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The Influence of Positive Mood on Different Aspects of Cognitive Control

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Abstract

Some evidence suggests that positive mood influences cognitive control. The current research investigated whether positive mood has differential effects on two aspects of cognitive control, working memory and prepotent response inhibition. In Study 1, following either a positive or neutral mood induction, participants completed the Running Memory Span (RMS), a measure primarily of working memory storage capacity, and the Stroop task, a measure of prepotent response inhibition. Results were that the positive mood group performed worse on the RMS task but not on the Stroop task. In Study 2, participants completed the RMS and another measure of prepotent response inhibition, the Flanker task. Results were that when in a positive mood state participants performed worse on the RMS but not on the Flanker task. Overall, this research suggests that positive mood has differential effects on cognitive control, impairing working memory but having no effect on prepotent response inhibition.

Keywords

positive mood; cognitive control; working memory; storage capacity; prepotent response inhibition

Mood can have differential effects on cognition. Mood states have been found to either benefit (e.g., Isen, Shalker, Clark, & Karp, 1978), impair (e.g., Phillips, Smith, & Gilhooly, 2002), or of have no effect (e.g., Phillips, Bull, Adams, & Fraser, 2002) on different aspects of cognition. For example, there is some evidence that positive mood might influence cognitive control (Rowe, Hirsh, & Anderson, 2007) and other reports that it might not (Phillips, Bull et al., 2002). These mixed results might be due to the fact that cognitive control is a broad construct involving multiple components. Cognitive control refers to "the mechanism that guides the entire cognitive system and orchestrates thinking and acting" (De Pisapia, Repovs, & Braver, 2008, p. 26). Understanding how mood influences cognitive control could be important for understanding emotion regulation (Ochsner & Gross, 2005). The current project investigated the effects of positive mood on two facets of cognitive control: working memory storage capacity and prepotent response inhibition (e.g., Cowan, Elliott, et al., 2005; Friedman & Miyake, 2004). Previous research has not directly investigated the effects of positive mood on storage capacity. In addition, there is inconsistent evidence regarding the effect of positive mood on prepotent response inhibition. However, previous research has involved relatively small sample sizes, and no previous research has examined the effect of the same positive mood manipulation on multiple prepotent inhibition tasks. Furthermore, previous research has not directly examined the influence of positive mood on multiple cognitive control components in the same research.

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Mood is a dispositional state that lasts for several minutes or hours (Mitchell & Phillips, 2007). Both detrimental and beneficial effects of positive mood states on complex cognitive measures that likely involve cognitive control have been reported. On the one hand, there is evidence that positive affective states are associated with increased distractibility (Dreisbach & Goschke, 2004) and impaired planning (Oaksford, Morris, Grainger, & Williams, 1996; Phillips, Smith et al., 2002). For example, people in a positive mood required more moves to match the goal set in the Tower of London task (Oaksford et al., 1996; Phillips, Smith et al., 2002). On the other hand, positive mood has also been shown to facilitate a broader focus of attention. For example, individuals in a positive mood state can recall more words than those in a negative mood state (Isen, Shalker, Clark, & Karp, 1978) and can generate more uses of a particular object (Phillips, Bull et al., 2002). Hence, positive mood can hinder or help different types of complex cognitive tasks. The current research examined whether positive mood has harmful or beneficial consequences for two aspects of cognitive control.

Working memory

Working memory refers to ‘the set of mental processes holding limited information in a temporarily accessible state in the service of cognition’ (Cowan, Elliott, et al., 2005, p. 42). Storage capacity in working memory can be defined as the number of chunks of information that can be maintained (Cowan, Elliott, et al., 2005). Although working memory storage capacity has typically been viewed as distinct from a central executive (Baddeley, 1986; Cowan, 1995), it has been argued to be centrally involved in attentional control and to be a central capacity limit for complex cognitive control tasks (Cowan, 2005). A large body of diverse findings suggests that the maximum working memory storage capacity is 3-5 chunks (Cowan, 2001, 2005; Luck & Vogel, 1997). Activation of posterior regions, such as the parietal lobes, is associated with storage of information in working memory (Braver, Gray, & Burgess, 2007; Postle, 2006; Postle, Berger, & D'Esposito, 1999; Todd & Marois, 2005). An example of a task thought to strongly reflect working memory storage capacity is the Running Memory Span task (RMS; Cowan, Elliott, et al., 2005). In the RMS task, participants hear a series of digits through headphones at a rate of 4 per second (i.e. 250 ms per stimulus). As soon as the series ends, they are asked to recall the last 6 digits they heard. Scores on the RMS have been found to correlate with working memory capacity measures, such as the OSPAN (Broadway & Engel, in press). Importantly, the presentation speed of the stimuli (i.e. 250 ms per item) in the RMS is intended to be too fast for people to use effortful updating, chunking, or rehearsal operations (Bunting, Cowan, & Saults, 2006; Cowan et al., 2005; Hockey, 1973). Nonetheless, although the task attempts to minimize the influence of these cognitive operations, it is still possible that they might contribute to performance of the RMS task.

