Memory & Cognition (2022) 50:911–924
https://doi.org/10.3758/s13421-021-01257-z

# Stimuli with a positive valence can facilitate cognitive control

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Accepted: 4 November 2021 / Published online: 18 November 2021


**Abstract**

In the process of interacting with people and objects, humans assign affective valence. By using an association-transfer paradigm, the current study investigated whether the emotion associated with a stimulus would have an impact on cognitive control outcomes. During the association phase of two experiments reported here, participants identified the emotion expressed by an actor's face as either positive (i.e., smiling) or negative (i.e., frowning). Half of the actors expressed positive emotions (MP) on 80% of trials, while the other half expressed negative emotions (MN) on 80% of trials. We tested the cognitive effect of these associations in two experiments. In the transfer phase of Experiment 1, the same actors from the association phase were shown with neutral expression during a gender Stroop task, requiring participants to identify the gender of the face while ignoring a gender word (congruent or incongruent) that was imposed upon the face. The Stroop effect was significant for the MN faces, but the effect disappeared for the MP faces. In the transfer phase of Experiment 2, the emotionless faces were presented in a task-switching paradigm, in which participants identified the age (i.e., old or young) or the gender depending on the task cue. The task switch cost was smaller (though significant) for the MP faces than for the MN faces. These results suggest that, relative to social stimuli associated with negative expressions, social stimuli associated with positive expressions can promote better cognitive control and inhibit distractor interference in goal-oriented behavior.

**Keywords** Cognitive control · Positive emotion · Emotion perception

## Introduction

Valence perception is a critical component of our daily life. Correctly identifying whether a person, object, or event is positive or negative in affective quality is essential to the human experience. The emotion of others or the emotional implication of a target stimulus is not only critical in determining the best immediate response, such as "approach or avoid" or "fight or flight," but also in calculating appropriate future responses. One interesting aspect of valence perception is that a stimulus (e.g., an object or a person) can hold a specific emotional valence even in the absence of present emotional content, like a smile or frown (De Houwer et al., 2001). The prior emotional episodes associated with a stimulus can play just as important a role as the currently expressed emotion. For example, people who suffer from a traumatic event sometimes later display maladaptive behavior toward neutral objects or people because of associations with an extremely negative situation. In contrast, commercial advertisements exploit the association between a product and positive emotion (e.g., a happy family at McDonald's). Clearly, an emotionally valenced association can have different consequences depending on whether it is positive or negative (Stuart et al., 1987).

In the present study, we examined how the associated valence of a human face influences cognitive control ability with respect to that stimulus. Cognitive control, sometimes referred to as executive functioning, is a set of processes responsible for selecting task-relevant target information and filtering out task-irrelevant distractor information in pursuit of a goal. This goal-oriented behavior is supported by two complementary cognitive modes: goal maintenance and goal

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shifting. Goal maintenance refers to the ability to establish and maintain a task set, so that goal-directed behaviors can be executed despite interference from conflicting alternative behaviors (Sakai, 2008). For example, in the color Stroop task, participants name the ink color in which a color word is written. Therefore, the best performance is attained by maintaining attentional focus on ink color and ignoring the word. In contrast, goal shifting refers to the ability to override a previous task set in order to perform a different task when multiple tasks are performed in sequence (Robbins, 2007). For example, in a task-switching paradigm, participants perform two distinct tasks (e.g., separate sets of stimulus-response mapping rules). Therefore, the best performance can be achieved by flexibly shifting task goals. While it is beyond the scope of the current study to determine the exact relationship between cognitive stability (i.e., goal maintenance) and cognitive flexibility (i.e., goal shifting), the present research examines how they are influenced by the emotional valence associated with the target stimulus.

Our main interest is the effect of the associated emotion, which requires exposure to the stimulus-emotion association for an extended amount of time. However, most of the previous studies have examined the immediate effect of emotion, such as how the processing of one emotional stimulus affects cognitive control on a subsequent trial (for a review, see Zinchenko et al., 2020). Typically, emotional stimuli are more salient than neutral stimuli and therefore attract attention more readily (Pilarczyk & Kuniecki, 2014; Straub et al., 2020). For this reason, many studies have contrasted the performance between negative/positive and neutral emotion conditions. For example, in a series of studies, Kanske and Kotz have demonstrated that task-irrelevant positive emotion stimuli, in comparison with task-irrelevant neutral stimuli, can reduce cognitive conflict markers such as the flanker effect (Kanske & Kotz, 2011c) and the Simon effect (Kanske & Kotz, 2012). Kanske and Kotz, however, also reported that a negative emotion stimulus can reduce the flanker effect (Kanske & Kotz, 2010, 2011a) and the Simon effect (Kanske & Kotz, 2011b) in comparison with a neutral emotion stimulus. It is clear that the presence of emotional content has an influence on cognitive measures.

Because both positive and negative emotional stimuli may heighten focus and facilitate cognitive performance, a more direct comparison is necessary to examine whether positive and negative valence have different effects on cognitive control. Using an emotion version of the Simon task, Schlaghecken et al. (2017) asked participants to respond to the emotion of a face (happy or sad) presented on either the left or the right side of the screen by responding with their left or right hand. In the Simon task, participants produce a spatial response to a non-spatial stimulus presented in a location that is either congruent or incongruent with the response location. Schlaghecken et al. found significantly smaller Simon effects for negative faces than for positive faces. In a very similar experimental setup, Lien et al. (2020) also demonstrated that the Simon effect was significantly smaller for negative faces than for positive faces. That is, when responding to a negative stimulus, the interference from the stimulus location was smaller than when responding to a positive stimulus, implying that cognitive control may be facilitated when the stimulus is associated with negative valence.

Yamaguchi et al. (2018) also utilized an emotion Simon task that asked participants to respond with a joystick. They examined the effect of emotional valence on approach/avoidance task performance. In their third experiment, participants responded to a positive stimulus (e.g., flowers) or a negative stimulus (e.g., spiders) by moving the joystick to the left or right. As the stimulus was also presented either on the left or the right location, this design inherently created an approach response to the compatible stimulus and an avoidance response to the incompatible stimulus, regardless of the valence. A positive stimulus typically elicits an approach response, while a negative stimulus elicits an avoidance response. Therefore, the compatible-incompatible nature of the Simon task amplifies the approach tendency when the stimulus is positive, possibly augmenting the Simon effect. However, with a negative stimulus, the compatible-incompatible stimulus location is against the avoidance tendency, diminishing the Simon effect. Yamaguchi et al. observed exactly this pattern of results: a smaller Simon effect with negative stimuli than with positive stimuli. Altogether, these results support the notion that a stimulus eliciting negative emotion can be handled with more cognitive control.

While such studies adopting the interference paradigm provide evidence for more efficient cognitive control with negative emotion, attentional set-switching studies have provided a different perspective. Several studies have shown that positive, as compared with negative, valence improves cognitive flexibility (Dreisbach & Goschke., 2004; Wang et al., 2017; Yang & Yang., 2014). Wang et al. (2017) adopted a set-switching paradigm in which participants maintained the same attentional set (e.g., performing the designated task on a red target while ignoring the blue distractor) over a certain number of trials, and then either kept the same attentional set or switched to a different attentional set. In their results, the cost of shifting the attentional set was substantially reduced when the task was accompanied by a photograph of a positive scene as opposed to a negative scene. Further, adopting the task-switching paradigm, in which participants performed two tasks with distinct stimulus-response mapping rules (e.g., categorizing stimuli by color or by shape), Yang and Yang (2014) observed that the task switch cost was substantially smaller when a positive rather than a neutral mood was induced. These results suggest that positive emotion facilitates flexible deployment of cognitive control.

