Psychological Research (2022) 86:585–596
https://doi.org/10.1007/s00426-021-01489-3

ORIGINAL ARTICLE

Cognitively demanding stimuli can acquire positive valence

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Received: 23 October 2020 / Accepted: 4 February 2021 / Published online: 14 March 2021

Abstract

Generally, people tend to avoid stimuli that require mental effort; effort can generate negative emotions. However, employing mental effort can also promote positive emotions, given a successful outcome. We investigated whether the level of cognitive effort associated with stimuli will elicit positive or negative emotions. In Experiment 1, participants performed a gender Stroop task during the association phase. The actors from the Stroop task expressed emotionlessness, while half of the actors were displayed in the mostly incongruent (MI) condition and the rest in the mostly congruent (MC) condition. In the transfer phase, we used the same actors for the emotion discrimination task, and the actors expressed a positive emotion half of the time and a negative emotion for the other half. For the MI actors, participants responded faster to positive emotion than to negative emotion, but this difference was not significant for the MC actors. In Experiment 2, the association phase involved a task switching paradigm in which half of the actors were presented in the mostly switching (MS) condition and the other in the mostly repetition (MR) condition. In the transfer phase, the same individuals' faces were used for emotion discrimination. For the MS actors, but not the MR actors, the responses were faster to positive emotion than to negative emotion. Our results imply that stimuli associated with more cognitive effort (i.e., MI and MS stimuli) may be perceived as more positive after a successful outcome of a task, although future research is required to replicate these findings.

Introduction

People are ambivalent about effort. The law of less effort (Hull, 1943) suggests that people prefer a task or a stimulus that is associated with less work. In contrast, the theory of learned industriousness (Eisenberger, 1992) suggests that more effort can be associated with added value because people work harder to acquire a more desirable outcome, leading to the opposite preference. Studies of the interactions between cognition and emotion have also shown that the emotional outcome of cognitive effort can be twofold. For example, a stimulus eliciting response conflict (e.g. incongruent Stroop stimulus) requires more cognitive effort to resolve the conflict. It has been shown that the mere presence of such a conflict stimulus can be perceived as an aversive, negative signal (for a review, see Dignath, Eder, Steinhauser, & Kiesel, 2020). However, the outcome of resolving such conflict can be positive (e.g., Ivanchei, et al., 2019; Schouppe, Braem et al., 2015). Therefore, as aptly captured in the effort paradox (Inzlicht, Shenhav, & Olivola, 2018), effort can be both costly and valued. Since both the law of less effort and learned industriousness emerge as an outcome of learning the association between the stimulus (or the task) and the amount of effort required to process the stimulus (or to perform the task), in the current study, we investigate how emotional valence may arise as a result of experiencing stimuli predominantly associated with a higher level of cognitive effort in comparison with stimuli predominantly associated with a lower level of cognitive effort.

In the cognitive control literature, cognitive effort is conceptualized as resources required to select the task-relevant target information while filtering out task-irrelevant distractors. In this study, we utilized two representative cognitive control paradigms: the Stroop task and task switching. In the Stroop task, participants respond to the target (color of the ink) while ignoring the distractor (word) that may be either congruent or incongruent with the target (i.e., the color of the ink can be the same as or different from the

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color word depicted). Typically, the response time is longer for an incongruent distractor (e.g., the word RED in blue) than with a congruent distractor (e.g., the word RED in red). This congruency effect reflects the extra cognitive effort to resolve the conflict between the target and the distractor, such that the higher the level of control, the smaller the congruency effect. Consequently, maintaining a high level of control requires mental effort to minimize the effect from the distractor. In contrast, maintaining a low level of control is cognitively lightweight, but is inevitably associated with a substantial congruency effect.

In a typical task switching paradigm, participants perform two or more tasks intermixed in a block of trials. The current task can be the same as the previous task (i.e., task repetition), or different from the previous task (i.e., task switching). The response time for task switching is slower than the response time for task repetition. This difference, referred to as switch cost, reflects interference from the different demands of the previous task when performing the second task. Therefore, in task switching, the distractor effect takes place in the temporal dimension, as opposed to the Stroop task, in which the distractor effect takes place in the spatial dimension. The switch cost has been interpreted as reflecting use of additional cognitive resources necessary to disengage from the previous task or to engage in a new task (for representative studies, see Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). Minimizing switch cost in the temporal dimension and the congruency effect in the spatial dimension can both be interpreted as requiring a high level of cognitive control (Chiu & Egner, 2017). Therefore, we utilized both paradigms to gain a clearer understanding of the emotion perception implications of building stimulus associations with different expectations of cognitive demand.

As mentioned earlier, the emotional outcome of processing cognitively demanding stimuli is not consistent in the current literature. The affective signaling hypothesis (Dignath, et al., 2020) suggests that cognitive conflict can provoke negative emotion. For example, in Dreisbach and Fischer (2012), after passively viewing a congruent Stroop stimulus as a prime, participants responded substantially faster to a picture or a word with positive valence than with negative valence, producing the positivity bias (Kauschke, Bahn, Vecker, & Schawrzer, 2019). Additionally, after viewing an incongruent Stroop stimulus, positivity bias was reduced, suggesting that the conflict in the incongruent prime may have facilitated negative emotion perception or interfered with positive emotion perception. Similarly, in an affective attribution paradigm (Damen, Strick, Taris, & Aarts, 2018; Goller, Kroiss, & Ansorge, 2019), participants judged a neutral stimulus (i.e., unfamiliar Chinese characters) as more negative when the stimulus was preceded by an incongruent prime relative to a congruent prime. Also, Kool, McGuire, Rosen, and Botvinick (2010) demonstrated that, when given a chance to choose from alternative sets of stimuli, people indeed chose the set associated with less cognitive effort. These results imply that the stimulus associated with a high level of cognitive effort (e.g., response conflict) may be associated with negative valence, which is consistent with the law of less effort (Hull, 1943).

