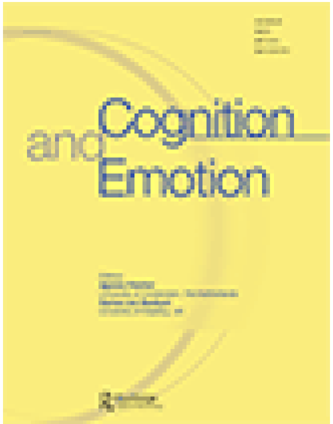

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Happiness increases verbal and spatial working memory capacity where sadness does not: Emotion, working memory and executive control

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Happiness increases verbal and spatial working memory capacity where sadness does not: Emotion, working memory and executive control

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The effects of emotion on working memory and executive control are often studied in isolation. Positive mood enhances verbal and impairs spatial working memory, whereas negative mood enhances spatial and impairs verbal working memory. Moreover, positive mood enhances executive control, whereas negative mood has little influence. We examined how emotion influences verbal and spatial working memory capacity, which requires executive control to coordinate between holding information in working memory and completing a secondary task. We predicted that positive mood would improve both verbal and spatial working memory capacity because of its influence on executive control. Positive, negative and neutral moods were induced followed by completing a verbal (Experiment 1) or spatial (Experiment 2) working memory operation span task to assess working memory capacity. Positive mood enhanced working memory capacity irrespective of the working memory domain, whereas negative mood had no influence on performance. Thus, positive mood was more successful holding information in working memory while processing task-irrelevant information, suggesting that the influence mood has on executive control supersedes the independent effects mood has on domain-specific working memory.

Keywords: Emotion; Working memory; Executive control; Working memory capacity.

Working memory is important for maintaining and manipulating information in mind, whereas executive control is important for coordinating among various goals or tasks in a flexible manner (Baddeley & Della Sala, 1998; Funahashi, 2001; Miyake & Friedman, 2012; Perner & Lang, 1999; Pessoa, 2009). Mood states are known to influence both working memory and executive control when assessed independently. However, less is known for how emotion influences tasks that require both working memory and executive control. The goal of the current study was to examine how positive and negative moods influence performance on a verbal and a spatial working memory operation span task that requires the involvement of both working memory and executive control.

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Working memory is a multi-component system that actively maintains and updates domain-specific information (Baddeley & Logie, 1999; Conway et al., 2005; Smith & Jonides, 1999). Two working memory domains, verbal and spatial (visuospatial), have been identified (D'Esposito et al., 1998; Fletcher & Hanson, 2001; Manoach et al., 2004; Petrides, 1995; Smith & Jonides, 1999). Using an n-back task, which requires active maintenance and updating of information within a single working memory domain, Gray (2001) observed that positive mood enhanced verbal working memory and impaired spatial working memory, whereas negative mood enhanced spatial working memory and impaired verbal working memory (see also Gray, Braver, & Raichle, 2002; Storbeck, 2012).

Executive control serves to coordinate among multiple task demands, facilitate the maintenance of goal-relevant representations and prevent interference from goal-irrelevant representations (Banich, 2009; Braver, 2012). Positive mood often enhances executive control particularly for cognitively demanding or challenging tasks (Fredrickson, 2001; Mitchell & Phillips, 2007; Padmala & Pessoa, 2011), whereas negative mood often has little influence on executive control (Mitchell & Phillips, 2007; see Pessoa, 2009, for a discussion on how negative stimuli compete with executive functions). However, these effects are nuanced. Specific to preventing interference, positive mood often impairs tasks that require proactive forms of control (maintain consistent goal-relevant dimensions; Dreisbach, 2006; Frober & Dreisbach, 2012, 2014; Martin & Kerns, 2011; Phillips, Bull, Adams, & Fraser, 2002), though not always (Chiew & Braver, 2014; Kuhl & Kazen, 1999; van Wouwe, Band, & Ridderinkhof, 2011). Negative mood when compared to a neutral (control) condition fails to influence proactive control (Dreisbach, 2006; Isaac et al., 2012). For tasks that require reactive control (detection and resolution of interference post conflict) or flexible control (shifting among mental-sets), positive mood enhances performance on such tasks (Ashby, Isen, & Turken, 1999; Dreisbach, 2006; Frober & Dreisbach, 2012, 2014). Interestingly, negative moods may improve reactive control on trials that follow errors (Kuhbandner & Zehetleitner, 2011; van Steenbergen, Band, & Hommel, 2010), but negative moods fail to have an influence for tasks that consistently require reactive control (Dreisbach, 2006). In sum, positive moods enhance both reactive control and executive control that involves coordinating among multiple task sets or goals, whereas negative moods often fail to influence executive control except when errors are made.