Working memory and positive mood

One possible way that positive mood could impair working memory is by increasing the spread of activation of items in working memory. Consistent with this, there is evidence that a positive mood is associated with increased spreading activation in the context of semantic priming (e.g., Hänze & Meyer, 1998; Storbeck & Clore, 2008) and, relatedly, that it improves judgment on the coherence of word triads (Bolte, Goschke, & Kuhl, 2003). If activation becomes more diffuse, it may be more difficult to retain a subset of items above a threshold level of activation in a working memory buffer (Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005). At the same time, more diffuse spreading activation could also make it more difficult to successfully retrieve items from working memory. For example, Davelaar et al. (2005) have posited that to retrieve a specific item from working memory it might be critical to inhibit the activation of other items in working memory.

Thus, positive mood may increase the spread of activation and impair the ability to store and retrieve working memory items.

It is possible that the effect of positive mood on working memory might account for some of the previous findings regarding the effect of positive mood on cognitive control. For example, a reduction in working memory storage could account for poorer planning with positive mood. However, to our knowledge, perhaps only one study has examined whether positive mood influences working memory storage capacity. In that study (Spies, Hesse, & Hummitzsch, 1996), participants underwent a positive or neutral mood induction and then completed a word span task while carrying out articulatory suppression. Importantly, articulatory suppression prevents rehearsal, thereby providing a measure of working memory minimally influenced by rehearsal. Overall, positive mood had a small but nonsignificant effect on performance while participants were engaged in articulatory suppression, $d = 0.28$. It is possible that with a larger sample size and with an even more direct measure of working memory capacity that a significant effect of positive mood on working memory might be found.

Prepotent response inhibition

In addition to working memory storage, the current research also examined the influence of positive mood on another aspect of cognitive control, prepotent response inhibition. Prepotent response inhibition requires “maintaining the task goal in a state of high activation in the face of more dominant but inappropriate responses” (Friedman & Miyake, 2004, p. 115). An example of a task that involves prepotent response inhibition is the Stroop task (Stroop, 1935). In this task, participants must maintain the task instructions (i.e. respond to the color of the stimulus) in order to inhibit and overcome the automatic response of reading the word (Cohen, Dunbar, & McClelland, 1990). The Flanker task is another example of a prepotent response inhibition task (Eriksen & Eriksen, 1974). Participants are told to respond to the center, target stimulus which is flanked by either compatible or incompatible distractor stimuli (i.e. flankers). The flankers can either be mapped to the same response key (i.e. stimulus incompatible trials) or a different response key (i.e. response incompatible trials) as the target letter. Previous research has consistently found evidence of prefrontal and anterior cingulate cortex activity during the performance of prepotent response inhibition tasks (Bunge, Hazeltine, Scanlon, Rosen, & Gabrieli, 2002; Hazeltine, Poldrack, & Gabrieli, 2000; Cabeza & Nyberg, 2000; MacDonald, Cohen, Stenger, & Carter, 2000; Nee, Wager, & Jonides, 2007).

Prepotent response inhibition and positive mood

Dopamine levels have been associated with positive affect (Ashby et al., 1999). In addition, it has been suggested that prepotent response inhibition might also be related to dopamine functioning. This is because dopamine levels, along with multiple dopamine receptors, are thought to be potentially important for maintaining task goals, which has been argued to be critical for prepotent response inhibition (Braver et al., 2007; Miller & Cohen, 2001). D2 receptors in the prefrontal cortex, which are activated during phasic dopamine bursts, are thought to be associated with destabilizing goal representations and updating goal information (Cohen, Braver, & Brown, 2002; O'Reilly, 2006). Also, previous research has suggested that emotions might have an effect on the lateral prefrontal cortex, but the exact effect is unclear (Wheeler, Davidson, & Tomarken, 1993; Harmon-Jones, 2004). Thus, one way that positive mood could impair prepotent response inhibition is by decreasing the ability to maintain a goal in the presence of dominant but inappropriate responses.

