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The impact of spontaneous and induced mood states on problem solving and memory

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ABSTRACT

Accumulating theoretical and empirical evidence suggests that task-irrelevant mood states have specific effects on insightful and analytical problem solving, but few studies have directly related those states to these two problem-solving strategies. The present research investigated the impact of pre-existing mood and experimentally induced mood states on solving problems that could be solved analytically or by insight. Results revealed that an induced negative moods, as compared to an induced neutral mood, increases the probability of analytic solutions. In contrast, spontaneous positive moods facilitated problem solving performance regardless of the specific solution strategy. Additionally, the process of generating solutions had a marked effect on subsequent memory recall regardless of recall interval. These findings provide support for the cognitive tuning theory.

1. Introduction

The issue of whether mood influences creative thinking has long attracted the interest of researchers. While creative cognition is far from being fully understood (Shen, Yuan, Liu, & Luo, 2017), there is a general agreement that problem-solving can proceed through the systematic testing of hypotheses—commonly referred to as analytical problem-solving—or through spontaneous insight (Friedman & Förster, 2000; Salvi, Bricolo, Kounios, Bowden, & Beeman, 2016; Shen, Yuan, Liu, & Luo, 2016), a kind of "aha!" experience (Jung-Beeman et al., 2004), often after an impasse. There is also some agreement among researchers that human creativity and problem-solving are affected by moods, but the extant literature has not yet reached a consensus. Earlier studies (e.g., Greene & Noice, 1988; Isen, Daubman, & Nowicki, 1987; for reviews, see Baas, De Dreu, & Nijstad, 2008; Davis, 2009) have suggested that a positive mood facilitates insight, as opposed to a neutral or negative mood; for example, in a seminal study Isen et al. (1987) observed the facilitatory effects of positive mood, induced by film segments and small gifts, on classical insight problem-solving and associative insight measured with Mednick's (1962) Remote Associates Test (RAT). Of the four experiments conducted, however, only

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one (Experiment 2) directly tested potential difference among all the three mood states (valence-based).

Recent correlational and experimental studies have yielded increasingly mixed results, albeit with a number of hints towards the positive impact of negative mood. In their frequently cited study, Kaufman and Vosburg (1997) assessed insight-based performance as a function of both a spontaneous mood and pre-task mood manipulation. Their findings illustrated a reversal of the standard observation: participants with a positive mood exhibited the poorest performance, while those with a negative mood facilitated the solution of classical insight problems. More recently, Tidikis, Ash, and Collier (2017) used Rebus puzzles and classical insight problems in two experiments; their results showed that high-arousing negative moods helped the participants to solve more insight puzzles than low-arousing negative moods, while both low-arousing negative and high-arousing positive moods facilitated performance as compared to low-arousing positive and high-arousing negative moods. Cognitive tuning theory (Friedman & Förster, 2000) accounts for observations of this sort by assuming that positive mood promotes a willingness to adopt a risky, explorative, and non-effortful/heuristic thinking style—which would likely lead to insight solutions—while negative moods promote a more conservative, careful, deliberative, and analytical style—which should make analytical solutions more likely. Along these lines, Hommel (2015) has suggested that positive mood is associated with a processing preference towards cognitive flexibility, while negative mood is associated with a bias towards persistence.

We considered that the existing inconsistencies might be related to three issues. First, many of the insight measures used in previous studies lack theoretical transparency. Specifically, the RAT and classical insight problems are two types of insight tasks widely used to investigate the potential influence of mood on creativity or insight; however, a substantial number of studies have demonstrated that the items of the RAT and its variants, such as the Compound Remote Associate task (CRA[1] ; Bowden & Jung-Beeman, 2003; Shen, Yuan, Liu, Yi, & Dou, 2016), are not always solved through insight but instead are often solved as a result of analytical thinking (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Accordingly, it does not seem to be appropriate to consider the RAT or RAT-like tasks as pure insight tasks, nor the resulting performance as a pure measure of insight—and the same holds for various classical insight problems (e.g., Shen, Yuan, Liu, Luo et al., 2016; Webb, Little, & Cropper, 2016).

Second, the major claims of cognitive tuning theory regarding the thinking styles promoted by positive and negative moods have not yet been systematically tested with respect to the choice of analytical or insight solutions. Finally, previous studies have seldom distinguished between naturally existing moods (individuals' existing mood before entering the lab: Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009) and experimentally induced moods (in the lab: Sakaki & Niki, 2011), even though the two likely involve distinct neurocognitive mechanisms: spontaneous mood might influence insight by activating the anterior cingulate cortex that is thought to be associated with attention and cognitive control (see Subramaniam et al., 2009), whereas experimentally induced mood might operate through the medial prefrontal cortex (Sakaki & Niki, 2011) that is considered to promote internally driven strategy shifts (Schuck et al., 2015; Yuan & Shen, 2016).

