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Positive affect improves working memory: Implications for controlled cognitive processing

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This study examined the effects of positive affect on working memory (WM) and short-term memory (STM). Given that WM involves both storage and controlled processing and that STM primarily involves storage processing, we hypothesised that if positive affect facilitates controlled processing, it should improve WM more than STM. The results demonstrated that positive affect, compared with neutral affect, significantly enhanced WM, as measured by the operation span task. The influence of positive affect on STM, however, was weaker. These results suggest that positive affect enhances WM, a task that involves controlled processing, not just storage processing. Additional analyses of recall and processing times and accuracy further suggest that improved WM under positive affect is not attributable to motivational differences, but results instead from improved controlled cognitive processing.

Keywords: Positive affect; Controlled processes; Working memory; Short-term memory; Inhibitory control.

A substantial body of research spanning four decades has shown that mild positive affect systematically improves cognitive performance on a wide range of tasks that assess creativity, problem solving, categorisation, word association, verbal fluency, variety seeking, reasoning, perspective taking in interpersonal negotiation, and decision making (see Isen, 2008, for a review). To date, however, it has not been clear what types of fundamental processes underlie or contribute to these advantages of positive affect.

The neuropsychological theory of the influence of positive affect on cognitive processes posits that positive affect is associated with the release of

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dopamine into prefrontal brain regions that are believed to contribute positively to both controlled attention and working memory (WM), which refers to a multicomponent system responsible for active maintenance of information in the face of ongoing interference (Ashby, Isen, & Turken, 1999; Engle, Tuholski, Laughlin, & Conway, 1999). Consistent with this theoretical view, studies have also reported that positive affect improves performance on a wide range of higher-order cognitive tasks that are assumed to involve WM capacity or attentional control. Those include the 2-back task (Gray, 2001), the Stroop task (Kuhl & Kazen, 1999), set-switching tasks (e.g., Isen & Shmidt, 2007), and tasks involving rule-described category learning (Nadler, Minda, & Rabi, 2010). Given these theoretical and empirical studies, it seems plausible to suggest that positive affect may enhance WM. Still in question, however, is whether the observed effects are due to an improvement in short-term storage processing or in controlled processing, both of which are viewed as critical components of WM.

Several theories have been proposed to account for differences between short-term memory (STM) and WM. In a theory proposed by Cowan (1995), STM refers to the small amount of information that is kept in a temporarily accessible state in memory through continuous rehearsal. WM, in contrast, is viewed as a more extensive and dynamic memory system than STM, one that concerns not only temporary retention but also the processing of information in support of cognitive activity. According to the multi-component theory (Baddeley & Hitch, 1974), WM consists of: (1) slave systems (e.g., phonological loop, visuospatial sketch pad, and episodic buffer), which are responsible for the short-term maintenance of information; and (2) a "central executive" that is responsible for co-ordinating multiple cognitive processes and for the supervision of information integration by directing attention to relevant information while inhibiting irrelevant information. The latter component is what makes WM different from STM. Similarly, the controlled-attention hypothesis proposes that the main difference between STM and WM is that WM involves controlled processing dedicated to keeping a representation active in the face of a concurrent requirement (Engle et al., 1999). While these views have contributed to the notion that STM and WM are distinct constructs, Unsworth and Engle (2007) contend that STM and WM are overlapping constructs that rely on the same basic processes (e.g., rehearsal, maintenance, updating, and controlled search) but differ in the extent to which these processes operate in a particular task (p. 1046). Taken together, these theoretical accounts of the relation between STM and WM, although they emphasise slightly different aspects, lead to a prediction that STM performance will be related to—but nonetheless distinguishable from—WM performance.

To date, however, there has been little discussion in the literature as to whether positive affect would have similar or differential effects on these memory systems. Moreover, the literature is not clear as to whether the observed effects of positive affect on a variant of WM tasks are due to an improvement in storage processing or controlled processing. Thus, the present work aimed to investigate the influence of positive affect on both WM and STM, in part to shed light on the cognitive mechanisms underlying the beneficial effects of positive affect on a broad range of cognitive processes. Given the well-documented beneficial effects of positive affect on complex cognitive processes such as inhibition control (e.g., Gray, 2001; Kuhl & Kazen, 1999) and cognitive flexibility—which refers to the ability to both focus and broaden thought and to switch between those processes, thus bringing a wide range of ideas to bear on a specific issue or problem effectively (e.g., Isen, 2008)—we speculated that the main locus of positive affect's facilitating effects would likely lie in improved controlled processing as compared to simple storage processing. Thus, we hypothesised that if positive affect improves controlled processing more than storage processing, it should have greater facilitation effects on WM than STM. The simple word-span and complex operation-span tasks were employed as measures of

STM capacity and of WM capacity, respectively, because they are among the most widely used measurement tools in cognitive psychology (Conway et al., 2005).