It should be noted that there are a number of differences between the above-mentioned studies with different implications regarding the relationship between emotion and cognitive performance. For example, in the interference paradigm studies, the emotion changed on a trial-by-trial basis, resulting in a phasic effect of emotion. However, in the switching studies, the emotion was induced and maintained over a block of trials, resulting in a tonic effect of emotion. Also, in many previous studies with the interference paradigm, participants directly responded to the emotional content of the target stimulus. That is, the emotion was the relevant target dimension. However, in the studies with the task-switching paradigm, participants responded to a non-emotional target stimulus, rendering the induced emotion irrelevant to the task. Further, differences in stimulus domain to manipulate emotional status (e.g., schematic faces, emotional scenes, and inducing positive emotion with a surprise gift) make it difficult to draw a strong conclusion from the previous studies.

More critically, the studies mentioned above examined the effects of emotion on different types of cognitive control. For example, the studies that demonstrated better cognitive control with negative emotion adopted the interference paradigm, in which the stability of cognitive control is emphasized more. Efficiency during the Simon task can be best achieved by persistently maintaining the goal of responding to the non-spatial target while filtering out the spatial distractor. In contrast, the switching studies that demonstrated better cognitive control with positive emotion emphasized the flexibility of cognitive control. The switch cost can be minimized when participants do not perseverate on the previous task when they need to switch to a different task. Therefore, one may argue that the previous studies imply that negative emotion is more effective for cognitive stability, but that positive emotion is more effective for cognitive flexibility. However, the emotional impact on cognitive flexibility and cognitive stability have been studied separately. Consequently, these studies inevitably adopted different styles of manipulating the emotion factor, which further undermines the direct comparison between the two camps of literature. Therefore, we aim to directly compare the effects of positive and negative emotions on cognitive control in one study.

Another difference of the current study from the previous literature is that we are interested in the effect of an already established emotional valence toward a stimulus, rather than the immediate effect of emotion on cognitive control. While the associated effect of emotion on cognitive control has received very little attention to date, Tae et al. (2021) examined the effect of associated cognitive control on emotion, which is the opposite direction of our interest. Adopting an association-transfer paradigm, Tae et al. investigated how stimuli would be perceived emotionally, when the stimuli are associated with either a high level of cognitive control or a low level of cognitive control. In the association phase of Experiment 1 of Tae et al., participants performed the gender Stroop task with some actors appearing more frequently in the congruent condition (i.e., low cognitive control) and other actors more frequently in the incongruent condition (i.e., high cognitive control). In the transfer phase, participants performed the emotion recognition task with the same actors from the association phase, now expressing either positive or negative emotion. Tae et al.'s (2021) results show that the actors associated with high cognitive control were responded to faster when they expressed positive emotion than when they expressed negative emotion. The stimuli in the low cognitive control condition did not show such an effect, suggesting that the stimulus associated with a high level of control can be perceived as positive.

Further, in the association phase of Experiment 2 in Tae et al. (2021), cognitive control was manipulated by associating either frequent task switching or frequent task repetition with specific actors. Some actors appeared more frequently when the current task was different from the previous one (i.e., high level of control), while others more frequently appeared for repeating the same task (i.e., low level of control). The transfer results for this experiment also showed that, for the actors associated with high cognitive control, positive emotion was recognized faster than negative emotion. The actors associated with low cognitive control did not show such an effect. These results are consistent with the notion that successful conflict resolution can be more positive than negative (Ivanchei et al., 2019; Schouppe et al., 2015). Based on Tae et al.'s results, we can infer that, if the high cognitive control results in more positive than negative emotion, it is reasonable to expect that positive emotion should in turn promote cognitive control. We tested this implication using the same association-transfer paradigm but flipping the components of each phase: we begin with emotion association and then test the transfer to cognitive performance. In addition, to maintain the continuity from Tae et al.'s study, we adopted the gender Stroop task to examine cognitive stability rather than the Simon task utilized in many previous studies.

In sum, the aim of the current study was twofold. First, we investigated the effect of emotion on two different types of cognitive control (i.e., stability and flexibility) in one study, using the same manipulation of emotion processing. Second, we investigated the effect of already established emotion, rather than its immediate effect, using an association-transfer paradigm. In the association phase of two experiments reported here, participants performed an emotion recognition task with stimuli associated with either negative or positive emotion. Half of the actors frequently displayed a positive (i.e., happy) emotion and the other half frequently displayed a negative (i.e., angry) emotion. Then, in the transfer phase, with the emotionless faces of the same actors from the association phase, participants completed a gender Stroop task in Experiment 1, or task switching between an age task (i.e., to judge a face as old or young) and a gender task (i.e., to judge a face as male or female) in Experiment 2.

The previous literature leads to several hypotheses. For example, some studies (e.g., Schlaghecken et al., 2017; Yamaguchi et al., 2018) suggest that negative valence promotes cognitive stability. Thus, one would expect that the Stroop effect in Experiment 1 will be smaller for the faces that are associated with negative valence than positive valence. Other previous studies (e.g., Wang et al., 2017; Yang & Yang., 2014) suggest that positive valence promotes cognitive flexibility. Therefore, one would expect that the task-switch cost in Experiment 2 will be smaller for the faces associated with positive valence than the faces associated with negative valence. Further, yet another group of studies (e.g., Ivanchei et al., 2019; Schouppe et al., 2015; Tae et al., 2021) suggest that a high level of cognitive control favors positive rather than negative emotion. Then, one would expect that positive emotion may in turn facilitate cognitive control. The current study, therefore, provides an opportunity to investigate whether the cognitive control facilitated by positive emotion can be generalized to both cognitive stability in the Stroop task (Experiment 1) and cognitive flexibility in task switching (Experiment 2).

## Experiment 1

Experiment 1 tested whether stimulus-specific positivity and stimulus-specific negativity have different effects on cognitive performance during a task that requires cognitive stability. The association phase is intended to expose participants to associations between actors' faces and either positive or negative emotion, and the transfer phase tests how participants' cognitive control performance differs for the same faces (but with neutral expression) depending on this learned association (positive or negative). In the association phase of Experiment 1, participants performed an emotion recognition task. Half of the actors displayed a positive emotion (e.g., happy) on 80% of the trials they appeared in, the mostly positive (MP) condition. The other half displayed a negative emotion (e.g., angry) on 80% of the trials they appeared in, the mostly negative (MN) condition. During the transfer phase, the same actors appeared in an emotionless, neutral state, and participants performed the gender Stroop task, responding to the gender of the face while ignoring the gender word imposed upon the face. If item-specific negativity facilitates cognitive stability, the congruency effect (the difference in reaction time for congruent vs. incongruent faces) should be smaller for the MN faces than for the MP faces. However, if item-specific positivity facilitates cognitive stability, the congruency effect should be smaller for the MP faces than for the MN faces.

## Method

### Participants

In Experiment 1, we recruited 53 college students (38 females, $M_{age}$ = 20.5 years) from The George Washington University for course credit.[1] All participants had normal or corrected-to-normal vision and they provided written informed consent before participating in the experiment.

### Materials

Participants performed an emotion-recognition task for the association phase and the gender Stroop task for the transfer phase. For each task, we used face stimuli of 12 actors (six males and six females) from the Karolinska Directed Emotional Faces (KDEF, Lundqvist et al., 1998). For the emotion-recognition task, positive (i.e., happy) and negative (i.e., angry) faces of the actors were used. For the gender Stroop task, emotionless, neutral faces of the same actors were used with a superimposed gender word (i.e., "MALE," "FEMALE," "MAN," or "WOMAN"). The list of identification codes of these pictures is presented in Appendix Table 5.