To address these issues and provide clearer evidence in regard to whether positive or negative mood facilitates insight, the present study was conducted. In addition to assessing the effects of spontaneous and experimentally induced mood states on strategy use (analytical versus insight) during problem-solving, we also assessed the impact of mood states and strategies on subsequent memory recall. One might speculate that insight solutions, which commonly converge into a single solution without going through alternatives, make it easier to remember the respective solution. Indeed, several behavioral and neuroimaging studies have reported that the subjective experience accompanying insight-based problem solutions ("aha!" experiences) boosts the subsequent memory recall, which can be either immediate (e.g., Ludmer, Dudai, & Rubin, 2011) or delayed (up to several days later; e.g., Danek, Fraps, von Müller, Grothe, & Öllinger, 2013; Kizilirmak, da Silva, Imamoglu, & Richardson-Klavehn, 2016); however, the evidence for long-term memory effects is still sparse. A study that is particularly relevant in this respect stems from Kizilirmak, da Silva et al. (2016), who examined the potential influence of solution generation and induced "aha!" experiences on subsequent long-term memory formation. The findings illustrated that the solution generation (generated solution vs. presented solution) process and the induced "aha!" experience ("aha!" vs. no "aha!") both influence subsequent long-term memory formation (see also Wills, Soraci, Chechile, & Taylor, 2000). Despite this, given the task-dependence of problem-solving processes in triggering insight experiences (Shen, Yuan, Liu, Zhang et al., 2016; Webb, Little, & Cropper, 2017), it remains to be seen whether these findings can be generalized to CRA problems. Accordingly, we employed well-controlled CRA problems and assessed the solution strategies, before testing the impact of the solution generation and subjective experience accompanying spontaneous solutions on subsequent memory recall for those CRA problems and their solutions.

2. Methods

2.1. Participants

A total of 102 right-handed native Chinese college students (57 males, $M_{age} = 18.11$, $SD = 0.74$) were compensated with 15 RMB

[1] To the best of our knowledge, the major and most important difference between the RAT and CRA is solution strategy. Generally, the CRA needs the solver to generate a single word (solution) that can match the given triad to form three two-word/character compounds, in which *compounding* is the only solution approach. However, one classic RAT problem could be solved in one fixed way, e.g., compounding, or solved by the combination of multiple approaches, e.g., compounding, constituting a phrase or finding a synonym/antonym. For example, the solution to the classic RAT problem "same, head, tennis" is "match", which is because the synonym of "same" is the word "match", the words "head" and "match" can form a compound, and the words "tennis" and "match" can form a phrase with understandable meanings.

for their participation in this study. No participant had any history of neurological/psychiatric illness (self-reported) and all participants had normal or corrected-to-normal vision. They were randomly assigned to one of three groups, in which pictures were used to induce positive, neutral, and negative mood states, respectively (34 participants per group). Informed consent was obtained from all participants prior to the experiments being conducted. Data from five participants were discarded due to random response patterns (1) and violating the rule of pressing a key within the given time interval to indicate the solutions obtained (four of these participants provided a solution to the given CRA problem). Data from another 20 participants were excluded from analysis due to suspiciously long response times (> 10 s) or because participants did not provide a key-press response or solution (irrespective of the correctness of the solution candidates) to the CRA problem.

The final sample consisted of 77 participants (43 males, M_{age} = 18.16, SD = 0.65). Specifically, 25, 26, and 26 individuals were assigned to the groups with induced neutral (13 males, M_{age} = 18.24, SD = 0.66), negative (15 males, M_{age} = 18.04, SD = 0.77), and positive (15 males, M_{age} = 18.19, SD = 0.49) mood, respectively. In each of the three groups, the 12 participants with the lowest PA-NA scores (the difference between the PA subscale and the NA subscale) were categorized as the spontaneous negative mood sub-groups[2] and the remaining participants as the spontaneous positive mood sub-groups.

2.2. Stimuli

2.2.1. CRA problems

A total of 48 validated and well-controlled Chinese CRA problems selected from a published paper (Shen, Yuan, Liu, Yi et al., 2016) were used, as in previous studies (e.g., Shen, Yuan et al., 2018). In addition, five other items were selected for practice. All the problems were of medium difficulty and were drawn from another relatively large (> 100) homogeneous sample (see Shen, Yuan, Liu, Yi et al., 2016). Each item of the test consisted of three Chinese characters (e.g., 命/男/学, literally meaning destiny/male/learning) that prompted the subjects to think of a single solution character (e.g., 生, literally meaning person). This solution matches the triad provided previously (e.g., 生命/男生/学生, literally meaning life/men/student) to form three Chinese phrases or compound words. Throughout the test, the problems (horizontally placed) and their corresponding solutions appeared in the center of the screen with boldface letters in size 24 font with black on gray coloring.

