced self-regulation following SA may involve improved updating. Our finding together with a similar view proposed by Koole and van Knippenberg (2007) that SA bolsters mental control via updating suggest that SA allows individuals to filter out unwanted information from working memory and thus facilitates focus on goal-relevant information. However, whether the AUT and SA improve updating through the same cognitive or neural processes is unknown and requires further investigation.

We replicated the finding that both the brief AUT and SA interventions significantly bolster insight problem solving. This shows the robustness of the AUT and SA intervention effects in improving insight problem solving, and additionally extends the demonstrated benefits of the SA intervention for insight problem solving to the different SA intervention task developed by Napper *et al.* (2009). Also, consistent with previous findings (Ash & Wiley, 2006; Fleck, 2008; Gilhooly & Fioratou, 2009), we found that the overall process of insight problem solving is positively associated with updating capacity. Furthermore, significantly higher solution rates in both the SA and the AUT conditions than in the control condition were observed for four of the six insight problems, with numerically higher solution rates than the control condition for all six problems, indicating that the intervention effects were not confined to only one or a few problems.

One additional notable caveat should be addressed. For each aspect of central executive function, only a single measure was used. This is because a previous study from our lab (Wen, 2011) indicated that for both 10-min AUT and SA interventions, the beneficial effects of the intervention dissipated about 45–50 min after the intervention. To arrange executive tasks tapping each of the three central executive aspects as well as the insight problem-solving task within 45–50 min after the intervention, we assessed each of the three aspects with one robustly reliable task. However, further investigation into the AUT and SA effects on composite (rather than single) measures of shifting, updating, and inhibition is necessary.

GENERAL DISCUSSION

The present research demonstrates that two brief interventions, involving engagement in the 'alternative uses task' (AUT) and an SA task, improved both ill-defined insight problem solving and novel, on-the-spot fluid reasoning problem solving. We have also begun to illuminate possible mechanisms underlying the beneficial effects of the AUT and SA interventions and to provide direct comparisons of these interventions that have, until now, largely been isolated and treated separately in the cognitive psychology and social psychology literatures. In Experiment 1, we provided initial evidence that the intervention effects did not involve mood enhancement and new evidence that the benefits were found against both a simple word association comparison condition, and against a Neutral Baseline. In Experiment 2 we showed that both the AUT and SA improved one aspect of executive function that is critical to goal-directed behaviour (Duncan *et al.*, 1996; Lezak, 1995), namely updating capacity.

At a broader theoretical and also practical level, this research demonstrates that even very brief interventions can be effective in bolstering multiple forms of novel, on-the-spot problem solving. Notably, both the AUT and SA interventions adopted here demonstrated beneficial 'far-transfer' to diverse problem-solving tasks that shared little similarity of surface structure with the dependent tasks. Additionally, the facilitation of subsequent problem solving occurred with no explicit or direct mention of the potential relevance of the initial task for the subsequent task. Taken together, these outcomes suggest that largely central, common or 'domain-general' functions for subsequent problem solving were facilitated rather than that participants familiarized themselves with certain problem-solving strategies via the interventions. We have here suggested that these facilitated functions relate to goal-related processing.

Previous research has generally adopted either 'pure' cognition-based techniques as intervention tools to improve problem-solving abilities, such as the AUT in our current research and in Chrysikou's study (2006), or provided problem-solving strategic instructions (Ansburg & Dominowski, 2000; Cunningham & MacGregor, 2008) to improve insight problem solving, and working memory training to improve fluid intelligence (Jaeggi *et al.*, 2008; Jaeggi, Buschkuehl, Jonides, & Shah, 2011). The current research underscores the need to also consider the benefits for novel on-the-spot problem solving that may be gained from interventions that are drawn from both cognitive and socio-emotional domains and that do not require strict 'training' or narrowly construed practice, but that may nonetheless exercise, stretch, and extend central problem-solving capacities. A more inclusive view of interventions – including not only longer term but also briefer interventions, and focusing not only on strictly cognitive functions, promises to extend our understanding of our capacity for agilely solving multiple problems. It also promises to extend our capacity to bolster mental agility not only in young and healthy individuals (as here) but also in older adults, and other populations such as depressed individuals, where optimal problem solving may be compromised. Exploring the efficacy and mechanisms of both the brief interventions examined here, and of combinations of interventions, is a crucial direction for future research.

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