### Procedure and design

In the association phase, participants were instructed to respond to the emotion of the actor as accurately and as quickly as possible. Each trial started with a fixation cross presented at the center of the screen for 500 ms, followed by a face stimulus, which was displayed until a response was made. The participants pressed "5" or "6" on the number keypad for "positive" or "negative" responses, respectively, and the response-to-key mapping was counterbalanced across participants. After the response, the screen went black for 1,000 ms until the next fixation cross appeared. There were 16 practice trials with an equal number of positive and negative trials. In the main association phase, positive and negative faces of 12 actors were presented 25 times, resulting in 600 trials presented in five blocks. In the transfer phase, the participants responded to the gender of the face as accurately and as quickly as possible, while ignoring the

[1] We conducted a sensitivity power analysis to examine whether our result provided enough power. The sensitivity analysis indicated that, with the sample size of 53, the effect size ($f$) is expected to be ≥ 0.25, which equals $\eta^2$= .06. We obtained greater effect sizes than suggested in both the association and the transfer phases.

superimposing gender word. The time course of fixation, face presentation, and black screen was identical to the association phase. Participants pressed "1" or "2" for "MALE" or "FEMALE" responses and the response-to-key mapping was counterbalanced across participants. Each congruent and incongruent stimulus of 12 actors was shown four times, and these 96 trials were presented in two blocks.

Figure 1 depicts the overall design of Experiment 1. During the association phase, while keeping the overall proportions of positive and negative faces at 50%, six actors (three males and three females) appeared with a positive expression for 40 out of 50 presentations, the mostly positive (MP) condition. The other six actors appeared with a negative expression for 40 out of 50 presentations, the mostly negative (MN) condition. The MP and MN faces were randomly intermixed during the association phase. In the transfer phase, congruent and incongruent trials were intermixed.

## Results and discussion

In Experiment 1, response time (RT) and accuracy were analyzed, for both of which practice trials were excluded. For the RT analysis, incorrect trials (2.37% of all experimental trials) and trials with RTs above 3 SDs from each participant's mean RT (1.78% of all experimental trials) were further excluded. For both association and transfer phases, the descriptive statistics are presented in Table 1, the full ANOVA results are presented in Table 2, and Fig. 2 depicts the RT results.

For the association phase, RTs and accuracies were subjected to a 2 × 2 repeated-measures ANOVA with item-specific proportion valence (Mostly Positive and Mostly Negative) and valence (Positive and Negative) as within-subject variables. For RT of the association phase, while the main effects of proportion valence and valence were not significant, *ps* $> .06$, there was a significant interaction between item-specific proportion valence and valence of the faces $F(1,52) = 14.43$, $p < .001$, $\eta_p^2 = .21$. In the MN condition, the response to negative faces ($M = 666$ ms, 95% CI [623, 710]) was faster than to positive faces ($M = 685$ ms, 95% CI [641, 729]), $t(52) = 2.47$ , $p < .05$. In the MP condition, the response to positive faces ($M = 649$ ms, 95% CI [611, 687]) was faster than to negative faces ($M = 709$ ms, 95% CI [641, 776]), $t(52) = 3.04$, $p < .01$. For the accuracy, the interaction effect was also significant, $F(1,52) = 21.75$, $p < .001$, $\eta_p^2 = .29$. While the affective priming effect was not shown in the MN condition ($M = .96$), $p > .07$, the accuracy of positive faces ($M = .97$, 95% CI [96, 98]) was higher than negative

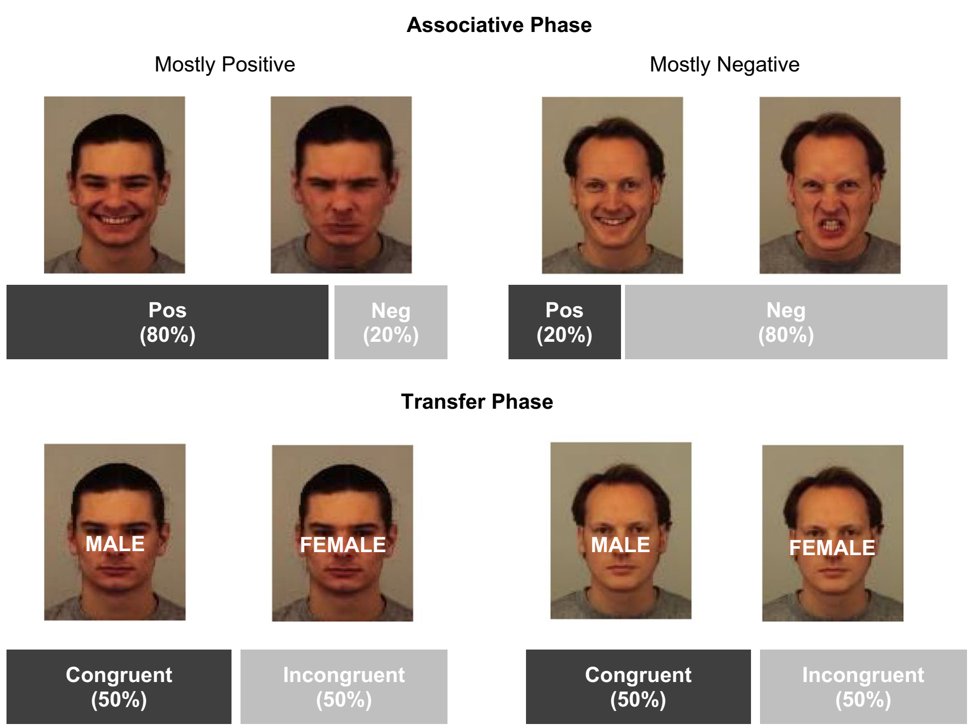


**Fig. 1** Overall design of Experiment 1. In the associative phase, positive and negative faces were presented and participants judged the emotion of the face. Some faces appeared 80% of the times in the positive (Pos) condition and other face appeared 80% of the times in the negative (Neg) condition. In the transfer phase, participants were asked to decide gender of the face while ignoring the overlapped gender word. Congruent and Incongruent stimuli were presented equally often

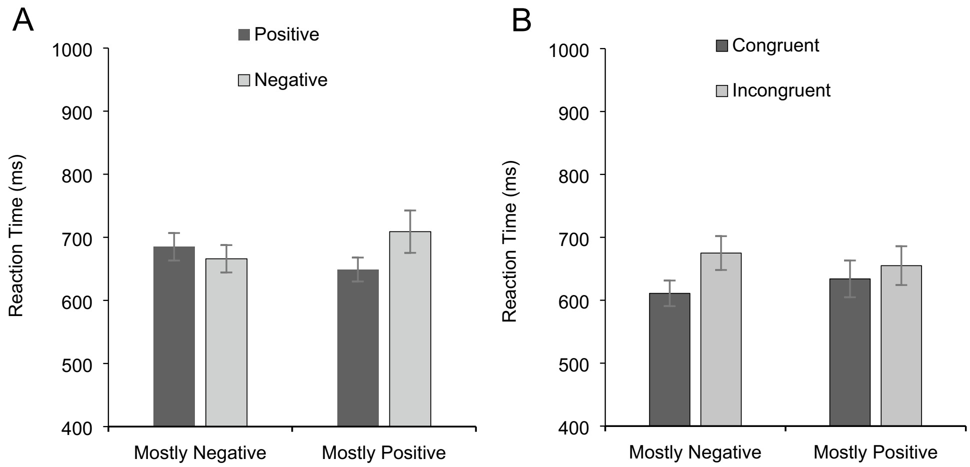


**Fig. 2** The results of Experiment 1 for each type of trial. **Panel A:** Mean reaction time for positive (dark gray bar) and negative (light gray bar) faces in associative phase. **Panel B:** Mean reaction time for congruent (dark gray bar) and incongruent (light gray bar) stimuli in transfer phase. Error bars represent standard errors

faces (*M* = .95, 95% CI [93, 96]) in the MP condition, *t*(52) = 4.27, $p < .001$. Other effects were not significant for accuracy, *ps* > .05.