2.2.2. Affective pictures

Similarly to Sakaki and Niki (2011), we used briefly presented affective pictures as the mood-induction method. To do so, a total of 159 valence-based positive, neutral, and negative affective pictures were selected from the Chinese Affective Picture System (CAPS), including 48 individual affective pictures (and five additional pictures for each practice) for each of the three valences to experimentally induce participants' positive, neutral, and negative moods (Huang & Luo, 2004). The positive pictures involve pleasant images like lovely animals and beautiful landscapes. Negative modulators consisted of unpleasant pictures like car accidents and aggressive behaviors. Neutral pictures primarily consisted of low-arousing and neutral images such as cups and masks. The pictures were 11 × 8 cm^2, which were displayed on a 17-inch gray background with a refresh frequency of 85 Hz and a resolution of 1024 × 768 pixels.

2.2.3. Positive and Negative Affect Schedule (PANAS–State)

The Positive and Negative Affect Schedule (PANAS–State) (Watson, Clark, & Tellegen, 1988) was used to measure the participants' naturally existing, non-elicited moods. The PANAS includes two subscales, the positive affect (PA) and the negative affect (NA), both of which consist of 10 (positive/negative) items. Participants' responses are provided on a 5-point Likert-type scale (1 representing *very slightly or not at all* and 5 representing *extremely*). The PA and NA subscales have exhibited marked correlations with conceptually related mood measures (Watson et al., 1988; Yik, Russell, & Barrett, 1999). The alpha coefficients for the PA and NA subscales were 0.82 and 0.79, respectively.

2.3. Experimental procedure

There were two separate testing sessions performed exactly three days apart: Session 1 mainly consisted of CRA problem-solving and immediate memory test, and Session 2 (delayed memory test), which was conducted three days after the CRA problem-solving and immediate memory test.

The single trial sequence of the CRA problem-solving is illustrated in Fig. 1. This session consisted of two parts: five practice trials and the actual experiment with 48 trials. Participants were recruited from the general education psychology curriculum. In the experiments, they were invited to sit approximately 80 cm away from a computer screen. Prior to the experimental test, the participants were instructed in the meaning of the terms "aha!" experience and "mental impasse". If participants could not understand the accurate meanings they could ask the experimenter to expand upon the concept until they completely understood it. After filling in an informed consent form and the PANAS, participants were orally instructed to watch the computer screen and to remember how to execute the experimental operations according to the standard procedural demonstration. Participants were asked to initiate their test by focusing their eyes on the red-colored fixation cross (lasting about 500 ms) in the center of the gray computer screen, followed by

[2] This is mainly because the 11th and 12th lowest participants in the group of 25 participants have the equal PA-NA score and both the 13th and 14th lowest participants in the other two groups of 26 participants have the equal PA-NA score.

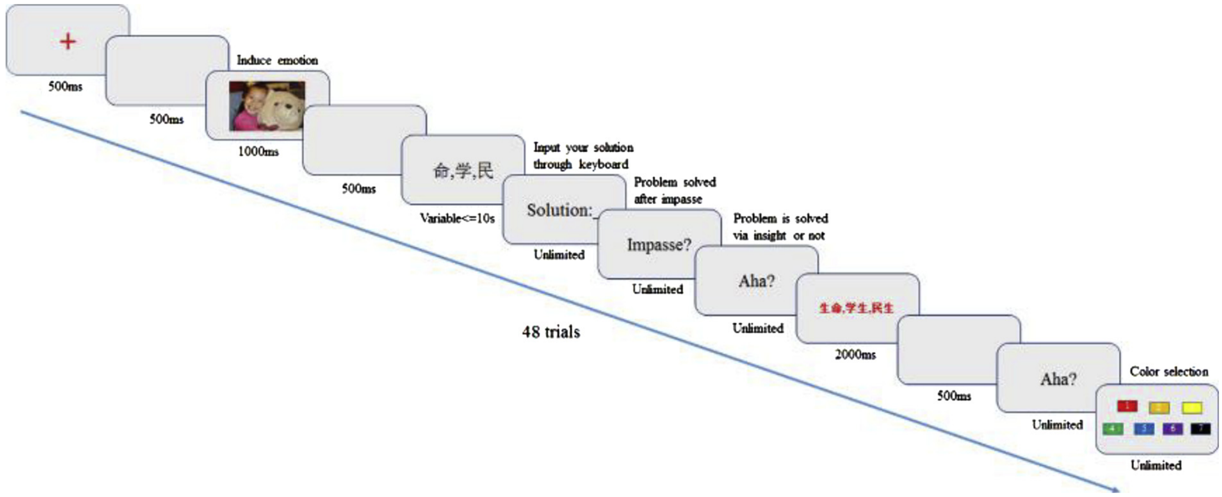

Fig. 1. A schematic illustration of a trial in the experiment.