The working memory span task requires the involvement of both working memory and executive control. The working memory span task like an n-back task can assess working memory ability; however, the span task places greater demands on executive control compared to the n-back task (Kane, Conway, Miura, & Colflesh, 2007; Kwong See & Ryan, 1995; Oberauer, 2005). Specifically, the working memory span task requires executive control to coordinate between the primary goal of remembering information in working memory and a secondary goal of processing distracting information (Case, Kurland, & Goldberg, 1982; Conway & Engle, 1996; Conway et al., 2005). One study found that an induced positive mood compared to a neutral state enhanced working memory capacity within a verbal working memory operation span task (Yang, Yang, & Isen, 2013). However, there are many questions as to how mood, working memory and executive control interact to influence performance on a verbal and spatial operation span tasks.

Design and predictions

Our main question concerns whether the influence mood has on working memory supersedes the influence mood has on executive control or vice versa. Furthermore, a main goal of this paper was to extend the findings of Yang et al. (2013) on a verbal operation span task and to examine how both positive and negative moods influence a spatial operation span task. As mentioned above, Yang et al. (2013) observed that positive mood compared to a neutral state improved performance on a verbal operation span task; however, a negative mood condition was not included, and therefore it remains unknown how a negative mood influences a verbal operation span task. Specifically, will negative mood impair performance because it impairs verbal working memory (Gray, 2001), or will performance be similar to a control condition because it has limited influence on executive control? In Experiment 1, we predicted that the positive mood condition would perform better on the verbal operation span task compared to both the neutral and negative conditions, and that there would be no difference in performance between the neutral and negative conditions. The other and more interesting question is how mood influences performance on a spatial operation span task. First, if positive mood benefits executive control, does that benefit supersede the negative effect positive mood has on spatial working memory? Second, if negative mood fails to influence executive control, does the benefit a negative mood has on spatial working memory improve executive control and working memory capacity? In Experiment 2, we predicted that the positive condition would perform better than both the neutral and negative conditions, because positive mood enhances executive control. We further predicted that the negative and neutral conditions would have similar performance given that negative moods often have similar performance to neutral conditions on executive control tasks. Thus, we predicted that the influence emotion has on executive control would supersede the influence emotion has on domain-specific working memory.

To test these predictions, we ran two experiments with a similar design that varied only with respect to the working memory domain (i.e., verbal, spatial) utilised within the working memory span task. A positive, negative and neutral mood was induced between participants. Participants then completed a verbal operation span task (Experiment 1) or a spatial operation span task (Experiment 2). The secondary task for both the verbal and spatial operation span task was to solve simple math equations using order of operations. Within the verbal and spatial operation span tasks, we manipulated the number of items to be remembered, which consisted of presenting a set of 3, 5 or 7 items. Prior research suggests that for the average college student a range of 2–5 items is adequate to assess working memory capacity (Conway et al., 2005; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004), and therefore, the 7-item sets will serve as the most challenging condition.

VERBAL OPERATION SPAN TASK (EXPERIMENT 1)

Method

Participants

One hundred twenty (90 females, 28 males, 2 unreported) undergraduate students from Queens College participated to fulfil a course requirement. All participants had normal or corrected-to-normal vision. Their mean age was 20.62 years (SD = 4.29). Determination of sample size was based on the sample size of Storbeck (2012).

Stimuli and apparatus

Mood induction. Positive mood (happiness) was induced with a 5-minute clip from *Jerry Seinfeld: Stand up in New York*, negative mood (sadness) with a 5-minute clip from *The Champ* and neutral mood with a 5-minute clip from *If Dolphins Could Talk* (Rottenberg, Ray, & Gross, 2007; Storbeck, 2012; Storbeck & Clore, 2011).

Mood manipulation check. The mood check consisted of a total of four questions, two questions assessing valence and two questions assessing arousal. Participants were instructed to indicate how they felt while viewing the movie using a 6-point scale, and each question consisted of different anchors. For arousal, the anchors were “not at all aroused” (1) to “very aroused” (6) and “not at all alert” (1) to “very alert” (6). For valence, the anchors were “negative” (1) to “positive” (6) and “sad” (1) to “happy” (6). The two arousal questions were averaged together to create the composite score *arousal*, and the two valence questions were averaged together to create the composite score *valence*.