For the transfer phase with the gender Stroop task, RTs and accuracies were subjected to a 2 × 2 repeated-measures ANOVA with two within-subject factors: previous item-specific proportion valence (Mostly Positive and Mostly Negative) and congruency (Congruent and Incongruent). For the response time, there was a significant congruency effect, $F(1,52) = 9.79$, $p < .005$, $\eta_p^2 = .15$, in which congruent items (*M* = 622 ms, 95% CI [576, 669]) were faster than incongruent items (*M* = 665 ms, 95% CI [609, 722]). Furthermore, the interaction between previous proportion valence and congruency was significant, $F(1,52) = 7.1$, $p < .05$, $\eta_p^2 = .12$. The congruency effect was not significant for MP items, $p > .24$. However, in the MN condition, the congruent items (*M* = 611 ms, 95% CI [570, 652]) were faster than the incongruent items (*M* = 675 ms, 95% CI [622, 729]), $t(52) = -4.65$, $p < .001$. For the accuracy data, there was a main effect of congruency, $F(1,52) = 17.61$, $p < .001$, $\eta_p^2 = .25$. The accuracy was higher for congruent stimuli (*M* = .97, 95% CI [96, 98]) than for incongruent stimuli (*M* = .94, 95% CI [93, 96]). The congruency effect was modulated by proportion valence stimulus in the association phase, $F(1,52) = 8.19$, $p < .01$, $\eta_p^2 = .13$. In the MN condition, the mean accuracy for incongruent stimuli (*M* = .94, 95% CI [92, 95]) was lower than for congruent stimuli (*M* = .98, 95% CI [96, 99]), $t(52) = -4.96$, p < .001, but the effect disappeared in the MP condition (*M* = .96), $p > .1$.

We found that the difference between congruent and incongruent stimuli disappeared in the mostly positive condition in the transfer phase, suggesting that the item-specific positive valence, as opposed to the negative valence, of the association phase facilitated target processing while filtering out the distractor. The current result is not consistent with previous studies that have found that negative valence, rather than positive valence, increases cognitive control (Lien et al., 2020; Schlaghekcen et al., 2017; Yamaguchi et al., 2018). However, it is consistent with Tae et al. (2021), who found that the high level of cognitive control can result in positive emotion. We discuss this further in the *General discussion*.

## Experiment 2

Experiment 2 tested the effect of emotion on a different type of cognitive control: goal shifting. While the congruency effect reflects the amount of cognitive control to filter out the concurrent distractor, the switch cost reflects the cognitive effort to disengage from the previous task and to engage in the current task. Identical with Experiment 1, the participants performed the emotion recognition task with positive or negative faces of eight actors from FACES (Ebner et al., 2010). Half of the actors displayed a positive emotion on 80% of the trials they appeared in, the mostly positive (MP) condition. The other half displayed a negative emotion on 80% of the trials they appeared in, the mostly negative (MN) condition. In the transfer phase, participants performed an age task (categorizing the age of the actor) and a gender task (categorizing the gender of the actor). The actors from the association phase appeared in the transfer phase with a neutral expression. The age task and the gender task were randomly intermixed, and the color of the picture frame indicated which task to perform. Therefore, the two consecutive trials may involve the same task (task repetition) or a different task (task switch). Typically, the response time is slower when switching to a different task (e.g., from the age task to the gender task) than repeating a task (e.g., from the age task to the age task). Therefore, the extent of cognitive control is measured by the reaction time difference between the switch trials and the repetition trials. If a negative emotion facilitates cognitive flexibility (i.e., switching ability), then the switch cost of the previously MN faces will be smaller than the switch cost of the previously MP faces. If a positive emotion facilitates cognitive flexibility (i.e., switching ability), however, then the switch cost of the previously MP faces will be smaller than the switch cost of the previously MN faces.

One interesting aspect of the task-switching paradigm is that it can provide an opportunity to examine the effect of trial congruency between two tasks. In Experiment 2, we asked participants to perform either the age task or the gender task with the same set of human faces. Each face is associated with a particular response category from each task (e.g., young and male, old and female), and the correct response category becomes different depending on the task. Further, we adopted two-to-one response-to-key mapping: one response category from each task was mapped to the same response key. For example, for some participants, "MALE" and "OLD" were assigned to "1" on the keypad, and "FEMALE" and "YOUNG" were assigned to "2" on the keypad. Then, old male faces and young female faces are responded to with the same key regardless of the task, therefore congruent. However, young male faces and old female faces are associated with two different response keys, and the correct response must be selected depending on the target dimension of the task (e.g., age for the age task), while ignoring the distractor dimension (e.g., gender for the age task), therefore incongruent. Because the congruency effect was modulated in Experiment 1, Experiment 2 further allows us to examine whether associated emotion modulates the congruency effect (in addition to or instead of switch cost) when the congruency is embedded in a more complex task structure.

## Method

### Participants

In Experiment 2, 38 college students (20 females, $M_{age}$ = 21.2 years) at The George Washington University participated for course credit.[2] All participants had normal or corrected-to-normal vision and they provided written informed consent before the experiment.

[2] The sensitivity analysis indicated that, with the sample size of 38, the effect size (*f*) is expected to be ≥ 0.30, which equals to $\eta^2$= .085. We obtained greater effect sizes than suggested in both the association and the transfer phases.

### Materials

Experiment 2 adopted the association-transfer paradigm used in Experiment 1. In the association phase, participants performed the emotion recognition task with positive (i.e., happy) and negative (i.e., angry) faces. We selected positive and negative faces of eight actors (two old males, two old females, two young males, and two young females) from FACES (Ebner et al., 2010). In the transfer phase, the pictures of the same actors were presented with neutral emotion. Each face was presented with one of two colored frames, communicating the task to perform. If the picture was presented with a green frame, participants judged whether the actor was young or old. If the picture was presented with a yellow frame, they judged whether the actor was male or female. The list of identification codes of these pictures is presented in Appendix Table 6.

### Procedure

In the association phase, participants were instructed to identify the emotion of the face as accurately and as quickly as possible. Each trial started with a fixation cross for 300 ms at the center of the screen, followed by a face stimulus that was displayed until a response was made. The keys "5" and "6" on the keypad were used for "positive" and "negative" responses and the response-to-key mapping was counterbalanced across participants. After the response, feedback was presented at the center of the screen for 300 ms. There were 16 practice trials with an equal proportion of positive and negative stimuli. In the main association phase, each of the eight actors appeared 120 times, resulting in 960 trials presented in eight blocks. In the transfer phase, the participants responded to the gender or age of a neutral face stimulus. The duration of each trial component was identical to the association phase. The face stimulus appeared with a green or yellow frame. One of two response keys was assigned to one response of each task. For example, "1" is assigned to "MALE" and "OLD" responses, and "2" to "FEMALE" and "YOUNG." The response grouping and the mapping between response category and key were counterbalanced across participants. Neutral, emotionless faces of the eight actors were presented 24 times, equally often for the age task and the gender task, resulting in 192 trials presented in three blocks. Because we selected the same number of actors from each category of age and gender (i.e., two actors from each of old-male, old-female, young-male, and young-female), there was an equal number of congruent and incongruent trials (i.e., 96 trials).