an emotional picture displayed for 1000-ms on a brief viewing screen after a 500-ms buffer screen. Subsequently, a blank gray screen came up for 500 ms. Next, a randomized sequence of 48 CRA problems was presented on the screen with Song style, No. 28, black, non-bold typeface. Once the CRA problem appeared, participants were required to attempt to solve it in a maximum presentation interval of 10 s and on their own initiative. The word problem remained until the subject solved the problem or 10,000 ms had elapsed. If the participant successfully solved the problem, she/he pressed the prescribed "Space" button on the keyboard, and a screen showing 'Solution?' prompted the participant to enter the solution. Participants had an unlimited amount of time in which to enter their solution and indicated when they finished by pressing 'Enter'. All the participants were informed that they should not continue to think of the CRA solution once the problem disappeared, irrespective of whether they were solved or not. The participants were subsequently required to judge whether they had experienced an impasse when solving the CRA problems and to rate the intensity of the experience, regardless of whether it was an impasse (-relevant) experience. They were asked to rate the intensity on a bipolar continuum of a 6-point scale. Similar to prior manipulations (Shen, Yuan et al., 2018), this 6-point scale varies from non-impasse (a 3-point intensity subscale from "−3" to "−1", where "−3" represents an extreme non-impasse) to impasse (a 3-point intensity subscale from "+1" to "+3", where "+3" represents an extreme impasse), regardless of the nature of this accompanied subjective experience. The operational definition of "impasse" was developed according to studies on impasse during insight problem-solving and the participants were informed of this prior to the practice sessions.

When the participants completed their trial-by-trial judgments about impasse, they proceeded to rate the intensity of the subjective experience accompanying the solution of the CRA problems ("aha!" [insight] or no-"aha!" [analytical]). The operational definitions of the "aha" experience or "insight feeling" were adopted from Jung-Beeman et al. (2004) and are entirely consistent with those of Shen, Yuan, Liu, Luo et al. (2016), and Shen, Yuan, Liu, Yi et al. (2016). During the "aha!" judgment, the participants were asked to rate their solution experience intensity on a bipolar continuum of a 6-point scale ranging from non-insight (a 3-point intensity subscale from "−3" to "−1", with "−3" indicating extremely non-insightful) to insight (a 3-point intensity subscale from "+1" to "+3", with "+3" indicating extremely insightful), regardless of the nature of the solution experience. Following the "aha!" judgment, the given CRA problems and their solutions were presented. These words appeared in the center of the monitor in red Song style, No.28[3], bold typeface and remained there for 2000 ms. After a 500-ms interval showing a blank gray screen, participants were asked to rate the intensity of their subjective experience towards the solution corresponding to the previous given problem. Finally, the procedure ended with a color selection screen in which the solver should have selected one of five colors to describe her/his feelings surrounding the whole process.

The purpose of the color judgment was to more or less continuously monitor mood. The PANAS is often used to assess changes in mood states and mood induction effectiveness (e.g., Grawitch, Munz, & Kramer, 2003; Subramaniam et al., 2009). However, repeatedly presenting the PANAS with only a short interval may have two shortcomings. For one, it might give away the goals of the experiment and thus induce experimental bias. For another, overly frequent repetition of PANAS questions is likely to elicit negative emotions and boredom, which would be counterproductive. To circumvent these problems, we made use of the well-established association between emotion and color, in such a way that participants were asked to select one color for each trial. Based on previous studies (e.g., Huang, Huang, & Li, 1991), seven colors were used: red, orange, yellow, green, blue, purple, and black. The boxes representing the seven colors, which were identical to the design of Huang et al. (1991) in form (see Fig. 1) and size (a rectangle with a length of 4 cm and width of 1.2 cm), were carefully devised based on the established association between color and the emotion of the Chinese population. At the end of the experimental procedure, all the participants were invited to map their personal emotions to each color (excluding individual differences in color perception and color-emotion association). All the nominated moods were

[3] The colored word was devised to attract attention and distinguish the current one from the previous problem.

further classified into three categories (neutral, negative, and positive) according to emotional valence.

To assess the influence of solution generation processing and the accompanied solution experience on subsequent immediate and delayed memory, participants were further invited to complete two memory tests pertaining to the presented items. In the immediate memory test session following the trial-by-trial CRA problems solving task, the participants were told: "Please try your best to recall just the presented problems and write them down on a piece of paper in five minutes". Furthermore, it was stressed that it would not be necessary to generate any new solutions for a good grade, but that the task depended solely on memory. Regardless of memory type, each participant earned one point if she/he correctly recalled a compound word (e.g., 生命). In other words, the solver earned a maximum of 3 points if she/he correctly recalled one CRA item consisting of three double-character words. The participants were informed that they would again be invited to complete a cognitive test several days later. Participants were not informed of the precise nature of this test (a memory test), which was to avoid intentional encoding and rehearsal in the meantime. In the second test session, namely the delayed memory test session, like the immediate memory recall test, the delayed memory test was conducted three days later using paper-and-pencil, which required individuals to correctly recognize the given compound word (one word of the given triad and its solution). If the participants correctly recognized a two-character compound word used in the previous CRAs, she/he earned one point. Apart from the two memory tests, all stimuli were presented, and participants' responses were automatically registered via E-prime 2.0 (Psychology Software Tools, Pittsburgh, PA). The effect size indicators of partial η^2 (i.e., ${\eta_p}^2$) and Cohen d (i.e., d_C) were individually reported for the F and t tests, respectively.