Verbal working memory span task. A modified version of the operation span task (Conway et al.,

2005) was used to assess working memory capacity specific to the domain of verbal working memory. The working memory span task consisted of two components: the verbal working memory task and the operation task (math problems). A set consisted of a learning phase for the words, answering math problems and recalling the words presented during the learning phase. The learning phase consisted of presenting 3, 5 or 7 neutral words with similar levels of frequency and length in a sequential order [words were obtained from and validated using the ANEW (Bradley & Lang, 1999) and MRC (Wilson, 1988) databases]. Each word was presented for 3 seconds. After the last word was presented, a solved math problem was presented (e.g., 6/(3 – 2) = 0), and the participants indicated if the given answer was correct by pressing "A" or incorrect by pressing "L". The math problems were simple problems; however, the correct order of operations had to be used to correctly solve them. Once the participant recorded their response to the math problem, the participants were asked to recall the words in the correct sequence they were presented. For each recall response, participants were prompted with "Please recall the X word presented" with the X representing first, second, third, etc. word presented during the learning phase.

Procedure

Participants were first informed about the nature of the study, and then they were asked to consent to participating and signed the consent form. Participants were randomly assigned to one of three mood conditions (positive, negative, neutral). Prior to the mood induction, all participants received 15 practice trials of the math task; 15 trials of the word recall task divided into sets containing 3, 5 and 7 trials; and three two-trial sets of the complex span task (learn, math problem, recall). Mood states were induced, and participants were instructed to watch the movie and focus on their feelings. Participants then completed the experimental trials of the complex span task. Participants completed 15 sets with five of each: three-trial, five-trial and seven-trial sets. Participants then completed the mood check and demographic questionnaires and were then debriefed.

Results

Prior research has often failed to find processing/storage trade-offs between solving the math problems and recalling items presented during the working memory task. It is quite common to remove participants who fail to score above an 80% criterion (Conway et al., 2005). Following those procedures, two participants who scored lower than the criterion of 80% were removed from the analysis. One individual in the positive condition failed to report demographic and mood manipulation check information, but their data were still included in span task analysis (except for the regression results).

Mood manipulation check

Two one-way analyses of variance (ANOVAs) were run to assess group differences for the valence score and the arousal score. For valence, as expected, we observed a significant main effect, $F(2, 115) = 232.20$, $p < .01$, $\eta^2 = 0.80$. The Tukey post-hoc analyses revealed that the positive condition reported more positive feelings compared to the negative, $p < .01$, and the neutral, $p = .03$, conditions (Tukey post-hoc analyses were used for all reported post-hoc tests). The neutral condition reported more positive feelings compared to the negative condition, $p < .01$. There was also a main effect of arousal, $F(2, 115) = 5.82$, $p < .01$, $\eta^2 = 0.10$. The positive, $p < .01$, and negative, $p = .02$, conditions reported a higher arousal score compared to the neutral condition. The positive and negative conditions reported similar levels of arousal, $p = .95$. See Table 1 for all descriptive statistics for both Experiments 1 and 2.

Working memory span task

Math problems. We assessed performance on the math (processing) task to determine whether emotion influenced performance and to ensure there was no processing/storage trade-offs. The one-way ANOVA of emotion (positive, negative,

Table 1. *Descriptive statistics for Experiments 1 and 2*

Conditions	*Positive*	*Negative*	*Neutral*
Experiment 1—verbal			
Valence	4.96 (0.70)	1.79 (0.72)	4.54 (0.71)
Arousal	3.97 (1.21)	3.90 (0.99)	3.22 (1.03)
Math performance	0.97 (0.02)	0.94 (0.05)	0.95 (0.04)
PC mean	0.85 (0.10)	0.73 (0.16)	0.76 (0.14)
AorN mean	0.65 (0.20)	0.45 (0.20)	0.50 (0.20)
AorN 3	0.87 (0.19)	0.70 (0.22)	0.76 (0.25)
AorN 5	0.74 (0.28)	0.45 (0.31)	0.54 (0.31)
AorN 7	0.36 (0.31)	0.22 (0.24)	0.20 (0.22)
RT SS 3	899.60 (305)	945.72 (389)	998.76 (494)
RT SS 5	920.29 (466)	1026.22 (501)	944.27 (452)
RT SS 7	1146.36 (573)	1274.03 (723)	1208.97 (591)
Experiment 2—spatial			
Valence	4.99 (0.93)	1.82 (0.86)	4.14 (0.87)
Arousal	3.86 (1.07)	3.51 (1.01)	3.50 (1.12)
Math performance	98 (0.03)	0.96 (0.03)	0.95 (0.05)
PC mean	0.71 (0.12)	0.59 (0.18)	0.61 (0.18)
AorN mean	0.44 (0.17)	0.30 (0.19)	0.33 (0.17)
AorN 3	0.79 (0.24)	0.60 (0.30)	0.66 (0.24)
AorN 5	0.42 (0.28)	0.21 (0.26)	0.24 (0.20)
AorN 7	0.12 (0.17)	0.08 (0.14)	0.09 (0.19)
RT SS 3	3575.82 (1333)	3575.79 (1068)	3301.54 (709)
RT SS 5	3624.80 (1214)	3512.30 (860)	3427.11 (628)
RT SS 7	3892.27 (1437)	3657.54 (901)	3460.99 (657)