**Table 1** Accuracy and reaction time with standard deviation in parentheses for each condition in Experiment 1

| | Accuracy | | | |
|---|---|---|---|---|
| | Association phase | | Transfer phase | |
| | Positive | Negative | Congruent | Incongruent |
| Mostly Negative | .96 (.04) | .97 (.03) | .98 (.04) | .94 (.06) |
| Mostly Positive | .98 (.03) | .95 (.05) | .97 (.06) | .95 (.06) |
| | Reaction time | | | |
| | Association phase | | Transfer phase | |
| | Positive | Negative | Congruent | Incongruent |
| Mostly Negative | 685 (22) | 666 (22) | 611 (20) | 675 (27) |
| Mostly Positive | 649 (19) | 709 (34) | 634 (29) | 655 (31) |

During the association phase, while keeping the overall proportion of positive and negative at 50%, we manipulated the positive or negative proportion to be different at the item level. Four actors (one from each category of old male, young male, old female, and young female) appeared with a positive expression for 96 out of 120 times, the mostly positive (MP) condition. The other four actors appeared with a negative expression for 96 out of 120 times, the mostly negative (MN) condition. The MP and MN faces were randomly intermixed during the association phase. During the transfer phase, the overall proportion of task repetition and switching trials was 50%, and the proportion of congruent and incongruent trials was also 50%.

## Results and discussion

In Experiment 2, RT and accuracy were analyzed, for both of which practice trials were excluded. For RT, incorrect trials (4.53% of all experiment trials) and trials with RTs longer than 3 SDs from each participant's mean RT (1.57% of all experiment trials) were further excluded. For both association and transfer phases, the descriptive statistics are presented in Table 3, the full ANOVA results are presented in Table 4, and Fig. 3 depicts the RT results.

For the association phase, both RTs and accuracy were subjected to a two-way ANOVA with item-specific proportion valence (Mostly Positive and Mostly Negative) and valence (Positive and Negative). For RT data, participants took longer to identify the negative emotion ($M$ = 560 ms, 95% CI [539, 581]) than the positive emotion ($M$ = 552 ms, 95% CI [532, 572]), $F(1, 37) = 4.23$, $p < .05$, $\eta_p^2 = .1$. While the main effect on item-specific proportion valence was not significant, p >.95, there was a significant interaction between item-specific proportion valence and valence of the face, $F(1, 37) = 38.38$, $p < .001$, $\eta_p^2 = .5$. In the MN condition, the response to negative faces ($M$ = 549 ms, 95% CI [529, 570]) was faster than the response to positive faces ($M$ = 563 ms, 95% CI [541, 584]), $t(37) = -2.59$ , $p < .05$. In the MP condition, the response to positive faces ($M$ = 542 ms, 95% CI [522, 561]) was faster than to negative faces ($M$ = 570 ms, 95% CI [547, 594]), $t(37)$

**Table 2** Complete ANOVA results of accuracy and reaction time of Experiment 1

| Association phase | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Accuracy | | | Reaction time | | |
| Source | *df* | *F* | *p* | $\eta^2$ | *F* | *P* | $\eta^2$ |
| PV | 1, 52 | .01 | .894 | .001 | .24 | .62 | .005 |
| V | 1, 52 | 3.88 | .054 | .07 | 3.64 | .062 | .066 |
| PV x V | 1, 52 | 21.75 | .001** | .275 | 14.43 | .001** | .217 |
| Transfer phase | | | | | | | |
| | | Accuracy | | | Reaction time | | |
| Source | *df* | *F* | *p* | $\eta^2$ | *F* | *P* | $\eta^2$ |
| PV | 1, 52 | .09 | .757 | .002 | .01 | .917 | .001 |
| C | 1, 52 | 17.61 | .001** | .253 | 9.79 | .003** | .159 |
| PV x C | 1, 52 | 8.19 | .006** | .136 | 7.1 | .01* | .12 |

*Note.* *p <.05. **p<.01

*PV p*roportion valence, *V* valence, *C* congruency

**Table 3** Accuracy and reaction time with standard deviation in parentheses for each condition in Experiment 2

| | | | | | | |
|---|---|---|---|---|---|---|
| | Accuracy | | | | | |
| | Association phase | | Transfer phase | | | |
| | Positive | Negative | Repeat | | Switch | |
| | | | Congruent | Incongruent | Congruent | Incongruent |
| Mostly Negative | .94 (.06) | .96 (.04) | .91 (.08) | .84 (.12) | .91 (.12) | .73 (.17) |
| Mostly Positive | .96 (.03) | .94 (.05) | .95 (.06) | .83 (.1) | .91 (.12) | .74 (.19) |
| | Reaction time | | | | | |
| | Association phase | | Transfer phase | | | |
| | Positive | Negative | Repeat | | Switch | |
| | | | Congruent | Incongruent | Congruent | Incongruent |
| Mostly Negative | 563 (65) | 549 (61) | 747 (128) | 765 (106) | 883 (159) | 984 (183) |
| Mostly Positive | 542 (59) | 570 (70) | 750 (124) | 792 (113) | 877 (167) | 956 (153) |

**Table 4** Complete ANOVA results of accuracy and reaction time of Experiment 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Association phase | | | | | | | |
| | | Accuracy | | | Reaction time | | |
| Source | *df* | *F* | *p* | $\eta^2$ | *F* | *P* | $\eta^2$ |
| PV | 1, 37 | .22 | .64 | .006 | .003 | .989 | .000 |
| V | 1, 37 | .66 | .419 | .018 | 4.23 | .047* | .103 |
| PV x V | 1, 37 | 10.46 | .003** | .22 | 38.38 | .001** | .509 |
| Transfer phase | | | | | | | |
| | | Accuracy | | | Reaction time | | |
| Source | *df* | *F* | *p* | $\eta^2$ | *F* | *P* | $\eta^2$ |
| PV | 1, 37 | .21 | .646 | .006 | .01 | .907 | .001 |
| TT | 1, 37 | 18.34 | .001** | .331 | 140.91 | .001** | .792 |
| C | 1, 37 | 61.05 | .001** | .623 | 26.08 | .001** | .413 |
| PV x TT | 1, 37 | .14 | .708 | .004 | 4.8 | .035* | .115 |
| PV x C | 1, 37 | .02 | .882 | .001 | .01 | .942 | .001 |
| TT x C | 1, 37 | 13.61 | .001** | .269 | 11.2 | .002** | .232 |
| PV x TT x C | 1, 37 | 2.16 | .15 | .055 | 1.6 | .213 | .042 |

**p <.05. **p<.01*

*PV* proportion valence, *V* valance, *TT* trial type, *C* congruency

= -5.83 , $p < .001$. For the accuracy data, the interaction effect was also significant, $F(1,37) = 10.46$, $p < .01$, $\eta_p^2 = .22$. In the MP condition, the accuracy of positive faces was higher ($M = .96$, 95% CI [94, 96]) than negative ($M = .94$, 95% CI [92, 96]), $t(37) = 2.33$, $p < .05$. In the MN condition, the accuracy of negative faces ($M = .96$, 95% CI [94, 97]) was higher than positive ($M = .95$, 95% CI [91, 95]) , $t(37) = 3.15$, $p < .01$. Other effects were not significant for accuracy, *ps* > .41.