However, evidence also shows that a conflict stimulus can result in a positive valence (for a review, see Inzlicht, Schehav, & Olivola, 2018). In the above-mentioned studies that report evidence of conflict as an aversive signal, participants passively viewed either an incongruent prime or a congruent prime. Therefore, the results from those studies may only reflect the effect of conflict detection. To directly test the effect of resolving the conflict, Schouppe, Braem et al. (2015) asked participants to explicitly respond to a Stroop stimulus (e.g., responding to the color while ignoring the word) that is presented before an affective judgment task. In their study, the positivity bias (i.e., faster response to the positive stimulus than to the negative stimulus) was, in fact, greater following an incongruent Stroop prime than a congruent prime, which is the opposite of Dreisbach and Fischer (2012). Schouppe, Braem et al. (2015) interpreted that a positive response was facilitated to a greater extent by successfully responding to an incongruent stimulus than by responding to a congruent stimulus. Similarly, Ivanchei et al. (2019), using the flanker task, demonstrated a greater positivity bias after responding to an incongruent prime than after responding to a congruent prime. These results support the notion of no pain no gain (Schouppe, Braemet al., 2015) in the sense that successful management of conflict can prime positivity. Consistent with learned industriousness (Eisenberger, 1992), these studies suggest that the stimulus associated with a high level of cognitive effort may be associated with positive valence, when the conflict has been successfully resolved.

The notion of resolved conflict as a positive experience is consistent with the reward value and prediction model (RVPM, Silvetti, Seurinck, & Verguts, 2011). According to this model, prediction error represents the difference between actual and expected rewards. If the actual reward exceeds the predicted reward, this leads to a positive prediction error. If the actual reward is equal to the expected reward, there is no prediction error. If the actual reward is less than the expected reward, this leads to a negative prediction error. Incongruent trials initially lead participants to be biased to expect more errors and slower responses times. Therefore, participants expect low success rates (i.e., low reward) when encountering incongruent trials. When participants continuously and successfully perform these challenging incongruent trials, a positive prediction error is experienced (the actual reward of overcoming the conflict exceeds the expected reward). For example, even though the overall performance with incongruent stimuli may be still poorer (e.g., lower accuracies and slower response times) than with congruent stimuli, people may feel more positive after executing a correct response on incongruent trials. In order to effectively test the RVPM's prediction, it is important to consider the temporal aspect (effects across the length of an experiment) because it takes a while to acquire the higher-than-expected success rate. However, many aforementioned studies primarily focused on the transient emotional consequence of either perceiving the conflict or resolving the conflict by examining the priming effect of the conflict stimulus trial-by-trial. To our knowledge, very few studies have considered the time that it takes to learn an association and thereby establish a prediction of the reward value. One exception is the Kool et al. (2010) study, which examined choices for a low-demand versus a high-demand option over time (in this study, participants made choices at their own pace, so response times were not assessed). Kool et al. found that participants did not initially demonstrate a bias towards a low-demand versus high-demand option, but by the third run they developed a substantial preference for the low-demand option (which persisted for the rest of the test session). Therefore, given that associations take time to develop, it is relevant to examine emotional valence categorization as a consequence of experiencing the associations between stimuli and amount of cognitive effort.

The specific goal of the current study is to examine whether forming an association between a stimulus and the level of cognitive effort demanded by tasks featuring the stimulus can prime positivity or negativity in affect perception. Therefore, instead of examining the trial by trial affective priming effect (where each incongruent prime would be expected to modulate response to the stimulus presented directly after), we adopted an association-transfer paradigm. During the association phase, participants were presented with emotionless faces for a cognitive control task. Half of these actors' faces were presented in a condition that requires a relatively high level of cognitive effort (e.g., incongruent Stroop or task switching), and the other half in a condition that requires a relatively low level of cognitive effort (e.g., congruent Stroop or task repetition). We expected that participants would experience associations between different groups of stimuli and different levels of cognitive effort. In the transfer phase, the same actors' faces were presented with either positive or negative emotions for an emotion recognition task. Therefore, by comparing the positivity bias in the transfer phase, we can examine whether any overarching bias toward perceiving positive or negative emotion has been established after the association phase.

To examine whether the emotion priming of the association between the stimulus and the high level of cognitive effort would be positive or negative, we utilized the empirical findings that both the congruency effect and the switch cost are contextually modulated. That is, the congruency effect is smaller when a stimulus is frequently presented as an incongruent stimulus than when a stimulus is frequently presented as a congruent stimulus, a phenomenon referred to as the item specific proportion congruency (ISPC) effect (Jacoby, Lindsay, & Hessels, 2003). For example, assume that the word RED appears 80% of the time in the incongruent condition, a mostly incongruent (MI) stimulus, and the word BLUE appears 80% of the time in the congruent condition, a mostly congruent (MC) stimulus. Then, the congruency effect is smaller for the MI stimuli (e.g., RED) than for the MC stimuli (e.g., BLUE). In terms of cognitive effort, the MI stimuli will require more cognitive effort more frequently than the MC stimuli. Therefore, the ISPC effect may be a result of exerting a higher level of cognitive effort more consistently for the MI stimuli than for the MC stimuli. In terms of the emotional outcome, if cognitive effort is perceived as an aversive signal, then the MI stimuli will be perceived more negatively than the MC stimuli. However, from the perspective of the RVPM, the MI stimuli would provide more opportunities to overcome or resolve the conflict than the MC stimuli. If the MI stimuli allow the formation of the association between the stimuli and the frequently resolved conflict, then the MI stimuli will be perceived more positively than the MC stimuli.