There is some evidence suggesting that positive mood might impair prepotent response inhibition tasks. In one study, Dreisbach (2006) reported that sustained processing of positive stimuli (i.e., seeing a positive picture before each trial) resulted in poorer performance on a prepotent response inhibition task, the AX-CPT (Braver et al., 2001). However, this study did not examine whether a sustained increase in positive mood was associated with impaired prepotent response inhibition. In other research, Phillips Bull et al., (2002) reported a trend for a positive mood group to exhibit a larger Stroop interference effect than a neutral mood group, suggesting poorer prepotent response inhibition with positive mood. In addition, Rowe et al. (2007) reported that positive mood was associated with greater Flanker inference compared to neutral and sad mood. However, in this study, Flanker interference was measured as a combination of stimulus and response interference, whereas it has been argued that perhaps response interference is most strongly related to prepotent response inhibition and cognitive control (van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). At the same time, both the Phillips, Bull et al. study and the Rowe et al. study involved somewhat small sample sizes (n = 36 and 24, respectively). Thus, additional research, using a larger sample size, could provide clearer evidence of the detrimental effects of positive mood on prepotent response inhibition.

In the current research, in two studies, we examined the effect of positive mood on two facets of cognitive control: working memory and prepotent response inhibition. Previous research has not explicitly examined the effect of positive mood on storage capacity, and, thus, has not investigated how positive mood influences these two aspects of cognitive control in the same study. Based on previous theory and research suggesting that positive mood increases spreading activation and could destabilize goal representations, it was hypothesized that positive mood would impair working memory and prepotent response inhibition.

Study One

In Study 1, while in either a positive or a neutral mood condition, participants completed two cognitive control tasks: the RMS and the Stroop tasks. The RMS has been well validated as a measure of working memory (Cowan, Elliott, et al., 2005), and the Stroop task is a well-validated prepotent response inhibition task (e.g., Friedman & Miyake, 2004).

Method

Participants—One hundred eighty participants (51.1% females, 83.5% Caucasian, mean age 19.3 years) were recruited from a large, midwestern university. They received course credit for participating. Participants were randomly assigned to either a positive mood group (n = 87) or a neutral mood group (n = 93).

Measures

Demographic questionnaire: Participants provided information regarding their age, sex, race/ethnicity, and year in school.

Mood measure: To assess current mood, participants were shown 16 positively and negatively valenced words with both high and low arousal levels (e.g. serene, elated, sad, anger). They were asked, “How are you feeling right now?” and were given a 5-point scale (1 – not at all to 5 – very strongly) to respond. These words have been used frequently in previous research to assess self-reported mood (e.g., Barrett, 2004). Because of computer failure, one participant in the positive mood group at Time 1, one participant in the neutral mood group at Time 2, and 2 participants in the neutral mood group at Time 3 did not complete the mood measure.

Materials

Mood induction: To manipulate people's moods, participants watched two separate videos. Participants in the positive mood group viewed a 10-minute and a 5-minute clip from Jerry Seinfeld's stand-up comedy show entitled, "I'm telling you for the last time" (Columbus 81 Productions, 1998). In these videos, Seinfeld gives a commentary on Halloween, the Olympics, and scuba diving without using any vulgar or derogatory language. Numerous studies have also used 5-10 minute video clips to elicit positive mood (e.g., Gray, 2001; Gray & Braver, 2002; Isen et al., 1978; Phillips, Smith, et al., 2002).

Participants in the neutral group viewed 10-minute and 5-minute scenes from an instructional video entitled, "How do I? Flooring" (How do I? Productions, 2004). These clips explain how to install different kinds of flooring, including vinyl sheet flooring and baseboards. Two trade people discuss and demonstrate important safety rules, tools, products, preparation, installation, and clean-up procedures.

Working Memory: Running Span Task: This task was designed to measure working memory storage capacity (Cowan, Elliott, et al., 2005). In addition to storage capacity, it also involves encoding and possibly updating of information. In this task (Cowan, Elliott, et al., 2005), 12 to 20 random single-digit numbers were presented through a headset to participants at a rate of 4 per second. Participants were instructed to try to remember the last 6 digits they heard in forward order. After the digits were presented, participants entered each digit they could recall into numbered slots (#1-6) presented on the computer screen. They were told guessing was "okay" and that they could leave slots blank. There were a total of 18 trials. Participants received 1 point if their response for each slot matched (a) the correct response (e.g., If "2" was the 6th to last digit presented and the participant entered "2" for #6 slot) or (b) the correct response to the slot either before or after the entered slot (e.g., If "2" was the 6th to last digit presented and the participant entered "2" for #5 slot). This scoring method seems to reflect a more accurate measure of storage capacity than only counting responses as correct if they were in exactly the right slot. For example, if the last sixth digits presented were "6, 2, 3, 7, 9, 5" and the participant's responses were "2, 3, 7, 9, 1, 5" then the participant would receive 5 points rather than only 1 point. In this example, a score of 5 presumably more accurately reflects the amount of information that the participant retained in working memory than a score of only 1.