PC, partial-credit unit scoring; AorN, all-or-nothing unity scoring; RT SS, reaction time for set size. The table presents the means and standard deviations (in parentheses).

neutral) for overall math performance revealed a significant main effect, $F(2, 117) = 4.61$, $p = .01$, $\eta^2 = 0.07$. The positive condition performed better than the negative condition, $p = .01$, whereas the positive condition performed similarly to the neutral condition, $p = .10$. There were no performance differences between the negative and neutral conditions, $p = .67$.

Verbal working memory span task. It is common to examine a single score referred to as the working memory capacity score. The working memory capacity score can be computed using two different scoring methods; partial-scoring and all-or-nothing (Conway et al., 2005). The partial-scoring method is suggested to be more optimal than the all-or-nothing scoring method. But, both scoring methods were assessed. There are two aspects to the recall phase: (1) memory for the items presented and (2) memory for the order in which the items were presented. The partial-scoring method includes only overall memory for presented items (part 1), whereas the all-or-nothing scoring requires complete accuracy (recall of all items in the order they were presented in). For the partial-credit scoring, a point was received for each item correctly recalled irrespective of order. Therefore, the mean accuracy reflects the percent of items recalled from the entire set. For the all-or-nothing scoring, a point was received if and only if each item of the set was correctly recalled in the order presented. Therefore, the mean accuracy reflects whether the entire set was recalled accurately (1) or inaccurately (0). Typically, the partial-credit scoring leads to a higher mean than the all-or-nothing scoring; however, prior research finds that both scores predict similar outcome measures (e.g., general fluid intelligence; Conway et al., 2005; Engle, Kane, & Tuholski, 1999).

For the partial-credit unit scoring, we conducted a repeated-measures analysis to examine whether emotion interacted with set size, and critically, we did not observe a significant emotion by set-size interaction, $F(4, 234) = 1.02$, $p = .40$, $\eta^2 = .02$. Not unexpectedly, there was a main effect for set size, $F(2, 234) = 113.11$, $p < .01$, $\eta^2 = 0.49$, with the smallest set having the highest accuracy and the largest set the lowest level of accuracy, all ps $< .01$. As predicted, we observed a significant main effect for emotion, $F(2, 117) = 7.66$, $p < .01$, $\eta^2 = 0.12$. The positive condition recalled more words than the negative, $p < .01$, and the neutral, $p = .03$, conditions. The negative condition recalled a similar number of words as the neutral condition, $p = .44$.[1] See Figure 1 for a display of the means by emotion and set size and Table 1 for the overall mean.

The same analysis was conducted for the all-or-nothing scoring, and we failed to observe an interaction effect, $F(4, 234) = 1.89$, $p = .11$, $\eta^2 = 0.03$. We did observe a significant set-size effect, $F(2, 234) = 192.33$, $p < .01$, $\eta^2 = 0.62$. All set sizes differed from each other, all ps $< .01$, with the smallest set size being associated with the highest accuracy and the largest set size associated with the lowest accuracy. As predicted, a significant main effect of emotion was observed, $F(2, 117) = 10.93$, $p < .01$, $\eta^2 = 0.16$. The positive condition was more accurate compared to the negative, $p < .01$, and the neutral, $p < .01$, conditions. The negative and neutral conditions had a similar capacity score, $p = .55$. See Table 1 for descriptive statistics.

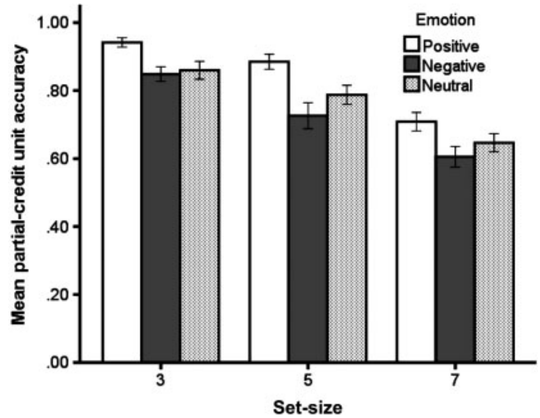

Figure 1. *Mean number of words recalled (verbal working memory capacity score) by set size for each mood condition in Experiment 1. Error bars represent one standard error of the mean.*