METHOD

Participants

Fifty-eight undergraduates participated in the study in exchange for extra credit. Participants who had learned English after the age of five were excluded.

Design

The type of memory task (word-span as an STM task vs. operation-span as a WM task) was manipulated within participants. Affect (positive and neutral) was manipulated between participants, who were randomly assigned to either the positive-affect or the neutral-affect condition.[1]

Materials

The Remote Associate Test (RAT) was used as a manipulation check on induced positive affect. Some research on affect has used an explicit manipulation check on induced mood by directly asking participants to indicate the degree of their current feeling states (e.g., Bless et al., 1996). Despite the assumed effectiveness of such methods, however, explicit self-reported measures may not be appropriate when positive affect is induced by an unexpected gift, because following the gift with an obvious question on mood could cause participants to be suspicious of the experimenter's intent in giving them the gift—which, in turn, could dispel the induced feeling state (Isen et al., 2008). It is therefore important that any manipulation check on induced mood be *implicit*. In view of these concerns, the RAT was employed as an implicit manipulation check because a number of studies have found that mild positive affect improves performance on the RAT (see Isen, 2008, for a review). In addition, successful performance on the RAT involves cognitive abilities such as verbal fluency, association, and insightful problem solving, all of which have been shown to improve under positive affect (e.g., Wiley & Jarosz, 2012). We therefore expected that participants in the positive-affect condition would perform better on the RAT than those in the control condition. In all, 21 RAT items of moderate difficulty were selected from the normative data of Bowden and Jung-Beeman (2003).

For word stimuli, 100 *non-arousing*, *neutral-valence* words were selected from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999). This was done because the emotional content of stimuli is known to affect the distribution of attention and controlled processing (Kensinger & Corkin, 2003). These words were divided into two sets, and each was used with equal frequency for each of the word-span (STM) and operation-span (WM) tasks. Valence, arousal level, length, and word frequency were equated across the two sets.

In the word-span task, participants were given a list of to-be-remembered words and asked to recall the list in the correct serial order. By contrast, the operation-span task required participants to engage in a processing activity, i.e., solving math problems, while trying to remember unrelated words such as the simple-span ones, e.g., "Is $(6/3)+2=4$ Yes/No? PLANT". A total of 50 operation strings served as stimuli for the processing component of the complex-spantask. The set size (i.e., the number of words to remember in a trial) varied from 3 to 7, with two trials at each set size.

[1] Baseline measures on both STM and WM were not collected because of methodological constraints such as practice effects or the loss of novelty, which are known to influence the effect of positive affect (see Isen, 2008, for a review). However, the random assignment of participants into the affect groups ensured that any differences between the groups were not systematic at the outset of the experiment, and therefore any variations in effect observed between groups can not be linked to any pre-existing differences in participants assigned to the groups.

Procedure

Positive affect was induced by giving participants an unexpected gift of a small bag containing hard candies that was attractively tied with a piece of yarn. Participants were told that the bag of candy was given as a token of appreciation for their participation. They were asked to put it with their books and take it with them when they left the lab—i.e., no participant ate the candy during the session. This method has been reported in the literature to be effective in inducing mild positive affect (see Isen, 2008, for reviews). Participants in the neutral condition did not receive such a gift and were unaware of its presence. After this, the RAT was administered as a manipulation check. Participants were given three minutes to answer as many items on the RAT as they could.

The memory phase consisted of the word-span (STM) task and the operation-span (WM) task. Participants were given a worksheet on which they were to write the words in order when the recall prompt appeared on the computer screen after each set. The order of these tasks was fixed, such that the word-span task was always administered prior to the operation-span task. Given that the word-span task is perceived as relatively easier than the operation-span task, it is believed that performing different tasks with an increasing difficulty is considered less disruptive of cognitive performance and induced affect. Further, this was done so that individual differences in WM would not be confounded with task order (e.g., Kail & Hall, 2001). Thus, any difference observed from the memory tasks can be attributable to induced affect.