Prepotent Response Inhibition: Stroop Task: In this task (Stroop, 1935), participants first practiced the color-response mappings for 64 trials, as they saw a row of "X"s in either red, green, blue or yellow on the computer screen and then pressed the corresponding key for that color (red = 1, green = 2, blue = 9, yellow = 0). Then, participants completed 7 blocks of 33 trials each in which they saw a word printed in color and were told to respond to the color. In order to increase prepotent response inhibition demands (Carter et al., 2000; Kane & Engle, 2003), most trials (> 72%) were congruent trials in which the color and word matched, which increased the need to maintain the goal in order to respond correctly for the infrequent incongruent trials. Based on models of prepotent response inhibition on the Stroop task, it is expected that poorer prepotent response inhibition would have the same qualitative effect on Stroop facilitation and interference (Cohen, Dunbar, & McClelland, 1990). Thus, we calculated the Stroop effect by subtracting congruent trials from incongruent trial, which combines both interference and facilitation effects. In addition, pilot testing equated the length of the Stroop and RMS tasks, with each task taking approximately 6 minutes to complete.

Procedure—After informed consent was obtained, participants were randomly assigned to the positive mood group or the neutral mood group. Participants from both groups completed an initial mood measure and then viewed a 10-minute video clip. After viewing the clip, participants completed the mood measure for a second time, and then completed either the working memory storage or the goal maintenance task, with task order counterbalanced across participants. Then, in order to provide a mood booster to ensure that participants were still in either a positive or neutral mood, participants viewed the second 5-minute movie clip. After watching the clip, they completed the mood measure a third time, followed by completing the other cognitive control task (i.e., the one yet to be completed). All measures and tasks were administered through E-prime software (Psychology Software Tools, 2006).

Results and Discussion

Mood manipulation—Positive mood ratings were examined in a 2 (neutral vs. positive mood group) × 3 (mood ratings collected at Time 1-3) repeated measures ANOVA. Current positive mood was calculated as the sum score of ratings of the positive mood words. As seen in Table 1, there was a main effect for mood group, $F(1, 175) = 10.82$, $p < .001$, and time, $F(2, 175) = 29.20$, $p < .001$, and a significant interaction between mood group and time, $F(2, 175) = 17.46$, $p < .001$. Planned post-hoc comparisons revealed the groups did not differ significantly in positive mood ratings at Time 1, $t(178) < 1$, $p = .73$, $d = .05$. In contrast, the groups differed significantly at Time 2, $t(178) = 4.99$, $p < .001$, $d = .75$, and Time 3, $t(177) = 2.53$, $p = .012$, $d = .38$. These results suggest that the mood induction induced a positive mood in the positive mood group after both mood inductions.

Cognitive control task performance—It was hypothesized that positive mood would impair both working memory storage capacity and prepotent response inhibition. As can be seen in Table 2, people in the positive mood group did significantly worse on the RMS than people in the neutral group, $t(178)= 2.14$, $p < .05$, $d = .32$, but there was no differences between the groups in the Stroop effect for error rates, $t(178) < 1$, $p = .33$, $d = -0.15$ or reaction times, $t(178) < 1$, $p = .75$, $d = -0.05$ (and, if anything, the positive mood group tended to have a smaller Stroop effect for both errors and reaction times). Thus, the hypothesis that positive mood would impair storage capacity was supported, but the hypothesis that positive mood would impair prepotent response inhibition was not supported.

Because positive mood ratings were lower after the positive mood booster than at baseline, we performed a secondary analysis on the task data only using performance after the initial mood induction. The results revealed the same pattern—the positive mood group performed significantly worse on the running span task, $t(174) = 2.14$, $p < .05$, but there were no differences between the groups on the Stroop task, $t(173) = 0.54$, $p = .59$.

Study Two

In Study 1, we found that the positive mood group had significantly worse performance than the neutral group on the RMS task. Thus, in Study 1, the hypothesis that positive mood would impair working memory was supported. In Study 2, we wanted to replicate this finding to further our understanding of the effect of positive mood on storage capacity.