Time spent on recalling words. One prediction might be that being in a positive mood may increase the motivation to persist on the task or dedicate more effort, and therefore, we assessed whether task persistence was influenced by emotion. We assessed the total time spent recalling the words by running a repeated-measures ANOVA with emotion as a between-subjects factor and set size as within-subjects. A significant effect of set size was observed, $F(2, 234) = 28.77$, $p < .01$, $\eta^2 = 0.20$. Post-hoc analyses revealed that recalling items for set size 7 took longer than recalling items for set size 3, $p < .01$, and set size 5, $p < .01$. No differences were observed between set size 3 and 5, $p = .63$. Critically, the main effect for emotion and the emotion by set-size interaction failed to achieve a level of significance, Fs < 1.

Regressions

We wanted to explore whether the self-reported arousal and/or valence during the mood induction predicted performance on the span task. Two regressions were run with the dependent variable being (1) partial-credit accuracy or (2) all-or-nothing accuracy with arousal and valence as the predictors. For the partial-credit scoring, the regression was significant, $F(2, 115) = 3.90$, $p = .02$, such that the more positive the mood during the induction resulted in better accuracy, $t = 2.60$, $p = .01$, whereas arousal did not predict accuracy, $t = 1.08$, $p = .28$. For the all-or-nothing accuracy, the regression was also significant, $F(2, 115) = 5.01$,

[1] We also performed a weighted partial-credit scoring algorithm following the procedures in Conway et al. (2005), and the results were conceptually replicated [$F(2, 117) = 6.93$, $p < 0.01$, $\eta^2 = 0.11$; Positive vs. Negative, $p < .01$; Positive vs. Neutral, $p = .05$; Negative vs. Neutral, $p = .40$].

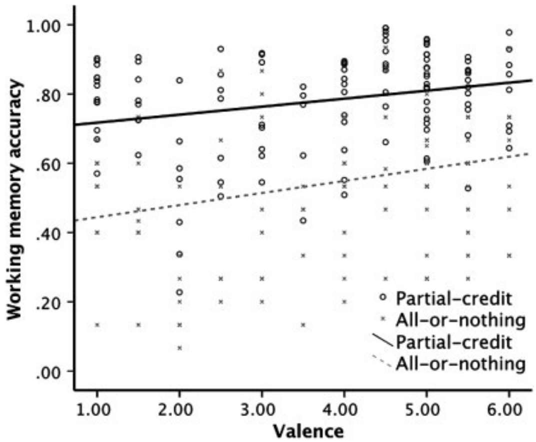

Figure 2. *A scatterplot with regression lines showing the relationship between self-reported valence and verbal working memory capacity score with partial-credit (open circles and solid regression line) and all-or-nothing (x's and dashed regression line) scoring methods (Experiment 1).*

p = .01, such that the more positive the person felt the more accurately they performed, t = 2.81, p < .01, whereas arousal did not predict accuracy, t = 1.51, p = .13. See Figure 2 for a scatterplot of the relationship between mood and accuracy.

DISCUSSION

We observed that positive mood improved performance on the complex span task compared to both the neutral and negative mood conditions. The positive condition performed better across all three set sizes, suggesting there was a consistent advantage, despite changes in task load or demand. Moreover, felt positive mood predicted successful performance on the task, suggesting that positive mood and not arousal served to best predict performance. The results are in line with prior research by Yang et al. (2013) in which they observed that positive mood improved performance on a complex working memory span task compared to a neutral mood condition. We extended their research by demonstrating that negative mood does not impair performance compared to a neutral induction.

EXPERIMENT 2

The previous experiment suggested that positive mood enhanced verbal working memory and executive control. However, it remains unclear whether positive or negative mood can enhance spatial working memory capacity. Negative mood may enhance spatial working memory capacity because it enhances spatial working memory (Gray, 2001), which may help guard against interference. However, because negative mood does not enhance executive control, negative mood may be at a disadvantage for preventing task-irrelevant information (math problems) from interfering with the spatial information held in working memory. Alternatively, positive mood may impair spatial working memory capacity because it impairs the ability to remember spatial information (Gray, 2001). However, positive mood enhances executive control, and therefore, it may result in a stronger maintenance of spatial information in working memory by preventing interference. We predicted that positive mood would enhance spatial working memory capacity compared to both the negative and neutral conditions.

Methods

Participants

One hundred (58 females, 38 males, 4 unreported) undergraduate students from Queens College participated to fulfil a course requirement. All participants had normal or corrected-to-normal vision. Their mean age was 20.66 years (SD = 4.57).