In the word-span task, participants were presented with a total of 10 trials (2 trials per each set size, which ranged from 3 to 7 words to be remembered in a trial). The order of the set sizes was randomised. For each trial, the fixation signal appeared on the computer screen for 300 ms and was followed by a series of words that were presented at a rate of one word per 1,000 ms. A single trial of set size 4 was used for practice.

In the operation-span task, participants were presented with a series of operations and to-be-remembered words. For each operation and word, participants verified whether the equation was correct or incorrect by pressing a key, and then silently read the to-be-remembered word for later recall. A single trial at set size 5 was used for practice, after which 10 trials (2 trials at each set size from 3 to 7) were presented in random order. Although all of the memory tasks were self-paced, two time variables in the WM task, *processing time* and *recall time*, were recorded to examine the temporal and motivational characteristics of the memory processing. After the tasks had been completed, a funnel questionnaire was administered using dichotomous (i.e., yes/no) questions asking about the purpose of the study and the use of any strategies during the memory task. Questions that were answered yes were then followed up with probe questions requiring more details.

RESULTS

Manipulation check

Table 1 presents performance on the RAT in each affect condition. Consistent with previous

Table 1. *Critical Measures as a function of induced affect*

	Positive affect (n = 29)	*Neutral affect (n = 29)*	*p*
Remote associate task (RAT)	9.1 (4.1)	6.7 (4.5)	.04
Partial-credit loading score (PCL)			
STM	38.7 (4.4)	36.9 (4.5)	.13
WM	40.5 (4.8)	35.4 (6.5)	.001
Partial-credit unit score (PCU)			
STM	7.18 (.71)	6.97 (1.0)	.35
WM	5.10 (2.1)	2.93 (1.9)	.0001
WM processing component			
Processing time (s)	3.3 (1.7)	3.5 (1.5)	.48
Recall time (s)	12.5 (3.1)	12.0 (2.9)	.64
Error rate (%)	4.9 (3.3)	6.5 (4.6)	.15

Notes: *SD*s are shown in parentheses. Processing time on the WM task refers to the total amount of time spent handling the operation-word string (i.e., verifying the equation). Error rates refer to the percentage of incorrect answers in verifying the equation in the WM task. The *p* represents a test of the significance of the difference between the two affect conditions.

findings (e.g., Estrada, Isen, & Young, 1994), an independent-samples t-test revealed that participants in the positive-affect condition performed significantly better than those in the neutral-affect condition, $t(56) = -2.09, p = .04, d = 0.56$. Given previous findings that differentiated positive affect from not only neutral affect but also negative affect and neutral arousal (Isen, 2008), this result demonstrates that the method used to induce positive affect in the present study was effective.

Memory performance

Correct responses in word-span and operation-span tasks were scored following the partial-credit unit procedure (PCU), in which the participant's score was expressed as the proportion of the total number of words recalled in a set (e.g., Conway et al., 2005). For example, recalling two items from a set of five words yielded a score of 2/5 = 0.4. This procedure was adopted because it is known to demonstrate better psychometric properties than the partial-credit load scoring (PCL).[2] Recall scores were submitted to a mixed-factor analysis of variance (ANOVA) with Induced Affect (positive vs. neutral) as a between-participant factor and the Type of Memory Task (word-span vs. operation-span) as a within-participant factor. As a result, the main effect of Induced Affect indicated that the positive-affect group significantly outperformed the neutral-affect group, $F(1, 56) = 14.7, p < .001, \eta^2 = .21, p_{rep} = .99$. The main effect of the Memory Task demonstrated that participants performed significantly worse on the operation-span task than on the word-span task, $F(1, 56) = 133.3, p < .001, \eta^2 = .7, p_{rep} = .99$, suggesting that the WM task required more rigorous processing than the STM task. Consistent with our hypothesis, a significant interaction emerged between the Memory Task and Induced Affect, $F(1, 56) = 13.6, p = .001, \eta^2 = .06, p_{rep} = .98$. Planned comparisons revealed that the positive-affect group significantly outperformed the neutral-affect group only on the WM task, $t(56) = -4.09, p < .001$; however, the groups did not differ on the STM task, $p = .35$.