Similarly, the switch cost is also modulated based on the item specific switch probability (ISSP). In Chiu and Egner (2017), participants performed multiple tasks intermixed within the same block. In doing so, the probability of switching was disproportionately high for certain stimuli (mostly switching, MS) and low for other stimuli (mostly repetition, MR), and the switch cost was smaller for the MS stimuli than for the MR stimuli. The ISSP effect also reflects the item-based regulation of cognitive control, so that the MS stimuli triggered a higher level of cognitive control, resulting in a smaller switch cost. In terms of the level of cognitive effort, the MS stimuli will be associated with a higher level of cognitive effort than the MR stimuli. If cognitive effort is perceived as an aversive signal, then the MS stimuli will be perceived more negatively than the MR stimuli. However, the MS stimuli will provide more opportunities to overcome or resolve the conflict than MR stimuli. If the MS stimuli allow the formation of the association between the stimuli and the frequently resolved conflict, then the MS stimuli will be perceived more positively than the MR stimuli.

Experiment 1

Using an association-transfer paradigm, Experiment 1 tested whether the levels of cognitive effort associated with MI stimuli (high level of effort) and MC stimuli (low level of effort) can be transferred to different emotional valences.

In the association phase, participants performed the gender Stroop task, with actors' faces selected from the Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998). The stimulus was an actor's face with a gender word (e.g., "MALE" or "FEMALE") imposed on it. The participants were instructed to respond to the gender of the face and disregard the word. Half of the faces were presented with incongruent gender words (e.g. a male face with "FEMALE" superimposed) 80% of the time, the MI condition, and the other half with congruent gender words 80% of the time, the MC condition. If the detection of cognitive conflict is the basis of emotional outcome, the association between the MI stimuli and the high level of cognitive effort will promote negativity. However, if resolving conflict serves as the basis of emotional outcome, then the association between the MI stimuli and the more frequent conflict resolution will promote positivity.

In the transfer phase, the same faces of the actors from the association phase were used, but with either a positive (i.e., happy) or a negative emotion (i.e., angry). The task was to recognize the emotion. To test if the MI and the MC faces acquired different emotional outcomes in the initial association phase, we analyzed the positivity bias, which refers to the faster response time for a positive stimulus than a negative stimulus (Kauschke, et al., 2019). The positivity bias will be pronounced if the stimulus valence is more positive, but the positivity bias will be smaller if the stimulus valence is more negative. If the emotional valence of the MI stimuli from the association phase is positive, then we would expect a greater positivity bias for the MI than for the MC stimuli. In contrast, if the emotional valence of the MI stimuli from the association phase is negative, then we would expect a smaller positivity bias for the MI than the MC stimuli.

Method

Participants

In Experiment 1, we recruited 58 college students at The George Washington University for course credit.[1] All participants had normal or corrected-to normal vision and they provided written informed consent before the experiment.

[1] In the two experiments reported here, the sample size was based on a power analysis using G*power (Faul, Erdfelder, Lang, & Buchner, 2007) for an ANOVA with 4 repeated measures, with the power of .95 and a medium effect size (e.g., $f = .25$). The estimated number of participants was 36, but in both experiments we ended up recruiting more because we did not turn down extra sign ups.

Materials

In Experiment 1, participants completed the gender Stroop task for the association phase and the emotion discrimination task for the transfer phase. For each task, we used the face stimuli of 12 actors (6 males and 6 females) from KDEF (Lundqvist, et al., 1998). For the gender Stroop task, we used emotionless faces with a superimposed gender word (i.e., "MALE, "FEMALE, "MAN," or "WOMAN"). For the emotion discrimination task, positive (i.e., happy) and negative (i.e., angry) faces of the same actors from the association phase were used. The list of identification codes of these pictures is presented in Appendix 1.

Procedure and design

The participants were informed that they would perform two tasks in two different phases of the experiment. In the association phase, they were instructed to respond to the gender of the face stimulus as accurately and as quickly as possible, while ignoring the imposing word. Each trial started with a fixation cross presented at the center of the screen for 500 ms. Then, the face stimulus appeared with a distractor gender word. The participants pressed "1" and "2" on the number keypad for "male" and "female" responses, and the response-to-key mapping was counterbalanced across the participants. After the response, the screen went blank for 1000 ms until the next trial started. There were 16 practice trials with an equal number of congruent and incongruent trials. In the association phase, emotionless faces of 12 KDEF actors were presented 50 times, resulting in 600 trials, presented in 5 blocks. In the transfer phase, the participants responded to the emotion expressed by the face as accurately and as quickly as possible. The time course of fixation, face presentation, and blank screen was identical to the association phase. The participants pressed "5" and "6" for "positive" and "negative" responses and the response-to-key mapping was counterbalanced across participants. Each positive and negative picture of 12 actors was shown twice, and these 48 trials were presented in one block.

Figure 1 depicts the overall design of Experiment 1. During the association phase, while keeping the overall proportion of congruent versus incongruent gender Stroop stimuli at 50%, we manipulated this congruency to be different at the item level. Six faces (3 males and 3 females) appeared with a congruent gender word for 40 out of 50 times, the mostly congruent (MC) condition. The other 6 faces appeared with an incongruent gender word for 40 out of 50 times, the mostly incongruent (MI) condition. This item-specific proportion congruency was not part of explicit instruction to participants. The MI and the MC faces were randomly intermixed during the association phase. During