Stimuli and apparatus

The mood induction, mood check and the demographic questionnaire were identical to Experiment 1.

Working memory span task. The spatial working memory span task was identical to the task in Experiment 1 with the exception of the spatial information to be maintained in working memory. For this task, participants were presented with a red box in 1 of 12 spatial locations on the screen (a non-visible 3 × 4 matrix). Each trial consisted of a unique spatial location within a set. After seeing 3, 5 or 7 red box locations on at a time, the math problem followed. The spatial recall task was then administered, and participants were asked to recall the spatial location of each red box presented in the sequence they were presented. Participants were provided a grid with 12 locations, and each location was associated with a letter to be pressed on the keyboard [top row from left to right (A, B, C, D), middle row (E, F, G, H) and bottom row (I, J, K, L)]. Participants were instructed to press the key corresponding to the location of the red box presented on X trial with X serving as the serial order position in which the box was presented.

Procedure

The procedure was identical to that of Experiment 1 with the exception that the working memory instructions were changed to reflect the spatial, rather than verbal, working memory task.

Results

One participant was removed from the analysis for failing to obtain an overall mean score of 80% on the processing (math) task.

Mood manipulation check

Two one-way ANOVAs were run to assess group differences for the valence score and the arousal score. For valence, we observed a significant main effect, $F(2, 97) = 121.04$, $p < .01$, $\eta^2 = 0.71$. The positive condition reported more positive feelings compared to the negative, $p < .01$, and the neutral, $p < .01$, conditions. The neutral condition reported more positive feelings compared to the negative condition, $p < .01$. For arousal, there were no differences among the groups, $F(2, 97) = 1.27$, $p = .29$, $\eta^2 = 0.03$.

Complex span task

Math problems. We assessed performance on the math task. The one-way ANOVA of emotion (positive, negative, neutral) for overall math performance revealed a significant main effect, $F(2, 97) = 4.55$, $p = .01$, $\eta^2 = 0.09$. Post-hoc analyses revealed that the positive condition performed better than the negative, $p = .06$ (marginal), and neutral, $p = .02$, conditions. There were no performance differences between the negative and neutral conditions, $p = .80$.

Working memory span task. For the partial-credit scoring, we conducted a repeated-measures analysis to examine whether emotion interacted with set size, and we did not observe a significant emotion by set-size interaction, $F < 1$. A main effect for set size was observed, $F(2, 194) = 236.62$, $p < .01$, $\eta^2 = 0.71$. All set sizes were significantly different from each other, ps < .01, with the smallest set size associated with the best accuracy and the largest set size associated with the worst accuracy. As predicted, a significant main effect for emotion was observed, $F(2, 97) = 5.33$, $p < .01$, $\eta^2 = .10$. The positive condition recalled more spatial locations than the negative, $p = .01$, and neutral, $p = .04$, conditions. The negative and neutral conditions showed similar levels of recall for the spatial locations, $p = .94$.[2] See Figure 3 for a display of the means by emotion and set size and Table 1 for the overall mean.

For the all-or-nothing scoring, we observed a significant emotion by set-size interaction, $F(4, 194) = 2.76$, $p = .03$, $\eta^2 = 0.05$. Simple contrasts revealed that within set size 3 and set size 5, the positive condition was more accurate than both the negative, ps < .01, and neutral, ps < .04, conditions (negative vs. neutral, ps > .36). However, for set size 7, there were no performance differences among the three conditions, ps > .33. There was also a main effect for set size, $F(1, 97) = 476.40$, $p < .01$, $\eta^2 = 0.83$, with all set sizes being significantly different from each other, ps < .01,

[2] The same weighted partial-credit scoring algorithm was ran as in Experiment 1 (see footnote 1), and the results were conceptually replicated [$F(2, 97) = 4.72$, $p = .01$, $\eta^2 = 0.09$; Positive vs. Negative, $p = .02$; Positive vs. Neutral, $p = .05$; Negative vs. Neutral, $p = .97$].