For the transfer phase, RTs and accuracy were subjected to three-way ANOVAs with item-specific proportion valence from the association phase (Mostly Positive and Mostly Negative), trial type (Switch and Repetition), and response congruency (Congruent and Incongruent) as within-subject factors. The response for repetition trials ($M = 763$ ms, 95% CI [730, 797]) was significantly faster than for the switch trials ($M = 925$ ms, 95% CI [876, 974]), $F(1, 37) = 140.91$, $p < .001$, $\eta_p^2 = .79$, and the response time for congruent trials ($M = 814$ ms, 95% CI [771, 857]) was significantly faster than for the incongruent trials ($M = 874$ ms, 95% CI [834, 914]) , $F(1, 37) = 26.08$, $p < .001$, $\eta_p^2 = .41$. While the main effect of previous valence proportion was not significant, $p > .9$, the task transition effect was modulated by the valence proportion during the association phase, $F(1, 37) = 4.8$, $p < .05$, $\eta_p^2 = .11$. In the MP condition, the difference between switch ($M = 933$ ms, 95% CI [881, 986]) and repetition trials ($M = 756$ ms, 95% CI [721, 790]) was significant, $t(37) = -11.29$, $p < .001$. Also in the MN condition, the difference between switch ($M = 917$ ms, 95% CI [868, 965]) and repetition trials ($M$

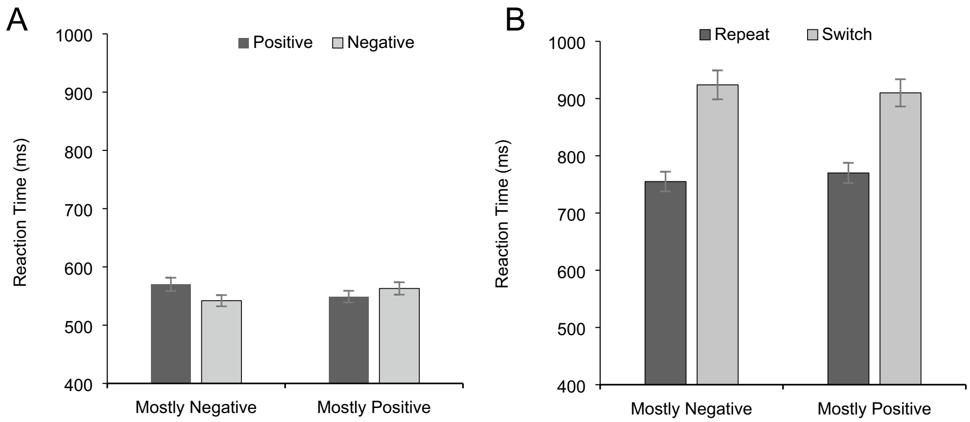


**Fig. 3** The results of Experiment 2 for each type of trial. **Panel A:** Mean reaction time for positive (dark gray bar) and negative (light gray bar) faces in associative phase. **Panel B:** Mean reaction time for repeat (dark gray bar) and switch (light gray bar) trials in transfer phase. Error bars represent standard errors. Although the design of the transfer phase includes one more variable (i.e., trial congruency), for the simplicity of the presentation and due to the lack of a significant three-way interaction, we present here the results based on two factors; proportional valence and task transition

= 771 ms, 95% CI [735, 806]) was significant, $t(37) = -9.63$, $p < .001$. However, the switch cost was smaller in the MP condition ($M = 145$ ms, 95% CI [115, 176]) than in the MN condition ($M = 177$ ms, 95% CI [145, 209]), $t(37) = 2.19$, $p < .05$. Also, there was an interaction effect between response congruency and trial types, $F(1, 37) = 11.2$, $p < .01$, $\eta_p^2 = .23$; congruency effect was greater in the switch trials ($M = 90$ ms, 95% CI [57, 123]) than in the repetition trials ($M = 29$ ms, 95% CI [3, 56]), $t(37) = 3.34$, $p < .01$. However, response congruency was not modulated by the valence proportion, $p > .8$, and the three-way interaction was not significant either, $p > .15$.

For accuracy data of the transfer phase, the accuracy for switch trials ($M = .82$, 95% CI [78, 86]) was lower than the accuracy for repetition trials ($M = .88$, 95% CI [86, 90]), $F(1, 37) = 18.34$, $p < .001$, $\eta_p^2 = .33$, and congruent trials ($M = .91$, 95% CI [89, 94]) were more accurate than the incongruent trials ($M = .79$, 95% CI [75, 82]), $F(1, 37) = 61.05$, $p < .001$, $\eta_p^2 = .62$. The congruency effect was modulated by the trials types, $F(1, 37) = 13.61$, $p < .005$, $\eta_p^2 = .26$. The accuracy difference between incongruent and congruent trials was bigger in the switch trials ($M = .17$, 95% CI [.12, .22]) than in the repeat trials ($M = .08$, 95% CI [.05, .11]), $t(37) = 3.68$, $p < .005$. Other effects were not significant, *ps* > .15.

We found that mostly positive items enhance cognitive flexibility; switch cost in the MP condition was significantly smaller than in the MN condition. However, different from Experiment 1, the associated emotion did not affect the congruency effect. We discuss the lack of an interaction between emotion and response congruency in the *General discussion*. Experiment 1 and Experiment 2 suggest that positively valenced stimuli lead to both increased cognitive stability and cognitive flexibility that protect against the influence of distractor stimuli.

## General discussion

The purpose of the current study was to investigate the effect of valence (positive vs. negative) on the stability and flexibility of cognitive control. In the association phase of both experiments reported here, participants identified the emotion of the face as positive or negative. Half of the faces were presented in the mostly positive (MP) condition and the other half in the mostly negative (MN) condition. In the transfer phase of Experiment 1, the same faces were presented in a neutral emotion and participants performed the gender Stoop task. The congruency effect (e.g., the difference in performance between the congruent and incongruent conditions) was significant for MN faces, but not for MP faces. This is an indication that positive valence can result in better cognitive stability than negative valence, in the sense that participants were better able to maintain the task rules for the gender Stroop task (i.e., identifying targets and ignoring distractors) for the faces associated with a positive emotion rather than for the faces associated with a negative emotion. The previous studies (e.g., Schlaghecken et al., 2017; Yamaguchi et al., 2018), which utilized the response conflict paradigm (e.g., the Simon task), implied that negative valence would promote cognitive stability. Although our data are not consistent with this hypothesis, they are consistent with the Tae et al. (2021) study, which suggests that more efficient cognitive control can result in positive valence toward the stimulus.

In the transfer phase of Experiment 2, participants identified the age or the gender of the face in a task-switching paradigm. The switch cost (e.g., the difference in reaction time between task switching and task repetition conditions) was smaller for the MP faces than for the MN faces. These results suggest that positive valence can promote better cognitive flexibility than negative valence. Participants were better able to flexibly switch between the age task and the gender task for the faces associated with a positive emotion than for the faces associated with a negative emotion. This result is consistent with the implication from the task-switching studies (e.g., Wang et al., 2017; Yang & Yang, 2014), which imply that positive emotion can promote cognitive control. In combination, the results imply that positive valence, in comparison with negative valence, enhances both cognitive stability and cognitive flexibility.

Additionally, in Experiment 2, we were able to examine the effect of trial congruency and its interaction with task transition and proportion valence. The congruency effect was in fact substantial in the task-switching paradigm, and it was greater with task switch than with task repetition, which is consistent with previous results (Eich et al., 2016; Kiesel et al., 2007; Meiran, 1996), suggesting that task switching may be more challenging with incongruent stimuli. However, the congruency effect was not modulated by the proportion valence, suggesting that the effect of associated emotion was limited to task transition in the task-switching paradigm. It is postulated that the task transition and the trial congruency may constitute a hierarchical structure, in which the congruency effect is subjected to task transition and the effect of emotion is targeted at the higher level of the hierarchy.

Before we further discuss our results, it should be noted that the association phases of the current study lack the baseline control condition with emotionless faces, which in some studies have been randomly inserted among positive and negative faces. Therefore, although we found the results showing more efficient cognitive control for positive stimuli than for negative stimuli, it is unclear whether such a difference is due to facilitated cognitive control for positive stimuli or due to impaired cognitive control for negative stimuli. Therefore, we acknowledge that the direction of change in cognitive control is not clear, but we focus on the relative difference between positive and negative stimuli in this discussion. Nonetheless, future research may include the neutral condition to further elucidate the exact nature of the difference between the effects of positive and negative valences.