In contrast, the hypothesis in Study 1 that positive mood would impair prepotent response inhibition was not supported. We did not find that people in the positive mood group did worse on a measure of prepotent response inhibition performance, the Stroop, than people in the neutral mood group. This result is inconsistent with one previous between-subjects study that reported a trend for positive mood to impair performance on the classic Stroop task (Phillips, Bull et al., 2002). However, our current Study 1 had a much larger sample size than this previous study (180 vs. 36). In addition to the Stroop, one previous study also reported that positive mood impaired performance on another prepotent response inhibition task, the Eriksen Flanker task (Rowe et al., 2007). Hence, in Study 2 we examined whether positive mood would have a significant effect on the Flanker task. At the same time, previous research has not distinguished between the effect of positive mood on different aspects of interference on the Flanker task. Importantly, response conflict on the Flanker task is thought to be most strongly related to cognitive control (Friedman & Miyake, 2004; van Veen et al., 2001). In Study 2, we examined whether positive mood would have an effect specifically on prepotent response inhibition. In addition, following the procedure of Rowe et al., we manipulated positive and neutral moods using a within-subject design. While in both the positive and neutral mood conditions, participants completed two cognitive control tasks, the RMS and Flanker tasks.

Method

Participants—One hundred four participants (59% female, 85% Caucasian, mean age 18.7 years) were recruited from a large, midwestern university. They received course credit for participating. Participants were randomly assigned to first receive the positive or the neutral mood induction.

Measures

Demographic questionnaire: Participants provided information regarding their age, sex, race/ethnicity, and year in school.

Mood measure: To assess their mood, participants were shown 8 positively and negatively valenced words with both high and low arousal levels and asked how they feel using a 5-point scale (1 – not at all to 5 – very strongly).

Materials

Mood induction: We utilized the same videos as in Study 1, but their length was shortened from 10 minutes to 6 minutes in order to maintain the 1-hour study limit. Because of the experimental program crashing, some participants were missing complete mood data after either (a) the first positive or neutral video or (b) after the second positive or neutral video.

Working Memory Storage: Running Span Task: This task was identical to the one described in Study 1. Fourteen people, 7 people assigned to be in the positive mood condition first and 7 people assigned to be in the neutral condition first, did not complete the RMS task in both the positive and neutral mood conditions because of (a) a computer problem in presenting sounds, or (b) the experiment computer program crashing. Thus, we only report data for participants with RMS task scores from both conditions (n = 90).

Prepotent Response Inhibition: Flanker Task: This task was based on the one designed by Eriksen and Eriksen (1974). Previous research has suggested that this task involves prepotent response inhibition (Friedman & Miyake, 2004). Participants saw a row of 5 letters on the center of the computer screen. The center target letter was flanked by compatible or incompatible letters (e.g., HHSHH). Participants were told to press the “1” key if the target letter was an “H” or “K” and to press the “2” key if it target letter was an “S” or “C.” The intertrial interval was 500ms and the stimuli remained on the screen until a response was recorded. Participants completed 3 blocks of 48 trials. A third of the trials were compatible trials. Another third of the trials were “stimulus” incompatible in which the target and flankers were associated with the same response (e.g., SSCSS), and the last third were “response” incompatible trials in which the target and flankers were associated with different responses (e.g., HHCHH). Reaction time is typically slower for targets flanked by incompatible compared to compatible letters, which is referred to as "flanker interference." We calculated flanker interference in two different ways to assess whether positive mood had an effect specifically on prepotent response inhibition (Bunge et al., 2002; Hazeltine et al., 2000; Rowe et al., 2007; van Veen, Cohen, Botvinick, Stenger & Carter, 2001). First, the "prepotent response inhibition" was calculated as the difference between response incompatible and stimulus incompatible trials in errors and reaction times. This measure focuses specifically on prepotent response conflict, which is thought to involve cognitive control mechanisms (Friedman & Miyake, 2004; van Veen et al., 2001). Second, the "visual focus of attention effect" was calculated as the difference between response incompatible and compatible trials. This measure combines response conflict with stimulus conflict and is consistent with how it was measured in one previous study that examined the influence of positive mood on Flanker task performance (Rowe et al., 2007). The task took approximately 6 minutes to complete.

Procedure—Mood was manipulated in a within-groups design. After informed consent was obtained, participants were randomly assigned to first receive either the positive or neutral mood condition. Participants from both groups completed an initial mood measure and then viewed a 6-minute video clip. After viewing the clip, participants completed the mood measure a second time, and then completed either the prepotent response inhibition or the working memory storage task, with task order counterbalanced across participants. Then, in order to provide a mood booster to ensure that participants were still in either a positive or neutral mood, participants viewed the second 5-minute movie clip and then completed the mood measure a third time, followed by completing the other cognitive control task. Participants then completed the same procedure in the other mood condition (e.g., if they initially had been in the neutral mood condition, they would then complete the same procedure in the positive mood condition). After the last cognitive task, participants completed the demographic questionnaire. All measures and tasks were administered through E-prime software (Psychology Software Tools, 2006). From the consenting to the debriefing processes, the study lasted about 1 hour.