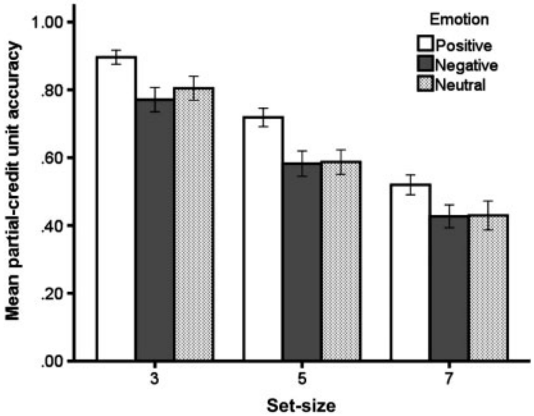

Figure 3. *Mean number of spatial locations recalled (spatial working memory capacity score) by set size for each mood condition in Experiment 2. Error bars represent one standard error of the mean.*

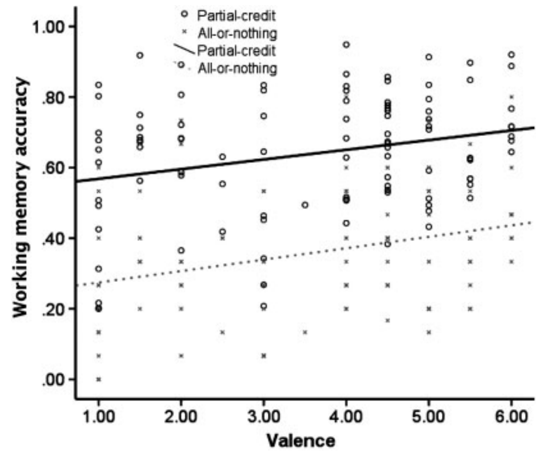

Figure 4. *A scatterplot with regression lines showing the relationship between self-reported valence and spatial working memory capacity score with partial-credit (open circles and solid regression line) and all-or-nothing (x's and dashed regression line) scoring methods (Experiment 2).*

with the smallest set size associated with the best accuracy and the largest set size associated with the worst accuracy. As predicted, for emotion we observed a significant main effect for set accuracy, $F(2, 97) = 7.08$, $p = .01$, $\eta^2 = 0.13$. The positive condition was more accurate compared to the negative, $p < .01$, and the neutral, $p = .03$, conditions. However, no differences were observed between the negative and neutral conditions, $p = .70$. See Table 1 for descriptive statistics.

Time spent on spatial recall. We assessed the total time spent recalling the spatial locations by running a repeated-measures ANOVA with emotion and set size. A significant effect of set size was observed, $F(2, 194) = 6.65$, $p < .01$, $\eta^2 = 0.06$. Pair-wise comparisons revealed that set size 7 took the longest to complete compared to both set size 3 and set size 5, ps < .01. There was no difference between set size 3 and set size 5, $p = .58$. The main effect for emotion, $F < 1$, and the emotion and set-size interaction, $F(24, 194) = 1.44$, $p = .23$, $\eta^2 = 0.03$, were non-significant.

Regressions. The same regressions were run as in Experiment 1 to determine whether valence or arousal predicted spatial working memory capacity. For the partial-credit score, the regression was significant, $F(2, 97) = 3.56$, $p = .03$, such that higher levels in positive mood predicted better spatial working memory capacity, $t = 2.62$, $p < .01$, whereas arousal did not predict accuracy, $t = 0.22$, $p = .83$. For the all-or-nothing scores, we observed another significant regression, $F(2, 97) = 4.43$, $p = .01$, where positive mood again predicted accuracy, $t = 2.92$, $p < .01$, but arousal did not, $t = 0.24$, $p = .81$. See Figure 4 for a scatterplot of the relationship between mood and accuracy.

DISCUSSION

Similar to the verbal complex span task, the positive condition had the highest spatial working memory capacity score compared to the negative and neutral conditions. However, for the all-or-nothing score, superior performance by the positive condition was only observed with set sizes 3 and 5, but not for set size 7. Critically, negative mood did not improve or impair executive control when compared to the neutral condition. Moreover, felt positive mood predicted successful performance on the spatial complex span task. In sum, positive mood was associated with enhanced executive control even when spatial information had to be maintained in working memory.

GENERAL DISCUSSION

The goal of this research was to extend our understanding for how positive and negative moods influence executive control when holding verbal or spatial information in working memory. Theoretically, there were three viable predictions. First, positive mood would enhance executive control regardless of the working memory domain, thereby enhancing both verbal and spatial working memory capacity. Second, negative mood would facilitate executive control specifically when spatial working memory was required. Third, an interaction between mood and working memory capacity would emerge. We observed that the positive, compared to negative and neutral, condition consistently produced the largest working memory capacity score, regardless of the working memory domain (verbal or spatial). Interestingly, the only time positive mood did not enhance performance was for very precise memory (all-or-nothing) in the 7 set-size spatial span task. This finding suggests that a small cognitive cost may arise when maintaining spatial information for individuals in positive moods. People in a negative mood had similar verbal and spatial working memory capacity score as those people in the neutral condition. These findings suggest that positive mood may enhance executive control, which helped to maintain verbal and spatial information in working memory while preventing interference from the processing task. Overall, the influence mood has on executive control superseded the influence mood has on working memory domains.