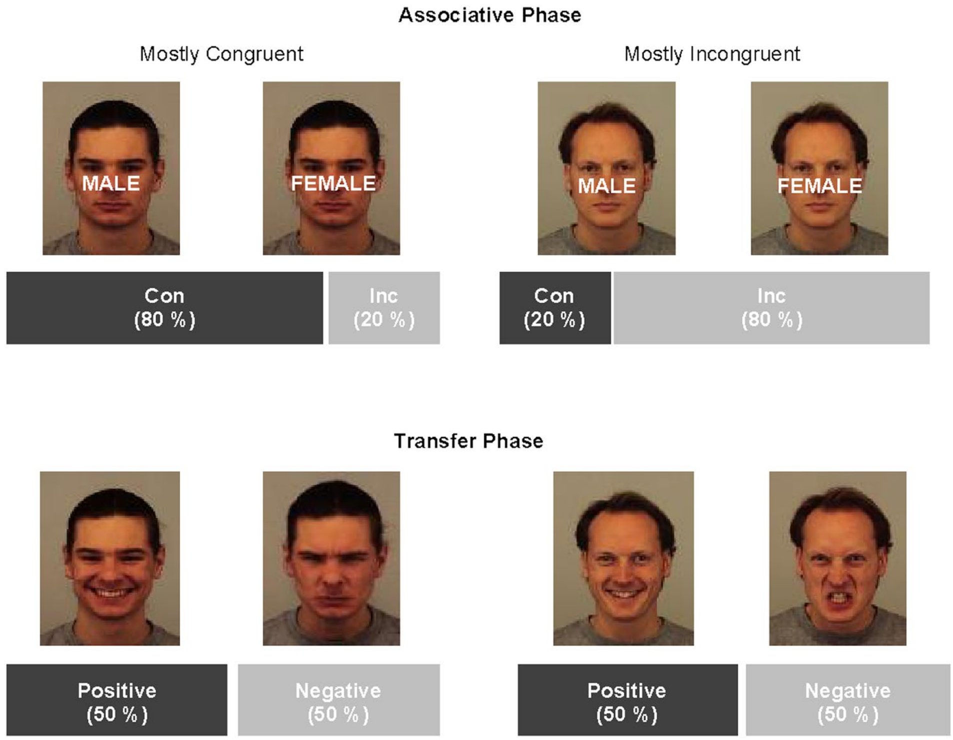

Fig. 1 Overall design of Experiment 1. In the associative phase, neutral faces were presented with gender word and participants judged the gender of the face. Some faces appeared 80% of the times in the congruent (Con) condition and other faces appeared 80% of the times in the incongruent (Inc) condition. In the transfer phase, participants were asked to decide emotion of the face. Positive and negative faces were presented equally often

the transfer phase, the proportions of negative and positive faces were equal.

Results and discussion

We excluded one participant from data analysis based on the percent accuracy of the association phase scoring lower than 80%, leaving 57 participants (40 females, $M_{age} = 20.3$). In Experiment 1, reaction time (RT) and accuracy were analyzed. For both RT and accuracy, practice trials of the association phase were excluded from data analysis. For RT, incorrect trials (3.77% of all experimental trials) and trials with RTs longer than 3 SDs from each participant's mean RT (1.48% of all experiment trials) were also removed.

For the gender Stroop task of the association phase, RTs from correct trials and accuracies were subjected to a two-way ANOVA with the within-subject factors of item specific proportion congruency (ISPC; MC and MI) and congruency (Congruent and Incongruent). Figure 2 presents the RT results of the association and the transfer phases of Experiment 1. For RT data, the response to the congruent stimulus ($M = 599$ ms, 95% CI [559, 639]) was faster than to the incongruent stimulus ($M = 635$ ms, 95% CI [586, 683]), resulting in the main effect of congruency, $F(1, 56) = 39.85$, $p < 0.001$, $\eta_p^2 = 0.416$. No other effects were significant, $ps > 0.63$. For accuracy data, the accuracy for the congruent stimulus ($M = 97\%$, 95% CI [96, 98]) was higher than the accuracy for the incongruent stimulus ($M = 95\%$, 95% CI [94, 96]), resulting in the main effect of congruency, $F(1, 56) = 28.8$, $p < 0.001$, $\eta_p^2 = 0.34$. No other effects were significant, $ps > 0.79$.

For the emotion discrimination task of the transfer phase, RTs from correct trials and accuracy were subjected to a two-way ANOVA with the within-subject factors of ISPC during the association phase (MC and MI) and valence (positive and negative). For the RT data, the main effect of valence was significant, $F(1, 56) = 18.86$, $p < 0.001$, $\eta_p^2 = 0.252$, in which the response to positive expressions ($M = 606$ ms, 95% CI [572, 640]) was faster than to negative expressions ($M = 643$ ms, 95% CI [603, 684]). While the main effect of ISPC during the association phase was not significant, $p > 0.18$, the interaction with valence was significant, $F(1, 56) = 4.31$, $p = 0.042$, $\eta_p^2 = 0.072$. For MI faces, participants responded significantly faster to positive faces ($M = 603$ ms, 95% CI [572, 633]) than to negative faces ($M = 659$ ms, 95% CI [615, 706]), $t(56) = -4.06$, $p < 0.001$. However, the positivity bias was not significant with MC faces, $p > 0.12$. We conducted a sensitivity power analysis using G*power for an ANOVA with 2 repeated measures (to account for the interaction), with a power of 0.95. For Experiment 1, we included a participant number of 57. The sensitivity analysis indicated that this number of subjects should result in an effect size f of greater than or equal to 0.242, which equals $\eta^2 = 0.055$. We have obtained a greater effect size than suggested. Our significant effects exceeded the threshold provided by the sensitivity analyses. Therefore,