3. Results

3.1. Manipulation check of mood induction

To assess the effectiveness of mood induction, the frequencies of the emotional color categories were analyzed for the three groups under three mood induction conditions by means of a repeated measure analysis of variance (ANOVA), with the group as the between-subject variable and the nominated emotional color valences as the with-subject variable. The results showed, of particular interest, a marked interaction between the group with emotional color valences, $F_{(4,\ 148)} = 8.46, p < 0.001, {\eta_p}^2 = 0.1$, and with the main effect of emotional color valences, $F_{(2,\ 148)} = 5.17, p < 0.01, {\eta_p}^2 = 0.07$. Moreover, to ascertain the potential differences, the frequencies of the emotional color categories were analyzed for each of the three groups by means of a one-way ANOVA. The frequency of the color categories differed in all three groups: in the positive group [$F_{(2,74)} = 10.37, p < 0.001, {\eta_p}^2 = 0.22$], the neutral group [$F_{(2,74)} = 7.32, p < 0.005, {\eta_p}^2 = 0.17$], and the negative group [$F_{(2,74)} = 7.50, p < 0.005, {\eta_p}^2 = 0.17$]. In the positive group, colors associated with a positive mood were reported more frequently than colors associated with a neutral mood ($MD = 16.77$, $SE = 3.68$, $t = 4.78$, $p < 0.001$, $d_C = 1.34$) or with a negative mood ($MD = 8.77$, $SE = 3.65$, $t = 2.21$, $p < 0.05$, $d_C = 0.62$), and with more frequent negative emotion colors than neutral emotion colors ($MD = 8.00$, $SE = 3.68$, $t = 2.26$, $p < 0.05$, $d_C = 1.34$). Similarly, in the neutral group, colors associated with neutral mood were reported more frequently than with positive mood ($MD = 9.81$, $SE = 3.71$, $t = 2.32$, $p = 0.010 < 0.05$, $d_C = 0.65$), with negative mood ($MD = 13.85$, $SE = 3.71$, $t = 3.91$, $p < 0.001$, $d_C = 1.09$), and with an insignificant difference between positive emotion colors and negative emotion colors ($MD = 4.04$, $SE = 3.68$, $t = 1.23$, $p > 0.05$, $d_C = 0.34$). Furthermore, in the negative group, colors associated with negative emotion colors were more frequently observed than with positive mood ($MD = 12.65$, $SE = 3.27$, $t = 4.25$, $p < 0.001$, $d_C = 1.18$), with neutral mood ($MD = 5.94$, $SE = 3.30$, $t = 1.60$, $p > 0.05$, $d_C = 0.45$), and more colors were associated with neutral mood than with positive mood ($MD = 6.72$, $SE = 3.30$, $t = 2.14$, $p < 0.05$, $d_C = 0.60$). These analyses demonstrate that mood induction is reliable. To exclude potential confounding effects, the one-way ANOVA were also applied to the PA-NA [$F_{(2,74)} = 0.85 < 1, p > 0.05$] and PA [$F_{(2,74)} = 0.96, p > 0.05$] and NA [$F_{(2,74)} = 1.13, p > 0.05, {\eta_p}^2 = 0.03$] scores, respectively. No effect of induced mood type was found, implying the overall levels of spontaneous moods among the three induced mood groups were equivalent.

Table 1
results on problem-solving and memory performance under different conditions.

Measure	Low PA-NA intensity ($M \pm SD$)			High PA-NA intensity ($M \pm SD$)		
	Negative	Neutral	Positive	Negative	Neutral	Positive
insight strategy (%)	43.72 ± 40.04	69.79 ± 29.97	48.24 ± 37.12	43.79 ± 35.63	73.40 ± 33.68	64.04 ± 37.47
Analytical solutions	2.03 ± 1.12	1.49 ± 1.10	1.86 ± 1.07	2.32 ± 0.81	1.30 ± 1.19	1.64 ± 1.16
Insight solutions	1.76 ± 1.02	2.50 ± 0.91	1.95 ± 1.07	1.87 ± 1.26	2.61 ± 0.77	2.39 ± 1.06
Analytical solution acc	0.67 ± 0.37	0.61 ± 0.42	0.75 ± 0.31	0.76 ± 0.30	0.52 ± 0.43	0.63 ± 0.41
Insight solution acc	0.84 ± 0.30	0.86 ± 0.28	0.77 ± 0.37	0.72 ± 0.40	0.92 ± 0.11	0.85 ± 0.26
Immediate memory	2.31 ± 0.79	2.27 ± 0.60	2.14 ± 0.75	2.04 ± 0.61	2.22 ± 0.56	2.40 ± 0.65
Delayed memory	1.37 ± 0.72	0.98 ± 0.93	0.92 ± 0.69	1.34 ± 0.61	1.16 ± 0.65	1.41 ± 0.62

Note: The values presented in the 2nd, 3rd, 6th and 7th rows are the transformed values of originally observed valued through a Ln(1 + X) transformation (that makes new values satisfy the normal distribution; for details see https://www.statisticshowto.datasciencecentral.com/probability-and-statistics/skewed-distribution/).