Given the similar trend toward positive affect improving performance on the STM task, although not significant, we performed a hierarchical regression analysis to examine whether positive affect can predict a significant degree of WM performance when the influence of STM is controlled. Consistent with the results described above, our regression model accounted for 26.8% of the variance in WM, $F(2, 55) = 10.1, p < .001$, with induced affect as a significant predictor of WM capacity, $\beta = 0.46, t(56) = 3.92, p < .001$. The standardised beta of STM approached significance, $\beta = 0.20, t(55) = 1.68, p = .09$, but the greater value of standardised beta for induced affect indicates that positive affect had a greater impact on WM than on STM. In contrast, we performed another regression analysis predicting STM by induced affect while controlling WM. This model accounted for only 6.4% of the variance in STM, $F(2, 55) = 1.87, p = .16$. WM capacity emerged as a marginally significant predictor of STM, $\beta = 0.25, t(56) = 1.9, p = .09$, but induced affect did not, $\beta = 0.01, t(55) = 0.03, p = .97$. Our findings suggest that although similar processes may operate in both STM and WM tasks, positive affect specifically enhances WM more than STM. Given that the WM task relies on controlled processes, the greater effect of positive affect on WM suggests that it is controlled processes that positive affect substantially improves in the WM task.

Motivational effects

We examined whether the observed superiority of the positive-affect group in the WM task might be attributable to motivational factors. To do this, we conducted four types of analyses. First, we examined whether the two groups differed in

[2] Correct recall responses were also scored by the partial-credit load procedure (PCL), in which a participant's score was represented by the sum of total words recalled. For example, recalling two items from a set of five words yields a score of 2. Results based on the PCL (see Table 1) were virtually identical with those obtained with the PCU.

terms of strategy, as assessed by the dichotomous items on the funnel questionnaire. The chi-square test, however, revealed that strategy use was independent of the induced affect, $\chi^2(1) = 0.15$, $p = .19$. In addition, to examine whether the two groups differed in their preferred types of strategies, we coded the type of strategy reported by each participant. Strategies related to simple repetition were coded as 0, while more advanced strategies, e.g., visual imaging or chunking, were coded as 1. Independent-sample *t*-tests revealed that the two affect groups did not differ in the type of strategies used, $t(56) = -1.69$, $p = .10$, suggesting that motivational differences—as reflected by the spontaneous use of strategies—cannot account for the substantial group differences in memory performance (e.g., Turley-Ames & Whitfield, 2003).

Second, we examined whether motivational differences were reflected in terms of processing efficiency. Based on findings from recent research (e.g., Friedman & Miyake, 2004), we hypothesised that if participants are motivated to enhance their overall memory performance, they will spend less time verifying the math component of the operation-span task—while, at the same time, making few errors—but spend longer recalling. A series of independent-sample *t*-tests, however, revealed no difference between groups in processing time, recall time spent on the operation-spantask, or error rates in verifying the math equation, all ps $> .14$.

Third, we conducted a similar regression analysis predicting WM performance by induced affect while controlling for both STM capacity and *motivational* variables, as described above. This regression model accounted for an even greater amount of the variance in WM (33.2%) than the outcome of the previous regression model, which did not control for motivational variables (26.8%), $F(5, 52) = 5.16$, $p = .001$. Even so, induced affect still emerged as a significant predictor of WM task performance, $\beta = 0.40$, $t(52) = 3.44$, $p = .001$.

Lastly, we checked whether time-on-task as an index of intrinsic motivation mediated the effect of positive affect on WM (e.g., Phillips, Smith, & Gilhooly, 2002). A Sobel test was performed to examine whether either the recall time or processing time mediated the effect of positive affect on the WM performance, but neither was significant, $z = 0.71$, $p = .48$, and $z = 0.42$, $p = .67$, respectively. Taken together, all of these findings suggest that that the beneficial effects of positive affect on working memory are not due to differences in motivation. Rather, it is induced affect that significantly improves WM capacity.

GENERAL DISCUSSION

Our findings demonstrate that positive affect improves WM more substantially than it improves STM. Critically, increased motivation was not likely the cause of the observed effect.[3] Hence, these results suggest that the main locus of the facilitating effects of positive affect lies in improved controlled processing rather than in simple storage processing or motivation. Given that WM is a critical and complex ability that underlies a wide range of cognitive and social processes, beneficial effects of positive affect on WM shed important light on the operation and implications of positive affect. Specifically, the facilitating effects of positive affect on these processes imply that this affective state has the potential to improve a wide range of both social and non-social processes that are linked to these abilities.