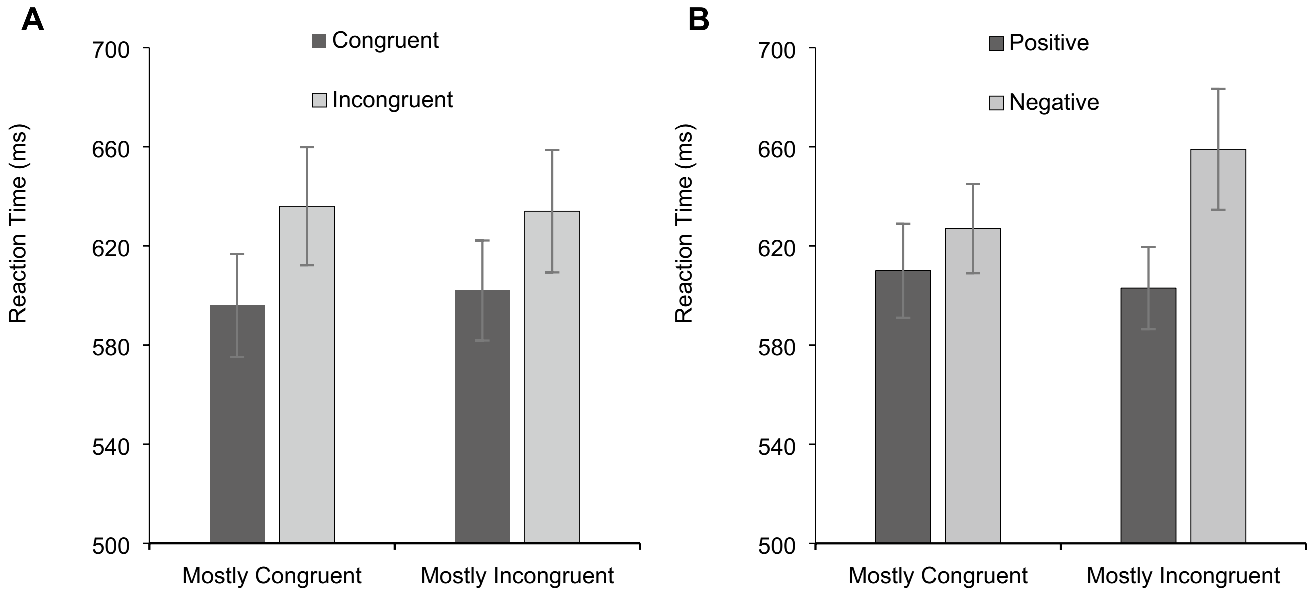

Fig. 2 The results of Experiment 1 for each types of trial. **a** Mean reaction time for congruent (dark gray bar) and incongruent (light gray bar) stimuli in associative phase. **b** Mean reaction time for positive (dark gray bar) and negative (light gray bar) faces in transfer phase. Error bars represent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

we conclude that we have sufficient power with the number of participants in our sample.

For the accuracy data of the transfer phase, the main effect of valence was significant, $F(1, 56) = 6.37$, $p = 0.014$, $\eta_p^2 = 0.102$; the accuracy for positive expressions ($M = 95\%$, 95% CI [94, 96]) was higher than the accuracy for negative expressions ($M = 93\%$, 95% CI [91, 94]). Other effects were not significant, $ps > 0.45$.

Experiment 1 results showed that the positivity bias was significant for MI stimuli but not for MC stimuli, suggesting that MI stimuli may have acquired positive valence through the association with the high level of cognitive effort. One unexpected finding is that we did not observe the ISPC effect during the association phase across all participants. It is possible that the transfer result may have been limited to those participants who showed the ISPC effect. We conducted an additional analysis, comparing the participants who showed the ISPC effect with those who did not. For each subject, we computed the ISPC score by subtracting the congruency effect (i.e., the difference of the incongruent and the congruent RTs) of the MI condition from the congruency effect of the MC condition. The higher ISPC score implies that participants have, implicitly or explicitly, adapted to the contingency between the stimulus and the proportion congruency. We tested whether these two groups of participants were different in their transfer results. The RTs from the transfer phase were subjected to a three-way ANOVA with ISPC score (high and low), ISPC during the association phase, and valence. In this analysis, while the interaction between proportion congruency and valence was still significant, $F(1, 55) = 4.22$, $p = 0.044$, $\eta_p^2 = 0.071$, this interaction was not modulated by participants' ISPC scores, $p > 0.85$. The result of this additional analysis suggests that the transition from a high level of cognitive effort to positive valence is not limited to learning the contingency between the stimulus and the level of effort.

Experiment 2

Experiment 1 demonstrated that a high level of cognitive effort can promote a positive valence toward the stimulus, supporting the learned industriousness theory of cognition-emotion interaction. Experiment 2 examined the transition from cognitive effort to emotion with a different type of cognitive control: task switching. While the congruency effect reflects the amount of cognitive effort required 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. It is a temporal rather than spatial challenge. In the association phase of Experiment 2, the participants performed the age task (i.e., to categorize the age of the actor) and the gender task (i.e., to categorize the gender of the actor). The two tasks were randomly intermixed, and the color of the picture frame indicated which task to perform. We used emotionless faces of 8 actors from FACES (Ebner, Riediger, &

Lindenberger, 2010). Half of the faces appeared on task switching trials 80% of the time, the mostly switching (MS) condition, and the other half on task repetition trials 80% of the time, the mostly repetition (MR) condition. In the transfer phase, the participants responded to the emotion expressed by the same actors from the association phase. The MS condition is more demanding because it requires a high level of cognitive control to disengage and re-engage between tasks, while the MR condition requires a lower level of control. If a high level of cognitive effort translates to a positive emotion, the response to positive MS faces will be faster than the response to negative MS faces. However, this positivity bias should be greatly reduced for the MR faces.

Method

Participants

In Experiment 2, 45 college students at The George Washington University participated for course credit. All participants had normal or corrected-to-normal vision and they provided written informed consent before the experiment.

Materials

Experiment 2 also adopted the association-transfer paradigm. In the association phase, participants performed the age task and the gender task. For both tasks, we used emotionless faces of 8 actors (2 old males, 2 old females, 2 young males, and 2 young females) from FACES (Ebner, Riediger, & Lindenberger, 2010). Each picture was presented with a colored frame, either a green frame indicating the age task or a yellow frame indicating the gender task. In the transfer phase, the pictures of the same actors were presented with either a positive (i.e., happy) or a negative (i.e., angry) emotion. The list of identification codes of these pictures is presented in Appendix 2.