Both the Stroop effect and the task switch cost can be reduced when the level of cognitive control is high. Therefore, one implication of our results is that positive emotion associated with a stimulus (relative to negative emotion) can elevate cognitive control. This implication is consistent with a previous study that showed that stimuli associated with a high level of cognitive control can trigger positive valence (Tae et al., 2021). In Tae et al. (2021), for faces associated with a high level of cognitive control (i.e., mostly incongruent or mostly switching), responses to positive emotion were faster than to negative emotion. This difference was not observed for the faces that were associated with low cognitive effort (i.e., mostly congruent or mostly repetition). The mostly incongruent or mostly switching items require resolution of cognitive conflict more often than mostly congruent or mostly repetition items. Therefore, Tae et al.'s finding suggests that exertion of cognitive effort can lead to positive emotion. Combined with the current results, just as the stimuli associated with persistent cognitive control can acquire positive valence, the persistent positive valence, in comparison with negative emotion, promotes higher cognitive effort leading to a smaller Stroop effect or a smaller switch cost.

One potential mechanism for the enhanced cognitive control with positive versus negative valence can be related to the findings that reward can increase efficient cognitive processing. For example, Krebs et al. (2010) showed that a reward-associated target decreased the Stroop effect but a reward-associated distractor increased the Stroop effect. That is, items associated with reward attract attention more strongly. Furthermore, Park et al. (2019) showed that the reward information is most effective when signaled by a stimulus with positive valence as opposed to a stimulus with negative or neutral emotion. Additionally, Park et al. suggested that positive emotion and reward may activate the same brain region (e.g., ventral striatum), implying that reward and positive emotion affect cognitive performance in a similar manner. This reward-based explanation is also consistent with the notion that positive valence increases dopamine (Schultz, 1998), and in turn that dopamine modulates maintenance and updating of information in the prefrontal cortex (Braver & Cohen, 2000), which regulates cognitive control.

A behavioral explanation for our results can be related to the approach tendency typically associated with positive emotion. Paulus and Wentura (2016), for example, compared behavioral tendencies for happy versus angry faces (Experiment 1a), and happy versus fearful faces (Experiment 1b). In these experiments, participants were asked to move a small virtual figure toward or away from the positive or negative face. The results showed that approach responses for happy faces were faster than avoidance responses, whereas the reverse pattern was found for angry and fearful faces. We argue that this approach tendency may render the target information stronger in comparison with the distractor. As demonstrated by Egner and Hirsh (2005), the reduction of the congruency effect can be explained by the amplification of the target information. In our results, the significant interactions were driven by the reduced Stroop effect or the reduced switch cost with the stimuli previously associated with positive emotion, reflecting the possible amplification of the target information.

However, approach-avoidance has also been adopted to explain the previous results that are not consistent with ours. For example, Schlaghecken et al. (2017) and Lien et al. (2020) found smaller Simon effects for negative faces than for positive faces. Yamaguchi et al. (2018) also found smaller Simon effects for negative stimuli (spiders) than for positive stimuli (flowers). Yamaguchi et al. suggested that the approach tendency toward a positive stimulus is consistent with the toward response to the congruent positive stimulus, magnifying the Simon effect, but inconsistent with the away response to the incongruent positive stimulus, reducing the Simon effect. We speculate that the task difference between the Simon task (e.g., in Yamaguchi et al. and Schlaghecken et al.) and the Stroop task (e.g., in the current study) may be critical in explaining the discrepancy. In the Simon task, the target and the distractor occupy the same location, and therefore approaching the target inherently means approaching the distractor. Therefore, when the target information is amplified due to "approach," the distractor can also be amplified. In contrast, especially in the version of the Stroop task that we used, although the distractor (the word) is imposed upon the target (the face), they are spatially separable. Therefore, the "approach" can be aimed just to the target without activating the distractor, exclusively amplifying the target information, which eventually reduces the distractor-related interference.

One key difference of our paradigm from previous studies is that we incorporated an association phase in which participants were exposed to the associations between faces and either positive or negative emotion. Then, in the transfer phase, participants responded to faces without emotion information. That is, the effects we observed in the transfer phase should have been based on the retrieved emotion. However, in the previous studies, emotion was present regardless of whether people directly responded to emotion or not. Despite this difference, we observed consistent results with the studies focusing on cognitive flexibility, namely task-switching studies. However, we observed different results from the studies focusing on cognitive stability, such as the studies that adopted an interference paradigm. The latter discrepancy may also be rooted in the different adaptive value associated with present negative emotion as opposed to present positive emotion. For example, the affect-as-information hypothesis suggests that negative emotion signals possible dangers in the environment (Schwarz & Clore, 2003), which then increases detailed, analytic processing. Such detail-focused processing may be the mechanism to increase cognitive control in the context of immediately available negative emotion. While it is intuitive that the present emotion and the associated (retrieved) emotion may function differently to some extent, the direct comparison seems to be rare in the current literature. It would be an interesting new direction for future research to investigate the similarities and the differences between immediately available emotion and associated emotion.

Here, we report that stimuli that have been associated with positive valence can lead to more efficient cognitive control than stimuli associated with a negative valence. Our results imply that positive emotion can promote better cognitive stability and flexibility than negative emotion, as demonstrated in a gender Stroop task (that requires maintaining a high level of cognitive control to reduce distractor interference) and a task-switching paradigm (that necessitates cognitive flexibility to switch between tasks). Our study adds to the growing body of literature that demonstrates that cognitively demanding stimuli can acquire positive valence, suggesting that there is an association between positive valence and increased cognitive control. Moreover, our methods involve a learned association (positive or negative), rather than an emotional stimulus that changes trial to trial. This has interesting and important implications for any environmental object, event, or person that is generally positive or negative, and the subsequent effects on cognitive control. Our very ability to use controlled and flexible attention may depend on our emotional associations with stimuli in the environment.

## Appendix

**Table 5** Identification codes of face stimuli in Experiment 1

| Association phase | | Transfer phase |
|---|---|---|
| Negative | Positive | Neutral |
| AF01ANS | AF01HAS | AF01NES |
| AF05ANS | AF05HAS | AF05NES |
| AF06ANS | AF06HAS | AF06NES |
| AF07ANS | AF07HAS | AF07NES |
| AF19ANS | AF19HAS | AF19NES |
| AF29ANS | AF29HAS | AF29NES |
| AM01ANS | AM01HAS | AM01NES |
| AM07ANS | AM07HAS | AM07NES |
| AM08ANS | AM08HAS | AM08NES |
| AM10ANS | AM10HAS | AM10NES |
| AM11ANS | AM11HAS | AM11NES |
| AM13ANS | AM13HAS | AM13NES |

AF = KDEF A series female model; AM = KDEF A series male model; ANS = Angry face; HAS = Happy face; NES = Neutral face

**Table 6** Identification codes of face stimuli in Experiment 2

| Association phase | | Transfer phase |
|---|---|---|
| Negative | Positive | Neutral |
| 021_o_f_a_a | 021_o_f_h_a | 021_o_f_n_a |
| 060_o_f_a_a | 060_o_f_h_a | 060_o_f_n_a |
| 125_y_f_a_b | 125_y_f_h_b | 125_y_f_n_b |
| 132_y_f_a_b | 132_y_f_h_b | 132_y_f_n_b |
| 033_o_m_a_b | 033_o_m_h_b | 033_o_m_n_b |
| 091_o_m_a_b | 091_o_m_h_b | 091_o_m_n_b |
| 109_y_m_a_b | 109_y_m_h_b | 109_y_m_n_b |
| 144_y_m_a_a | 144_y_m_h_a | 144_y_m_n_a |

o = Old; y = Young; f = Female; m = Male; 'a_a' = angry face from A set; 'a_b' = angry face from B set; 'h_a' = happy face from A set; 'h_b' = happy face from B set; 'n_a' = neutral face from A set; 'n_b' = neutral face from B set

**Author Note** This work was supported by the Ministry of Education of the Republic of Korea and the Nation Research Foundation of Korea (NRF- 2020S1A3A2A02103899).