Results and Discussion

Mood manipulation—First, we examined whether the mood induction increased positive mood. As can be seen in Table 3, the mood manipulation was successful. Paired t-tests revealed that positive mood ratings were significantly higher after watching the positive mood induction than after the neutral mood induction, $t(99) = 4.82$, $p < .001$, $d = .48$. Also, paired t-tests revealed that positive mood ratings were significantly higher after watching the positive mood booster than after the neutral mood booster, $t(93) = 7.43$, $p < .001$, $d = .77$.

Cognitive control task performance—As can be seen in Table 4, participants' performance on the RMS differed by mood condition. Participants' storage capacity was significantly smaller in the positive mood condition compared to the neutral mood condition, $t(89) = 2.58$, $p = .011$, $d = .27$. Thus, as in Study 1, the positive mood induction resulted in impaired working memory.

Next, we examined whether positive mood had an effect on the prepotent response inhibition effect. There were no significant differences between the positive and neutral mood conditions, for either percent errors, $t(103) < 1$, $p = 0.92$, $d = .01$, or reaction times, $t(103) = 1.04$, $p = 0.30$, $d = .10$. Hence, positive mood did not appear to significantly influence prepotent response inhibition. In addition, there was not a significant difference between the positive and neutral mood conditions for percent errors, $t(103) < 1$, $p = 0.65$, $d = .04$, or for reaction times, $t(103) = 1.68$, $p = 0.10$, $d = .16$, for the visual focus of attention effect.

General Discussion

The major goal of the current research was to examine the specific influence of positive mood on different aspects of cognitive control. Previous research has found that positive mood can have differential effects on cognition, and the current studies examined whether positive mood had differential effects on facets of cognitive control.

Evidence from the current research suggests that positive mood impairs storage capacity. Individuals recalled fewer digits on the RMS task in the positive mood condition compared to the neutral mood condition. This effect was found in two studies using either a between or a within-subject design. The finding that positive mood impairs storage capacity is generally consistent with those of Spies et al. (1996), who reported a trend for the positive mood group to perform less well than the neutral mood group on a word span task while carrying out articulatory suppression. The current finding also seems consistent with reports that positive mood impairs the ability to plan (Oaksford et al., 1996; Phillips, Smith et al., 2002), given the possible contribution of working memory storage and the maintenance of multiple pieces of information to planning (Wiener, Ehbauer, & Mallot, 2009). At the same time, the current research is complementary to research by Klein and Boals (2001) who reported that expressive writing about a negative event resulted in both long-term decreases in intrusive thoughts and improved performance on complex working memory capacity tasks. However, they did not examine the immediate effects of positive mood on working memory storage capacity. In contrast, the current research found that current positive mood results in poorer performance on a working memory storage task.

One possible explanation for poorer verbal WM is increased emotional arousal, which could disrupt right parietal lobe functioning (Heller, Nitschke, Etienne, & Miller, 1997). However, other research suggests that emotional arousal alone does not impair verbal WM (Shackman et al., 2006). Future research could examine whether positive mood's influence on working memory storage is related to an effect of positive mood on parietal lobe functioning.

Another possible explanation for why positive mood impairs storage capacity is that positive mood might increase the spread of activation of items in working memory, which could then decrease the ability to store information in the focus of attention. Positive mood has been associated with increased spreading activation in the context of semantic priming (e.g., Hänze & Meyer, 1998; Storbeck & Clore, 2008). Thus, if the spread of activation becomes more diffuse in a positive mood, it may be more difficult to retain items above a threshold level of activation in a working memory buffer (Davelaar et al., 2005), which may lead to impaired performance on the RMS task. This explanation might depend on whether working memory storage involves an activation-based storage mechanism that might be susceptible to increased spreading activation rather than a fixed slot storage mechanism (Davelaar et al., 2005). This suggests that future research on how positive mood influences working memory storage could help us to further understand mechanisms involved in working memory storage capacity.

In the current research, we investigated the effect of positive mood on verbal working memory storage capacity and found that positive mood had an effect on verbal working memory. However, it is possible that the effect of positive mood on storage capacity may vary by the type of stimuli used (Gray, 2001; Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric, & Davidson, 2006). For example, Shackman et al. (2006) reported that negative mood, induced by threat of a shock, hindered performance on a spatial N-back task but had no effect on a verbal N-back task. Therefore, based on these results, it appears that verbal and spatial working memory might be differentially affected by positive and negative mood. In contrast, Gray (2001) reported approach/pleasant stimuli facilitated performance on a verbal 2-back version of the N-back task, but withdrawal/unpleasant stimuli helped performance on a spatial 2-back version of the N-back task (also see Gray, Braver, & Raichle, 2002). Hence, the results of Gray (2001) are inconsistent with both the current finding that positive mood impaired the ability to store verbal material and with the findings of Shackman et al. (2006) that negative mood impaired spatial working memory.