3.2. The impact of mood states on insight and analytical strategies

Table 1 showed the descriptive results of problem-solving and memory performance under different conditions. To determine the degree to which participants' strategy choice in the CRA was affected by their naturally existing mood (indexing by the PA-NA score), we calculated how many solution attempts (irrespective of their accuracy) each participant carried out by insight. These percentages underwent a 3 (induced mood type: positive, neutral, negative) × 2 (spontaneous mood level: positive, negative) ANOVA. The only significant effect was a main effect of induced mood, $F_{(2, 76)} = 3.85$, $p < 0.05$, $\eta_p^2 = 0.10$. Further tests revealed that this effect manifested as a reduction of insight solutions under induced negative mood ($M \pm SD = 43.76 \pm 36.95$) rather than under induced neutral mood ($M \pm SD = 71.67 \pm 31.34$), $t = 2.90$, $p < 0.01$ $d_C = 0.81$, while the percentage obtained for induced positive mood ($M \pm SD = 56.75 \pm 37.43$) did not differ significantly from either induced neutral ($t = 1.54$, $d_C = 0.43$) or negative moods ($t = 1.26$, $d_C = 0.35$), $ps > 0.05$.

Next, we analyzed the number of correctly solved problems as a function of naturally existing mood, induced mood (positive, neutral, negative), and naturally existing mood (positive, negative). Significant effects were documented for pre-existing moods, $F_{(1,71)} = 4.80$, $p < 0.05$, $\eta_p^2 = 0.06$, indicating that a spontaneous positive mood ($M \pm SE = 3.23 \pm 0.21$) produced more solved problems than a spontaneous negative mood ($M \pm SE = 3.03 \pm 0.52$). Furthermore, a four-factor ANOVA, with solution type (insight, analytical) as the with-subject variable, and induced mood (positive, neutral, negative) and naturally existing mood (positive, negative) as the between-subject variables, was applied to the number of correctly solved problems. A marginally significant solution type main effect [$F_{(1,71)} = 3.52$, $p = 0.06$, $\eta_p^2 = 0.05$] was obtained, suggesting that insight solutions ($M \pm SE = 2.18 \pm 0.12$) were more frequent than analytical solutions ($M \pm SE = 1.77 \pm 0.12$). The only higher-order effect was an interaction of solution type with induced mood, $F_{(2,71)} = 4.05$, $p < 0.05$, $\eta_p^2 = 0.10$. Separate one-way ANOVAs for the two strategies showed that the impact of induced mood was significant for insight solutions, $F_{(2,74)} = 3.33$, $p < 0.05$, $\eta_p^2 = 0.08$; pairwise comparisons confirmed that fewer problems were solved under induced negative moods than under induced neutral moods, $MD = -0.74$, $SE = 0.29$, $p < 0.05$. The effect also reached significance for analytical solutions, $F_{(2,74)} = 3.56$, $p < 0.05$, $\eta_p^2 = 0.09$; pairwise comparisons illustrated that more problems were solved under induced negative moods than under induced neutral moods, $MD = 0.79$, $SE = 0.30$, $p < 0.05$. No other significant differences were observed, $ps > 0.05$.

Moreover, we analyzed the accuracy as a function of the solution type (insight, analytical), induced mood, and naturally existing mood. Only the main effect of the solution type was significant, $F_{(1,71)} = 8.18$, $p < 0.01$, $\eta_p^2 = 0.10$, demonstrating that accuracy was higher for insight solutions ($M \pm SD = 0.83 \pm 0.04$) than for analytical solutions ($M \pm SD = 0.66 \pm 0.04$). No other effect was significant, which also held for the analysis of the solution time.

Furthermore, the total number of correctly solved problems, regardless of the specific strategies, was found to have a close-to-significant correlation with the naturally existing positive mood (scored by subtracting the NA score from the PA score) [$r_{(77)} = 0.22$, $p = 0.053$] and was significantly associated with the PA score of the PANAS measure [$r_{(77)} = 0.28$, $p < 0.05$] (Fig. 2).