**Data availability** The experiments and datasets for this experiment are available at https://osf.io/ytehm and from the corresponding author on reasonable request.

## References

Braver, T. S., & Cohen, J. D. (2000). On the control of control: The role of dopamine in regulating prefrontal function and working memory. *: Attention and performance XVIII*, 713-737.

De Houwer, J., Thomas, S., & Baeyens, F. (2001). Association learning of likes and dislikes: A review of 25 years of research on human evaluative conditioning. *Psychological Bulletin*, *127*(6), 853. https://doi.org/10.1037/0033-2909.127.6.853

Dreisbach, G., & Goschke, T. (2004). How Positive Affect Modulates Cognitive Control: Reduced Perseveration at the Cost of Increased Distractibility. *Journal of Experimental Psychology: Learning Memory and Cognition*, *30*(2), 343–353. https://doi.org/10.1037/0278-7393.30.2.343

Ebner, N., Riediger, M., & Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: Development and validation. *Behavior Research Methods, 42,* 351-362. https://doi.org/10.3758/BRM.42.1.351.

Eich, T. S., Parker, D., Liu, D., Oh, H., Razlighi, Q., Gazes, Y., ... & Stern, Y. (2016). Functional brain and age-related changes associated with congruency in task switching. *Neuropsychologia*, *91*, 211-221. https://doi.org/10.1016/j.neuropsychologia.2016.08.009

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*, *8*(12), 1784-1790. https://doi.org/10.1038/nn1594

Ivanchei, I., Begler, A., Iamschinina, P., Filippova, M., Kuvaldina, M., & Chetverikov, A. (2019). A different kind of pain: Affective valence of errors and incongruence. *Cognition and Emotion*, 33(5), 1051–1058. https://doi.org/10.1080/02699931.2018.1520077.

Kanske, P., & Kotz, S. A. (2010). Modulation of early conflict processing: N200 responses to emotional words in a flanker task. *Neuropsychologia*, *48*(12), 3661-3664. https://doi.org/10.1016/j.neuropsychologia.2010.07.021

Kanske, P., & Kotz, S. A. (2011a). Emotion triggers executive attention: Anterior cingulate cortex and amygdala responses to emotional words in a conflict task. *Human Brain Mapping*, *32*(2), 198–208. https://doi.org/10.1002/hbm.21012

Kanske, P., & Kotz, S. A. (2011b). Emotion Speeds up Conflict Resolution: A New Role for the Ventral Anterior Cingulate Cortex? *Cerebral Cortex*, *21*(4), 911–919. https://doi.org/10.1093/cercor/bhq157

Kanske, P., & Kotz, S. A. (2011c). Conflict processing is modulated by positive emotion: ERP data from a flanker task. *Behavioural Brain Research*, *219*(2), 382–386. https://doi.org/10.1016/j.bbr.2011.01.043

Kanske, P., & Kotz, S. A. (2012). Effortful control, depression, and anxiety correlate with the influence of emotion on executive attentional control. *Biological Psychology*, *91*(1), 88–95. https://doi.org/10.1016/j.biopsycho.2012.04.007

Kiesel, A., Wendt, M., & Peters, A. (2007). Task switching: On the origin of response congruency effects. *Psychological Research*, *71*(2), 117-125. https://doi.org/10.1007/s00426-005-0004-8

Krebs, R. M., Boehler, C. N., & Woldorff, M. G. (2010). The influence of reward associations on conflict processing in the Stroop task. *Cognition*, *117*(3), 341–347. https://doi.org/10.1016/j.cognition.2010.08.018

Lien, M.-C., Proctor, R. W., & Hinkson, J. (2020). Emotion-induced attentional bias: Does it modulate the spatial Simon effect? *Cognition and Emotion*, *34*(8), 1591–1607. https://doi.org/10.1080/02699931.2020.1785847

Lundqvist, D., Flykt, A., & Öhman, A. (1998). The Karolinska directed emotional faces. : Karolinska Institute, Department of Clinical Neuroscience, Psychology Section.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22, 1423–1442. https://doi.org/10.1037/0278-7393.22.6.1423

Park, H. R. P., Kostandyan, M., Boehler, C. N., & Krebs, R. M. (2019). Winning smiles: Signalling reward by overlapping and non-overlapping emotional valence differentially affects performance and neural activity. *Neuropsychologia, 122,* 28–37. https://doi.org/10.1016/j.neuropsychologia.2018.11.018

Paulus, A., & Wentura, D. (2016). It depends: Approach and avoidance reactions to emotional expressions are influenced by the contrast emotions presented in the task. *Journal of Experimental Psychology: Human Perception and Performance, 42*(2), 197–212. https://doi.org/10.1037/xhp0000130

Pilarczyk, J., & Kuniecki, M. (2014). Emotional content of an image attracts attention more than visually salient features in various signal-to-noise ratio conditions. *Journal of Vision*, *14*(12), 1–19. https://doi.org/10.1167/14.12.4

Robbins, T. W. (2007). Shifting and stopping: fronto-striatal substrates, neurochemical modulation and clinical implications. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1481), 917-932. https://doi.org/10.1098/rstb.2007.2097

Sakai, K. (2008). Task set and prefrontal cortex. *Annual Review of Neuroscience*, 31, 219 –245. https://doi.org/10.1146/annurev.neuro.31.060407.125642

Schlaghecken, F., Blagrove, E., Mantantzis, K., Maylor, E. A., & Watson, D. G. (2017). Look on the bright side: Positivity bias modulates interference effects in the simon task. *Journal of Experimental Psychology: General*, *146*(6), 763–770. https://doi.org/10.1037/xge0000316

Schultz, W. (1998). Predictive reward signal of dopamine neurons. *Journal of Neurophysiology*, *80*(1), 1-27. https://doi.org/10.1152/jn.1998.80.1.1

Schwarz, N., & Clore, G. L. (2003). Mood as Information: 20 Years Later. *Psychological Inquiry, 14*(3-4), 296–303. https://doi.org/10.1207/S15327965PLI1403&4_20

Straub, E., Kiesel, A., & Dignath, D. (2020). Cognitive control of emotional distraction – valence-specific or general? *Cognition and Emotion*, *34*(4), 807–821. https://doi.org/10.1080/02699931.2019.1666799

Stuart, E. W., Shimp, T. A., & Engle, R. W. (1987). Classical conditioning of consumer attitudes: Four experiments in an advertising context. *Journal of Consumer Research*, *14*(3), 334-349. https://doi.org/10.1086/209117

Tae et al., (2021). Cognitively demanding stimuli can aquire positive valence. *Psychological Research*. https://doi.org/10.1007/s00426-021-01489-3

Wang, Y., Chen, J., & Yue, Z. (2017). Positive Emotion Facilitates Cognitive Flexibility: An fMRI Study. *Frontiers in Psychology*, *8*, 1832. https://doi.org/10.3389/fpsyg.2017.01832

Yamaguchi, M., Chen, J., Mishler, S., & Proctor, R. W. (2018). Flowers and spiders in spatial stimulus-response compatibility: does affective valence influence selection of task-sets or selection of responses? *Cognition and Emotion*, *32*(5), 1003–1017. https://doi.org/10.1080/02699931.2017.1381073

Yang, H., & Yang, S. (2014). Positive affect facilitates task switching in the dimensional change card sort task: Implications for the shifting aspect of executive function. *Cognition and Emotion*, *28*(7), 1242–1254. https://doi.org/10.1080/02699931.2013.879053

Zinchenko, A., Kotz, S. A., Schröger, E., & Kanske, P. (2020). Moving towards dynamics: Emotional modulation of cognitive and emotional control. *International Journal of Psychophysiology*, *147*, 193–201. https://doi.org/10.1016/j.ijpsycho.2019.10.018

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