Procedure

In the association phase, the participants responded to the gender or the age of a face stimulus as accurately and as quickly as possible. Each trial started with a fixation cross for 300 ms, followed by a face stimulus with a green or yellow frame at the center of the screen until a participant responded. 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. After the response, feedback was presented at the center of the screen for 500 ms. Before the main task, 16 trials of practice were provided for an equal proportion of the gender and the age tasks. In the main association phase, neutral faces of 8 actors were presented 120 times, resulting in 960 trials presented in 8 blocks. In the transfer phase, participants were instructed to respond to the emotion of the presented face as accurately and as quickly as possible. The duration of each trial component was identical to the association phase. The participants were instructed to press "5" and "6" for "positive" and "negative" responses and the response-to-key mapping was counterbalanced across participants. Each positive and negative picture of 8 actors was shown three times, resulting in 48 trials presented in one block.

During the association phase, while keeping the overall proportion of task repetition and switching at 50%, we manipulated the switching probability to be different at the item level. Four faces (one from each category of old male, young male, old female, and young female) appeared in the task switching trials for 96 out of 120 times, the mostly switching (MS) condition. The other 4 faces appeared in the task repetition trials for 96 out of 120 times, the mostly repetition (MR) condition. This item-specific switch proportion was not part of explicit instruction to participants. The MS and MR faces were randomly intermixed during the association phase. During the transfer phase, the proportion of positive and negative faces was 50%.

Results and discussion

We excluded 5 participants from data analysis based on the percent accuracy of the associative phase lower than 80%, leaving 40 participants (28 females, $M_{\text{age}} = 20.1$). In Experiment 2, RT and accuracy were analyzed. For both RT and accuracy, practice trials and the first trial of each block were excluded. For RT, incorrect trials (8.62% of all experimental trials) and trials with RTs longer than 3 SDs from each participant's mean RT (2.74% of all experiment trials) were removed.

Figure 3 presents the RT results of the association and the transfer phases. For the association phase, both response times and accuracy were subjected to a two-way ANOVA with item specific switch probability (ISSP; MS and MR) and trial type (switch and repeat). For RT data, participants took longer to respond on switch trials ($M = 874$ ms, 95% CI [826, 921]) than to repetition trials ($M = 782$ ms, 95% CI [746, 818]), $F(1, 39) = 100.02$, $p < 0.001$, $\eta_p^2 = 0.72$. Other effects were not significant, $ps > 0.26$. For accuracy data, the accuracy for switch trials ($M = 91\%$, 95% CI [88, 93]) was lower than the accuracy for repetition trials ($M = 92\%$, 95% CI [90, 95]), $F(1, 39) = 18.09$, $p < 0.001$, $\eta_p^2 = 0.31$, and other effects were not significant, $ps > 0.7$.

For the emotion discrimination task, RTs and accuracy were subjected to a two-way ANOVA with item specific

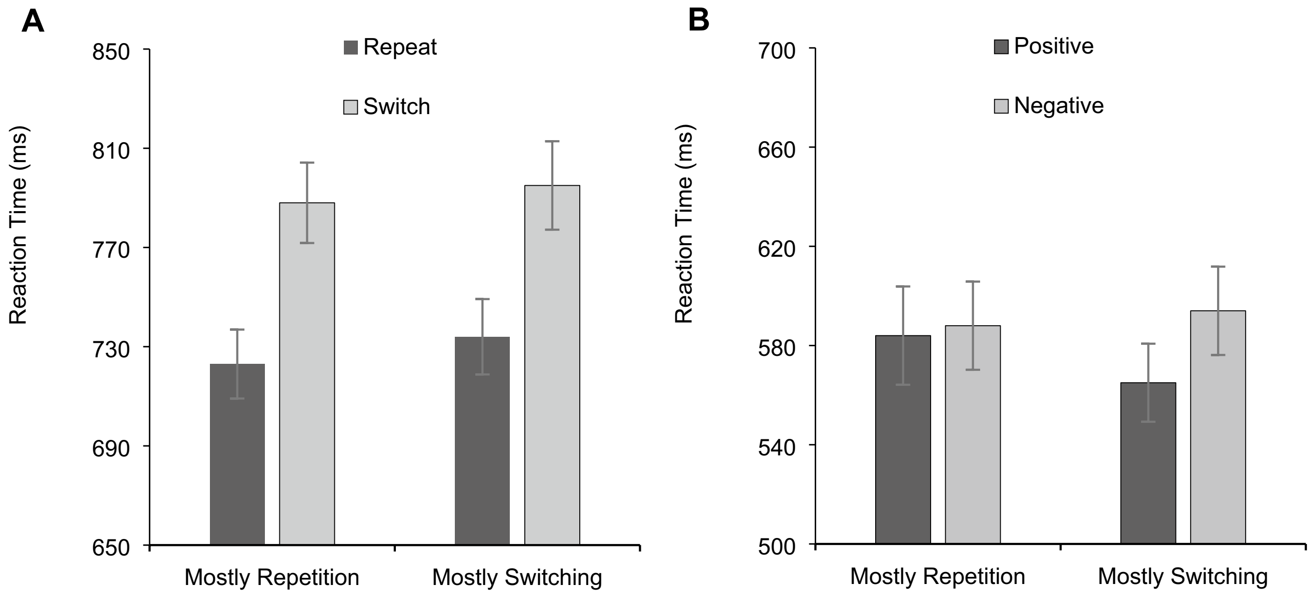

Fig. 3 The results of Experiment 2 for each types of trial. **a** Mean reaction time for repeat (dark gray bar) and switch (light gray bar) trials in associative phase. **b** Mean reaction time for positive (dark gray bar) and negative (light gray bar) faces in transfer phase. Error bars represent standard errors