There appear, however, to be some important differences between the RMS task used in the current research and the N-back task used by Gray (2001). For example, the RMS task has been strongly associated with other working memory capacity tasks (Cowan et al., 2005). However, some evidence suggests that the N-back is only weakly correlated with the operation span working memory capacity task (Kane, Conway, Miura, & Colflesh, 2007). At the same time, in contrast to the RMS task, N-back tasks are more computationally complex, requiring updating and controlled attention. Consistent with this, the N-Back task is associated with more diffuse brain activity than working memory storage tasks. In particular, N-Back tasks activate frontal regions (Braver et al., 2007; Braver & Cohen, 2000; O'Reilly, 2006) whereas working memory storage tasks are associated with activation primarily in parietal regions (Braver et al., 2007; Postle, 2006; Postle, Berger, & D'Esposito, 1999; Todd & Marois, 2005). In addition, there is evidence that positive affect might be specifically related to left frontal lobe activity (Davidson, 2000). Therefore, it is possible that differences between the cognitive processes and brain regions involved in the RMS and N-Back tasks can account for the difference in results between the current research and previous research by Gray and colleagues. One issue for future research is to continue to examine how specific cognitive control mechanisms involved in processing of different types of stimuli are influenced by positive and negative mood.

The finding that positive mood impairs working memory storage capacity has possible implications for academic performance. When in a positive mood state and given an oral examination, instructions, or lecture notes, students' ability to store that information in working memory could be impaired. For example, there is evidence that individuals with attention deficit hyperactivity disorder and bipolar disorder have deficits in working memory and problems with emotion regulation (Barkley, 1997; Sweeney, Kmiec, & Kupfer, 2000).

In contrast to working memory, evidence from the current research suggests that positive mood did not impair prepotent response inhibition. In two studies, there were no differences between the positive and neutral mood conditions on two prepotent response inhibition tasks, the Stroop and Flanker. Strong evidence suggests both tasks involve prepotent response inhibition (e.g., Friedman & Miyake, 2004). Therefore, the current study suggests that positive mood may not have an effect on prepotent response inhibition.

The current finding that positive mood did not impair prepotent response inhibition is divergent from the results of Rowe et al. (2007). With a somewhat small sample size (n = 24), Rowe and colleagues reported that positive mood was associated with greater Flanker inference compared to neutral and sad mood. However, in that study, Flanker interference was measured as a combination of stimulus and response interference, whereas it has been argued that perhaps response interference is most strongly related to cognitive control (van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). In the current study with a much larger sample size, we differentiated between response and stimulus interference and found no differences between the positive and neutral mood conditions. However, it is also possible to view the current research as consistent with the results of Rowe et al. (2007) in supporting an influence of positive mood on the visual scope of attention. In Study 2, when using a measure of Flanker interference similar to the one used by Rowe et al. (i.e. the ‘visual focus of attention effect,’ calculated as the difference between response incompatible and compatible trials), we found a trend for increased interference with positive mood. As suggested by Rowe et al. (2007), positive mood might increase the visual scope of attention, making participants more susceptible to visually presented distracters. This might increase interference to all types of visual distracters on the flanker task, whether the distracters involve stimulus or response conflict. An increased visual scope of attention effect after positive mood might reflect a different mechanism than preponent response inhibition. For example, for the Stroop task in Study 1, which does not involve needing to filter out spatially peripheral distracters, positive mood did not result in increased interference. Hence, the current research suggests that positive mood might increase the visual scope of attention but not impair prepotent response inhibition.

Results from the current study also might be divergent from the results of Phillips, Bull et al. (2002). Like our Study 1, Phillips and colleagues reported there were no significant differences in reaction time or errors between the positive and neutral mood groups in the standard Stroop task, but at least in that study there was a trend for a difference. However, our current Study 1 had a much larger sample size than this previous between-subjects study (180 vs. 36). At the same time, in a separate study, Phillips et al found that a positive mood group did worse on a version of the Stroop task that involved alternating, or switching, between reading the word and naming the color of the word. Thus, given other research that positive affect is associated with increased distractibility (Dreisbach & Goschke, 2004), it is possible positive mood is related to some aspect of controlled attention related to alternating task set and not necessarily prepotent response inhibition.