3.3. The impact of solution processing and experience on memory performance

Memory performance was analyzed by means of a 2 (memory type: immediate, delayed) × 3 (induced mood: positive, neutral, negative) × 2 (pre-existing mood: positive, negative) ANOVA. The analysis illustrated the marked effect of memory type, $F_{(1,71)} = 226.05$, $p < 0.001$, $\eta_p^2 = 0.76$, implying better performance in the immediate test ($M \pm SE = 2.23 \pm 0.07$) than in the delayed test ($M \pm SE = 1.19 \pm 0.08$). No other main effects or interactions were significant, $ps > 0.05$.

To investigate the potential effects of the solution generation and solution-related experience on subsequent memory recall, either immediate or delayed, a backward regression analysis was employed for immediate and delayed memory performance.

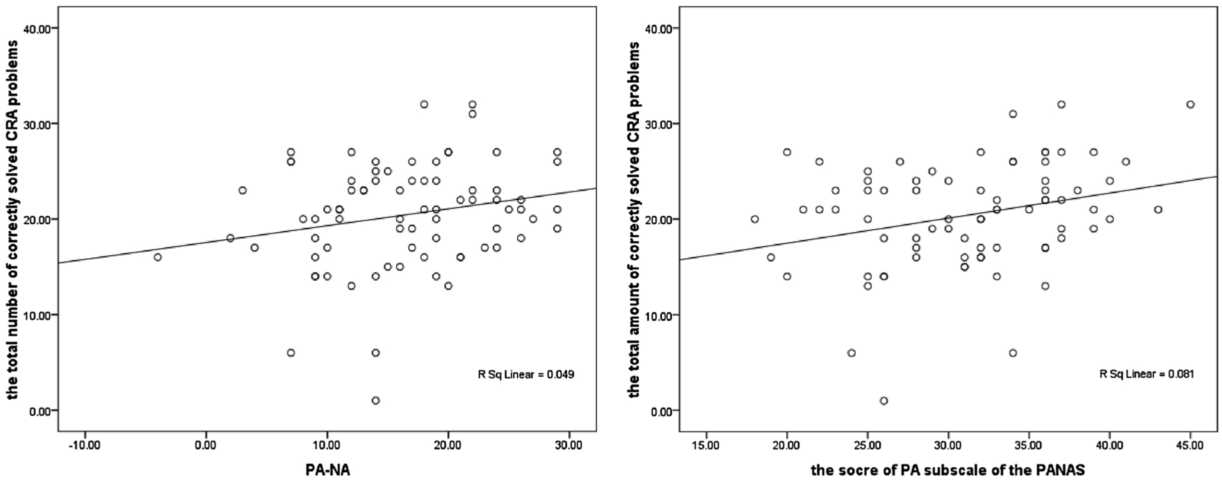

Fig. 2. Plots for the correlations between pre-existing mood and total of solved problems.

Consequently, the intensity of the subjective experience accompanying insight and analytical solutions, the number of correct insight solutions, the number of correct analytical solutions, the naturally existing mood score, the solution time of correct CRA problems solved via insight, and the solution time of those solved via analytical strategy were entered to predict the subsequent immediate or delayed memory performance. The results showed that the contributions from the number of problems correctly solved via insight and those via analytical strategy both reached the significance level ($p < 0.05$). Specifically, the number of correct insight solutions ($B = 0.14$, $SE = 0.06$, $\beta = 0.39$, $t = 2.24$, $p < 0.05$) and analytical solutions ($B = 0.17$, $SE = 0.07$, $\beta = 0.43$, $t = 2.45$, $p < 0.05$) are effective predictors of delayed memory performance, $R = 0.28$, $R^2 = 0.08$, $SE = 2.90$, $F_{(2, 74)} = 3.16$, $p < 0.05$; the same is true for immediate memory performance: $B = 0.43$, $SE = 0.16$, $\beta = 0.47$, $t = 2.68$, $p < 0.01$; $B = 0.46$, $SE = 0.19$, $\beta = 0.43$, $t = 2.48$, $p < 0.05$; and $R = 0.31$, $R^2 = 0.09$, $SE = 7.67$, $F_{(2, 74)} = 3.81$, $p < 0.05$. These results represent a generation effect and suggest that the deeper processing associated with generating solutions, regardless of the particular solution strategy, is an important predictor of immediate and delayed memory.

4. Discussion

One major goal of the present research was to test the predictions of the cognitive tuning theory (Friedman & Förster, 2000) by investigating how induced positive or negative mood states facilitate the solution of cognitive problems with different approaches. This theory argues that negative mood states inform the individual that the circumstances she/he is facing are unsafe, problematic, and threatening. Under these situations, the use of heuristics, which do not rely heavily on rational analysis and deliberation, seems more risky. As a result, individuals in negative mood states are posited to become less agreeable to take risks and necessitate the investing of cognitive resources into systemic processing, thereby increasing adherence to established programs of action and a dependence on initially accessible alternatives. To examine this hypothesis, a two-stage research design was conducted, which could also provide a number of useful insights into the effect of “aha!” experiences on subsequent memory performance. In the first stage, i.e., the spontaneous solution stage, the participants receiving a baseline mood assessment were assigned to one of three mood induction conditions each involving viewing one category of standardized affective pictures embedded in a trial-by-trial CRA solving task. Simultaneously, all the participants were asked to complete an immediate memory test following the CRA task. In the second stage, which took place three days later, the same participants were again invited to complete a memory test. Similar to Sakaki and Niki (2011), we induced positive, neutral, and negative moods by means of culturally appropriate affective pictures. The results show that induced negative mood, as compared to induced neutral mood, biased individuals to solve more problems analytically rather than through insight.