switching probability (ISSP) during the association phase (MS and MR) and valence (positive and negative) as factors. The response to the positive stimulus ($M = 574$ ms, 95% CI [539, 609]) was significantly faster than the negative stimulus ($M = 591$ ms, 95% CI [556, 627]), $F(1, 39) = 5.24$, $p = 0.027$, $\eta_p^2 = 0.11$. The valence effect was modulated by the switching probability during the association phase, $F(1, 39) = 4.9$, $p = 0.033$, $\eta_p^2 = 0.11$, while the main effect of the previous ISSP was not significant, $p > 0.32$. With MS faces, participants responded faster to positive ($M = 565$ ms, 95% CI [536, 597]) than to negative faces ($M = 594$ ms, 95% CI [564, 630]), $t(39) = -3.41$, $p = 0.002$, but this difference was not significant with MR faces, $p > 0.64$. For Experiment 2, to run a sensitivity analysis, we entered 40 as the participant number. This sensitivity analysis indicates that this number of subjects should result in an effect size f of greater than or equal to 0.292, which equals to $\eta^2 = 0.079$. We have obtained a greater effect size than suggested. Our significant effects exceeded the threshold provided by the sensitivity analyses. Therefore, we conclude that we have sufficient power with the number of participants in our sample. For accuracy data, there were no significant effects, $ps > 0.49$.

Experiment 2 results also show that MS items were responded to faster when they expressed positive as opposed to negative emotions, suggesting that the increased level of cognitive effort associated with MS items resulted in more positive emotion. However, as with the ISPC effect of Experiment 1, we did not observe the ISSP effect in Experiment 2. We conducted a further analysis, comparing those who showed the ISSP effect with those who did not. For each participant, we calculated the ISSP score by subtracting the switch cost of the MS condition from the switch cost of the MR condition. The higher ISSP score implies that participants have picked up, be it explicit or implicit, the association between the stimulus and the switching probability. The RTs from the transfer phase were subjected to a three-way ANOVA with ISSP score (high and low), ISSP during the association phase, and valence. In this analysis, the interaction between switching probability and valence was modulated by participants' ISSP score, $F(1, 38) = 4.86$, $p = 0.034$, $\eta_p^2 = 0.113$. The interaction between valence and switching probability was significant for high scorers, $F(1, 19) = 7.4$, $p = 0.014$, $\eta_p^2 = 0.28$, but this interaction effect was not significant for low scorers, $p > 0.92$. Unlike Experiment 1, the Experiment 2 results show that the transition of a high level of control to a positive emotion was limited to those participants who seem to have acquired the knowledge of the item specific switch probability. We will discuss this discrepancy further in the general discussion.

General discussion

The purpose of the current study was to investigate how various levels of cognitive effort demands can be translated to an emotional valence predisposition. The law of least effort (Hull, 1943) implies that the association between a stimulus and a high level of cognitive effort would result in an "avoidance" response, and therefore negative valence. In contrast, the idea of learned industriousness (Eisenberger,

1992) implies that such an association can result in positive valence, when exerting a high level of cognitive effort leads to successful performance. In the association phase of the Experiment 1, the participants performed the gender Stroop task with emotionless face stimuli. Half of the faces were presented in the mostly congruent (MC) condition and the other half in the mostly incongruent (MI) condition. In the transfer phase, the actors' faces displayed either positive emotions or negative emotions, and the positivity bias (i.e., the faster reaction time for positive than negative emotion) was significant for MI faces but not for MC faces. In Experiment 2, in the association phase, the participants performed the age task and the gender task in a task-switching paradigm. Half of the faces were presented in the mostly switching (MS) condition and the other half were presented in the mostly repetition condition (MR). In the transfer phase, participants responded to the emotion expressed by the actors, and the positivity bias was significant for MS faces but not for MR faces. Our interpretation of these results is that the MI and MS faces, which are associated with a higher level of cognitive effort, may have resulted in positive valence.

Our results are consistent with the notion that the resolved conflict may be associated with positive emotions (Inzlicht, Schehav, & Olivola, 2018), and we attempt to explain our results in two different ways. First, our results are consistent with the reward value and prediction model (RVPM, Silvetti, Seurinck, & Verguts, 2011), which proposes that incongruent trials, relative to congruent trials, evoke lower success expectancy. This is due to the subjectively experienced difficulty (e.g., longer reaction times and higher error probability) associated with the incongruent stimulus (Alexander & Brown, 2011). However, once the conflict is continuously resolved successfully, the incongruent stimulus will elicit a positive prediction error (i.e., greater success experience than initially expected), which should be greater than the prediction error from completing a congruent trial. In our experiments, the MI and the MS stimuli may have been associated with greater positive prediction errors due to the higher proportion of incongruent (Experiment 1) or switching (Experiment 2) trials.

Second, our results can also be explained by the perceptual enhancement of more demanding stimuli. For example, Egner and Hirsch (2005) proposed the target amplification hypothesis to explain the conflict adaptation effect in which the congruency effect is contextually modulated such that the effect is smaller following the successful processing of an incongruent stimulus. They proposed that the detection of the conflict promotes the amplification of the target dimension so that when the signal-to-noise ratio between the target and the distractor increases, this in turn minimizes the distractor-related influence. In the association phases of the current study, the participants processed half of the face stimuli in the more demanding conditions of mostly incongruent (MI) or mostly switching (MS), possibly amplifying the stimulus strength. In turn, the amplified signal may be viewed as positive.

However, one prominent alternative explanation for our results still exists. Our experimental design allowed the stimuli to stay on the screen until participants produced a response, which raises the possibility of a "mere exposure" (Montoya, Horton, Vevea, Citkowicz, & Lauber, 2017) as a confounding variable to the cognitive effort. It is worth noting that, in our results, the reaction times for the MI and MS faces were comparable to the reaction times for the MC and MR faces. However, in both experiments, the congruency effect and the task switch cost were substantial. Further, 80% of the MI and MS faces were presented in the incongruent or in the task switching condition, but only 20% of the MC and MR faces were presented in the incongruent or in the task switching condition. Therefore, the MI and MS faces were eventually presented for a longer duration than the faces in the MC and MR conditions. Thus, it is possible that we are observing an exposure effect, in which faces that were looked at for a longer amount of time were perceived as more positive simply because participants had greater exposure to these stimuli. If so, it is not the level of effort associated with the MI and MS faces, but the exposure duration that resulted in the positive valence in the transfer phases. Admittedly, the current design does not allow to dissociate these two confounding factors. Future research should investigate whether it is duration of the viewing time or level of cognitive effort that can explain our results. Specifically, it should be investigated whether similar effects prevail when the stimulus presentation time is held constant.