Research examining the influence of positive mood on tasks that particularly require prepotent response inhibition has in part been motivated by the view that positive mood can influence D2 receptor activation (Dreisbach, 2006). This activation is thought to be associated with destabilizing goal representations (Cohen, Braver, & Brown, 2002; O'Reilly, 2006), with any effect of positive mood on goal maintenance thought to be mediated by D2 receptor activation (Dreisbach & Goschke, 2004). The current lack of evidence for an influence of positive mood on prepotent response inhibition does not necessarily imply that D2 receptor activation does not influence prepotent response inhibition. Instead, perhaps positive mood is only somewhat associated with prefrontal cortex D2 receptor activity (O'Reilly, 2006). Future research could manipulate dopamine and D2 receptors directly using pharmacological manipulations (Frank & O'Reilly, 2006) to specifically investigate the effect of dopamine on prepotent response inhibition and goal maintenance. In addition, future research using the Stroop task could examine whether positive mood could have distinct effects on Stroop interference versus Stroop facilitation.

Overall, the current research suggests that positive mood has differential effects on cognitive control, impairing working memory but having no effect on prepotent response inhibition. Also, this research suggests that positive mood might increase the visual scope of attention. These results have implications for the possible effects of positive mood on parietal cortex and prefrontal cortex D2 receptor activity

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Table 1

Study 1 Means and Standard Deviations of Positive Mood Ratings

	Positive mood group	Neutral mood group
Time 1 (baseline)	23.16 (4.5)[a]	22.92 (4.70)[b]
Time 2 (after mood induction)	25.22 (4.92)[c]**	21.28 (5.61)[d]
Time 3 (after mood booster)	22.56 (5.64)[c]*	20.07 (7.35)[e]

* $p \leq .01$

** $p < .001$ (comparisons between mood ratings at each time point)

[a] n = 86,

[b] n = 93,

[c] n = 87,

[d] n = 92,

[e] n = 91

Table 2

Study 1 Means and Standard Deviations Cognitive Control Task Performance

	Positive mood group [a]	**Neutral mood group**[b]
	M (SD)	**M (SD)**
Running Memory Span		
Storage capacity (per trial)	3.71 (0.81)*	3.94 (0.62)
Stroop		
Percent error (PE)		
Congruent PE	6.66 (6.61)	5.17 (5.22)
Incongruent PE	8.25 (6.06)	7.61 (5.49)
Stroop effect PE	1.59 (6.97)	2.44 (4.49)
Reaction time (RT)		
Congruent RT	724.22 (119.62)	744.46 (120.04)
Incongruent RT	935.79 (176.88)	961.12 (185.36)
Stroop effect RT	211.57 (99.38)	216.67 (112.41)

* $p < .01$, indicates significant difference between positive and neutral mood groups

[a] n = 87,

[b] n = 93

Table 3

Study 2 Means and Standard Deviations of Positive Mood Ratings

Baseline	9.22 (2.23) [a]
After positive mood induction	11.13 (3.28) [a]*
After positive mood booster	10.78 (3.24) [a]*
After neutral mood induction	9.07 (3.31) [b]
After neutral mood booster	8.39 (3.20) [b]

*$p < .001$ (compared to neutral mood induction and booster)

[a] n = 100,

[b] n = 94

Table 4
Study 2 Means and Standard Deviations Cognitive Control Task Performance

	Mood Condition	
	Positive	**Neutral**
	M (SD)	**M (SD)**
Running Memory Span Task[a]		
Storage capacity (per trial)	3.80 (0.74)*	3.95 (0.79)
Flanker Task[b]		
Condition percent errors (PE)		
Compatible PE	3.13 (3.20)	3.48 (3.41)
Incompatible PE	5.08 (3.73)	5.08 (4.11)
Stimulus incompatible PE	2.76 (2.99)	2.88 (3.18)
Response incompatible PE	7.52 (6.38)	7.56 (5.87)
Effects for PE		
Visual focus of attention effect	4.39 (5.77)	4.09 (5.61)
Prepotent response inhibition effect	4.76 (5.63)	4.70 (5.30)
Condition reaction times (RT)		
Compatible RT	497.0 (77.28)	504.0 (88.70)
Incompatible RT	546.58 (75.61)	546.31 (79.95)
Stimulus incompatible RT	524.94 (77.44)	526.92 (85.50)
Response incompatible RT	570.37 (76.69)	567.56 (84.82)
Flanker effect RT		
Visual focus of attention effect	73.36 (41.61)	63.56 (43.33)
Prepotent response inhibition effect	45.43 (38.65)	40.65 (39.96)

* p = 0.011, indicates significant difference between positive and neutral mood groups

[a] n = 90,

[b] n = 104