Consistent with previous findings suggesting that negative mood facilitates analytical processing (Akbari & Hommel, 2012; Friedman & Förster, 2000), and with the absence of an impact of positive mood on insight (e.g., Jausovec, 1989), the present results provide evidence in support of cognitive tuning theory (De Dreu, Baas, & Nijstad, 2008; Schwarz & Bless, 1991). This theory posits that mood functions as an environmental cue regarding the current situation and corresponding processing requirements. Specifically, negative emotional states are thought to signal troublesome processing or threat, suggesting that current goals may be compromised, and that specific measures or actions should be taken to remedy the current situation (Friedman & Förster, 2000). As mentioned previously, to prevent impasses, individuals generally prefer a relatively careful, safe, detail-orientated, analytical, and conservative thinking or processing style. In support of this assumption, a recent study has reported a positive association between risk-aversion/avoidance and the performance of (self-reported) insight problem-solving measured using the same CRA task (Shen, Hommel, Yuan, Liu, & Zhang, 2018).

In addition to experimentally induced mood, spontaneous mood also affected performance by increasing the number of correctly solved problems irrespective of the adopted solution strategy. This fits with the findings of Subramaniam et al. (2009), who also observed a positive correlation between existing positive mood and the activation of the dorsal anterior cingulate cortex. Interestingly, solution strategies were sensitive to induced but not to pre-existing mood, suggesting that the two kinds of mood affect CRA problem-solving differently: While the impact of spontaneous mood on cognitive processes is likely due to the modulation of attentional processing and cognitive control (e.g., Rowe, Hirsh, & Anderson, 2007; Subramaniam et al., 2009), the impact of experimentally induced mood has been attributed to a role in semantic integration/control and flexible semantic access/searching (e.g., Li et al., 2013; Rowe et al., 2007). Nevertheless, researchers should keep in mind that the influence of experimentally induced mood states on the CRA problem-solving might involve some influences of pre-existing mood.

Another important aim of this study was to examine the potential effect of solution generation on subsequent memory recall. Consistent with previous findings (e.g., Kizilirmak, Wiegmann, & Richardson-Klavehn, 2016), we found a reliable effect of solution generation on subsequent memory—an effect that resembles the well-known superiority of successfully generated items over just presented items on later long-term memory performance. In contrast to previous observations, we failed to identify any evidence of the effect of the solution experience, particularly subjective experiences accompanying insight solutions, on subsequent memory recall. We can think of three possibilities why solution experiences did not show the effect. First, the subjective experience (with an “aha” moment or without one) might not have been sufficiently intense to facilitate or inhibit memory recall. Insight experiences might be task- or stimulus-specific (e.g., Webb et al., 2017), and so a number of insight-triggering tasks (e.g., degraded pictures recognition; Ludmer et al., 2011) and paradigms (e.g., solutions understanding) might produce stronger insight feelings, and this might be responsible for an impact on subsequent memory recall. Second, additional factors might mediate the effect of solution experience, such as the type of memory test (e.g., Kizilirmak, da Silva et al., 2016; Kizilirmak, Wiegmann et al., 2016) or the test delay (c.f., Danek et al., 2013). Third, behavioral experience measures might be less sensitive and may be better replaced by, for instance, amygdala-related neural activation (Ludmer et al., 2011). Overall, the case regarding the effect of insight experience on subsequent memory remains open.

A more methodological contribution of the present study relates to the utility of the self-assessed emotional color report in assessing mood and determining the effectiveness of mood induction. Our findings suggest that this method works, which implies that self-determined emotional color reports are a new and useful measure in assessing mood or emotion changes, particularly qualitative change. The emotional color report is qualitative in nature, which brings some limitations, but its use helps to avoid the frequent repetition of mood/emotional measures like PANAS within a short interval and provides a useful alternative tool when no direct mood measures are available.

5. Conclusion

In conclusion, the present findings provide new evidence for cognitive tuning theory by demonstrating that induced negative mood promotes the choice of analytical problem-solving strategies but impairs problem solutions through insight. In contrast, spontaneous positive mood facilitates problem-solving regardless of the specific solution strategy used.

Disclosure statement

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article. This manuscript is based on the data collected by Zhao Yuan and also used in her Master's thesis in Hohai University.

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