Although the effect of positive affect was more pronounced on WM than on STM, the similar tendency of positive affect to improve performance on the STM task is consistent with

[3] Friedman and Miyake (2004) have raised a methodological issue as to how the WM task was administered. They argue that compared to an experimenter-administered WM task, a self-paced WM task reduces its predictive power for other cognitive processes because of extra time allowed to implement strategies that may result in higher span scores. Our studies, however, did not find any differences in processing time or strategies used, suggesting that self-paced administration—at least in our study—is as appropriate as experimenter-controlled administration.

Unsworth and Engle's (2007) hypothesis that largely similar processes may underlie both STM and WM—although the extent to which these processes are involved and operate with a number of other processes likely differs. Thus, this suggests that positive affect may improve STM capacity under certain circumstances, in which controlled processes become more relevant to the STM tasks. For example, this may be the case when participants are encouraged to employ more effective and advanced rehearsal strategies, such as visual imaging or meaning-based chunking. Future research to examine potential conditions under which positive affect operates to improve STM processing would be important.

Several theories have been proposed to account for the relationship between positive emotion and cognitive performance. The first of these, the dopamine hypothesis (Ashby et al., 1999), posits that positive affect should improve higher order cognitive processes such as WM, controlled attention, inhibitory control, and executive functioning, and is consistent with our findings. Second, Fredrickson's broaden-and-build theory posits that positive affect prompts people to pursue a wider range of thoughts and actions than typical and to use such information to build resources (e.g., Fredrickson, 2001). Thus, to the extent that the broaden-and-build theory sees positive emotions as linked to increments in attention control (as people perceive broadly and build on that), it is also compatible with our finding that positive affect improves WM capacity. Third, Isen and colleagues have proposed that positive affect enhances cognitive flexibility, which involves the increased control of attention that is essential in the construct of WM (e.g., Engle et al., 1999). Given the amount of empirical evidence showing the facilitating effects of positive affect on cognitive organisation and integrative elaboration—all of which may well constitute a "controlled" aspect of working memory—this flexibility model also implies that positive affect would improve working memory.

While our findings provide evidence in favour of the theoretical assertions just described, they are not readily explained by the affect-as-information (AAI) model, which postulates that positive affect signals that the immediate environment is safe and benign, and thus careful and detailed processing is unnecessary; instead, heuristic and effortless processing ensues (e.g., Bless et al., 1996). This theory, therefore, predicts that performance on the WM task should be impaired during positive mood. Notably, however, our findings are partly compatible with the revised AAI model, which predicts that positive affect may lead to integrative, elaborative processing—provided that reliance on general knowledge is unnecessary (see Clore et al., 2001, for a review). In addition, our discrepant findings may be attributable, in part, to differing methodologies, including various aspects of design and implementation. For example, Isen (2008) argued that positive affect may not facilitate cognitive processes when the task at hand is dull or unpleasant. More importantly, recent research suggests that the impact of positive affect on attentional process depends on motivational intensity (Gable & Harmon-Jones, 2008). Specifically, positive affect that is low in approach motivation promotes a broadening of attention and cognition, whereas positive affect that is high in approach motivation has different consequences for attentional processes. Given that positive affect, as induced in our study, did not evoke high motivational intensity, our current findings can be reconciled with past research by suggesting that the beneficial effect of positive affect may be specific to mild or subtle positive affect with a low motivational approach.

Although we did not examine similarities and differences with regard to the effects of positive and negative affect on WM performance, we believe that our experimental approach, i.e., comparing a positive-affect condition to a neutral-affect condition, has distinct advantages and does not undermine the appropriateness of our method or otherwise qualify our findings. It is sometimes assumed that positive affect should be compared to negative affect. There are many reasons, however, why this may not be correct. First, it is difficult to directly compare the effects of positive and negative affect, because it is difficult to establish that the negative and positive affects induced are of comparable intensity. Moreover, it is evident that negative affect is not simply the inverse of positive affect, but rather a separate entity (e.g., Watson & Tellegen, 1985). Moreover, if one were to try to induce a comparison negative-affect state, it is unclear which negative affect (e.g., anger, fear, sadness, embarrassment, shame, guilt, and so on) would be appropriate.[4] Therefore, given that positive and negative affect are simply different states, positive affect should be compared to neutral affect, not to negative affect.

We conclude that *mild* positive affect improves WM through controlled processes. Future research will be needed to flesh out specific controlled processes—e.g., attentional shifting, inhibition control, or updating—that lead to the facilitation effect of positive affect on WM.

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