The current research adds another layer of complexity when examining how emotion influences tasks that involve single and/or multiple executive functions (e.g., executive control and working memory). Gray and colleagues (2001, 2002) observed that emotion interacts with working memory domains, but the current research paints a more muddled picture. We found that positive mood increased working memory capacity for all set levels (3, 5, 7), which suggests that positive mood enhanced executive control. However, given the graded performance in the spatial span task for the all-or-nothing score, it may suggest that the positive condition was cognitively taxed more when holding spatial, compared to verbal, information in working memory. How can these findings be reconciled with those findings with the n-back task? The n-back task may not require the same degree of executive control as the working memory span task (Kane et al., 2007). Specifically, the n-back task is correlated with short-term memory span and less correlated with working memory capacity (Roberts & Gibson, 2002). Moreover, the working memory span task is known to recruit executive control evidenced by the greater involvement of dorsolateral prefrontal cortex (Burgess, Gray, Conway, & Braver, 2011; Chein, Moore, & Conway, 2011; McNab & Klingberg, 2008; Osaka et al., 2003), whereas the n-back reveals higher involvement of the dorsolateral prefrontal cortex only when there are high levels of interference (Fales et al., 2008). Thus, with less demand placed on executive control by the n-back task, it may allow for any direct influence emotion has on working memory domains to be observed. Therefore, positive mood may improve spatial working memory during an n-back task when the demands for executive control are increased (e.g., 4-back task or increasing the number of lures—see Fales et al., 2008).

The main theories that would support the present findings are the neuropsychological theory of positive mood and the broaden-and-build hypothesis (Ashby, Isen, & Turken, 1999; Fredrickson, 2001). The neuropsychological theory of positive mood claims that positive mood increases dopamine, which is an important underlying biological mechanism for executive control and working memory. In support of this prediction, non-human primate studies have found that levels of dopamine increase in the prefrontal cortex as working memory task demands increase in a domain-general (verbal and visuospatial) manner (Goldman-Rakic, 1996; Mehta, Sahakian, McKenna, & Robbins, 1999; Williams & Goldman-Rakic, 1995). Moreover, dopamine facilitates adjustment, cognitive flexibility, switching between goals, and increases phasic activity in the prefrontal cortex. Success on the operation span task requires the ability to both hold information in working memory and switch among the various task demands (Chein et al., 2011; Engle, Kane, & Tuholski, 1999; Kane et al., 2004; Miyake & Friedman, 2012), which suggests that increasing dopamine via a happy mood should improve working memory capacity. The findings are also consistent with the broaden-and-build theory (Fredrickson, 2001), which argues that positive mood facilitates the broadening of cognition, coping and resiliency during challenging tasks. Therefore, positive mood may broaden cognition, which facilitates the ability to maintain information in working memory while solving and processing information from the math problems. The two theories presume different mechanisms and future research is needed to determine which component (dopamine, cognitive flexibility, executive control, coping) best explains the increase in working memory capacity when in a positive mood.

Future directions

Future studies of emotion and executive function interactions should be sensitive to the influence emotion has on specific executive functions independent of executive control. In the findings above, we suggest that positive mood facilitated executive control to enhance working memory capacity. Furthermore, the recruitment of executive control may have overshadowed the independent effects emotion has on specific working memory domains. Additional research needs to be conducted to directly examine the type of executive control that allowed people in positive moods to increase working memory capacity. Was the observed effect due to positive mood influencing proactive control, reactive control or coordination between task goals, or conversely, how did negative mood interact with the different types of control? Studies could examine these effects through modifying working memory tasks. For instance, proactive control is typical on an n-back task, but reactive control is often invoked when there are a high number of lure trials (a stimulus is presented again one trial after it would be considered a match stimulus; Fales et al., 2008). Manipulations such as these may better inform us on the relationships among emotion and executive control when engaged in working memory tasks or operation span tasks.

Conclusion

In sum, we observed that positive mood enhanced working memory capacity for both verbal and spatial working memory domains. Moreover, negative mood failed to reduce working memory capacity when compared to a neutral state, suggesting that negative moods do not impair executive control. The finding that positive mood generally enhances working memory capacity, irrespective of working memory domain, fits well with other research demonstrating that positive mood enhances cognitive flexibility, creativity, coping and executive control (Ashby et al., 1999; Dreisbach, 2006; Fredrickson, 2001; Mitchell & Phillips, 2007) all factors that are important for fluid intelligence.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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