In relation to the notion of conflict as an aversive signal, we note that the supporting evidence has been mostly obtained as a result of online adjustment of the valence or preference toward the stimulus. For example, in Kool et al. (2010), participants made a continuous choice between two sets of stimuli from trial to trial, and the proportion of choice of the set associated with less effort gradually increased over 500 trials. Also, in Dreisbach and Fischer (2012), the effect of processing an incongruent stimulus was observed as a priming effect on the subsequent task. While the law of less effort may better apply to a moment to moment preference, learned industriousness should emerge over time. The theory of learned industriousness (Eisenberger, 1992) suggests that, while the high level of effort itself may be aversive, the contingent reinforcement on the successful exertion of the high level of effort can remove the aversiveness. If people can continuously and successfully exert a high level of effort toward a stimulus over an extended period of time, they may develop a positive affect toward the stimulus.

However, if the positivity effect we observed is replicated and robust, it seems to stand in contrast to recent research using go/no-go and stop signal tasks that suggests that inhibiting a response can lead to a negative experience and subsequent devaluation of that stimulus (e.g., Allom, Mullan, & Hagger, 2016; Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017). One explanation for the devaluation effect is that the inhibition of a response towards a stimulus often triggers a conflict between the automatic tendency to respond and the need to inhibit the response tendency. Over time, therefore, the no-go stimuli become less attractive (i.e., less positive). One possibility for the discrepancy in findings between these studies and our study is that the nature of cognitive effort involved in the Go/no-go and stop signal tasks may be different from the cognitive effort involved in the Stroop and task-switching paradigms. For example, in the go/no-go and stop signal tasks, effort is needed when participants inhibit a response (e.g., as required on no-go trials) and abort the on-going cognitive processes, which may override the initial goal to complete the task. However, in the Stroop and task-switching paradigms, effort is required to select the target more efficiently so that the task goal can be accomplished. While it is only a conjecture that aborting the task goal may promote negative emotion and that accomplishing the goal may promote positive emotion, this contradiction in findings warrants further research.

As noted in the results sections, we failed to replicate the ISPC effect (Jacoby, Lindsay, & Hassels, 2003) and the ISSP effect (Chiu & Egner, 2017). Both the ISPC and the ISSP effects can be considered as the result of reactive control (Braver, 2012), in the sense that the need to increase the control level is externally triggered in response to the current stimulus. It has been suggested that the extent of reactive control is subjected to individual characteristics such as fluid intelligence (Burgess & Braver, 2010). Braver (2012) further suggested that personality traits can be related to the efficacy of reactive control. While it is beyond the scope of the current study to conjecture about the nature of the individual differences that may or may not be associated with the control to emotion transition, our results certainly call for further research to investigate the effects of various individual difference factors. We did not collect any awareness data regarding whether the learning of the association was explicit or not. Future research should investigate whether an explicit awareness of the difficulty level of the stimulus plays any role in the emotion-cognition interaction.

One other limitation in interpreting our results is that the type of emotion we examined here is the emotion ‘perceived’ by the participants, and not necessarily the emotion ‘experienced’ by the participants. Many previous studies we based our study on have used asocial emotion stimuli such as scenes or words. For example, Dreisbach and Fischer (2012) and Ivanchei et al. (2019) used images from the International Affective Picture System (IAPS, Lang, et al., 1997). Also, Dreisbach and Fischer (2012) and Schouppe, Braem et al. (2015) used emotion words. The emotional valence of scenes and words may be the result of interpretation of the semantic activation or the physiological changes elicited by the stimuli, therefore creating ‘experienced’ emotion. However, face stimuli fall into the category of social stimuli, which may create slightly different demands on perception. In a social exchange, we ‘read’ emotion from the interaction partner and this perceived emotion does not necessarily correspond to the induced emotion. For example, it would be straightforward to recognize ‘sadness’ from a crying person, but this perception does not guarantee which kind of emotion that the perceiver would experience. In fact, it has been also well established the kind of emotional processing of asocial stimuli is different from the emotional processing in a social context (Sabatinelli, et al., 2011). In the future, it would be worth exploring whether the emotional outcome of cognitive effort is domain specific or domain general.

In conclusion, we report that exerting a high level of cognitive effort may result in positive valence. However, our study also raises several important questions that we cannot address directly within the limits of the current study. Therefore, future research will need to replicate these results using an improved design, especially one that holds stimuli exposure constant. Previous studies have shown that simply perceiving conflict or detecting the cognitive demand associated with a stimulus may serve as an aversive event (Dreisbach & Fischer, 2012; Kool, et al., 2010). However, our results may imply that the consequence of processing the conflict can be different depending on the association between the stimulus and the level of cognitive effort. Having to raise the cognitive effort expended toward a stimulus only some of the times it is presented (against the associations and expectations formed previously) may be a negative experience, as in our mostly congruent and mostly repetition conditions. In contrast, the successful outcome of exerting a high level of cognitive effort may lead to a positive valence, as demonstrated in the mostly incongruent and the mostly switching conditions. These findings suggest that it is necessary to investigate further the factors that influence the interactions between cognitive effort and emotional valence.

Appendix 1: Identification codes of face stimuli of Experiment 1

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

Appendix 2: Identification codes of face stimuli of Experiment 2

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

Acknowledgements This research was supported by the Post-Doctoral Fellowship Program funded by the Korean Psychological Association awarded to Jini Tae.

Data availability The experiments and datasets for this experiment are available at https://osf.io/g62mh/ and from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards This study was approved by The George Washington University Institutional Review Board. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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