Emotional interference during conflict resolution depends on task context

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ABSTRACT
Evidence is currently mixed regarding the way in which cognitive conflict modulates the effect of emotion on task performance. The present study aimed to address methodological differences across previous studies and investigate the conditions under which interference from emotional stimuli can either be elicited or eliminated under high cognitive conflict. Four behavioural experiments were conducted with a university sample using a gender-discrimination stimulus-response compatibility task. In line with our previous findings, Experiment 1 found that when emotion and cognitive conflict conditions were blocked, emotional faces increased reaction time interference during response compatible trials (low conflict) but not response incompatible trials (high conflict). However, when conflict and emotion conditions were randomised in different configurations across Experiments 2 (all trials randomised), 3 (emotion blocked, compatibility randomised) and 4 (compatibility blocked, emotion randomised), emotion interfered with task performance across both high and low conflict trials. These results suggest that predictability of both compatibility and emotion is required in order to obtain reduced emotional interference under high cognitive conflict. Consistent with prior reports, a top–down anticipatory control mechanism seems to be engaged in the presence of negative emotion when there are incompatible stimulus-response mappings.

Task-irrelevant emotional information interferes with central task performance (Carretié, 2014); however, the extent to which this occurs varies with task demands (Murphy, Groeger, & Greene, 2016). One phenomenon receiving considerable empirical attention is the effect of emotion on cognitive conflict resolution, for example as operationalised by Stroop, flanker and Simon tasks. Evidence to date is conflicting, with some studies showing that reaction time interference on high conflict trials is increased in the presence of emotion (Hart, Green, Casp, & Belger, 2010; Sommer, Hajak, Döhnel, Meinhardt, & Müller, 2008), while others have shown reduced interference under these circumstances (Frühholz, Fehr, & Herrmann, 2009; Kanske & Kotz, 2011a, 2011b). Due to methodological differences across studies showing these opposing effects, it has not always been possible to isolate specific factors that may explain these discrepancies. Here we report four experiments using a well-controlled stimulus-response (S-R) compatibility task based on the Simon effect (Simon & Wolf, 1963), suggesting that top–down expectation influences whether or not we see reduced interference from emotional stimuli under high cognitive conflict.

Manipulations of cognitive conflict have shown that in many cases, emotion and conflict interact to increase reaction time interference on the crucial emotion/high conflict condition. For example, in an emotional priming study, Hart et al. (2010) asked participants to indicate the number of items presented in congruent (i.e. the digit 4 in an array of 4) or incongruent (i.e. the digit 4 in an array of 3) arrays during a number Stoop task. They found that participants were slowed even further by incongruent trials when preceded by aversive versus neutral stimuli. Similarly,
Sommer et al. (2008) presented participants with affective pictures to induce positive, negative or neutral affect in between blocks of Simon task trials and found that negative, but not positive or neutral valence pictures led to increased error rates (and marginally increased RTs) on incongruent (high conflict), but not on congruent (low conflict) trials, suggesting that emotion impairs cognitive control when the non-target stimulus is emotional, and particularly when the valence is negative (Padmala, Bauer, & Pessoa, 2011). This increase in interference has been explained in terms of increased competition between two resource intensive processes for limited cognitive capacity (Carretié, 2014; Desimone & Duncan, 1995; Ellis & Ashbrook, 1988).

However, several studies have reported opposing effects. For example, Frühholz et al. (2009) asked participants to indicate the valence of a centrally presented face (fearful, happy or neutral) presented on a task-irrelevant coloured background that was either congruently or incongruently associated with the target emotion in a prior training phase. They found that reaction time interference from colours incongruent with the target valence was significantly reduced in the presence of both fearful and happy faces relative to neutral. In this study, congruency was manipulated in the emotional domain. Zinchenko, Kanske, Obermeier, Schröger, and Kotz (2015) manipulated congruency in both emotional and cognitive domains across two experiments where participants had to either categorise spoken vowels (cognitive conflict) or their emotional valence (emotional conflict), while visual information was congruent or incongruent. Negative emotional stimuli produced increased RTs to incongruent stimuli when emotion was task-irrelevant (cognitive conflict task), however RTs to incongruent stimuli were reduced when emotion was task-relevant (emotional conflict), similar to the findings of Frühholz et al. (2009) where the source of conflict was also emotional.

As well as the source of conflict (cognitive vs. emotional), it is possible that the timing of processing of emotional information also plays a role in the effect emotions may have on conflict processing. For example, Hart et al. (2010) presented the aversive/neutral stimuli prior to each trial (for 150 ms) whereas Frühholz et al. (2009) conditioned a certain colour with a specific emotion prior to the experiment. Nonetheless, similar effects have also been found when emotion is presented simultaneously, is purely task-irrelevant, and congruency (conflict) is manipulated in a non-emotional task domain. For example, Kanske and Kotz (2011a) used a modified flanker task, in which participants had to indicate the colour of a centrally-presented word, flanked by the same words written in either a congruent or incongruent colour. Reaction time interference from the incongruent colour was reduced when negatively valenced words were presented, relative to neutral, in line with Zinchenko et al.’s (2015) findings.

The same pattern of results was seen with a conceptually similar conflict task using an auditory Simon task, in which participants identified the gender of a speaker presented in either the left or right ear, and responded with either the compatible or incompatible hand. The words presented were either negative or neutral in valence (Kanske & Kotz, 2011b). The authors suggest that these effects represent an adaptive triggering of cognitive control by salient emotional stimuli, which improves cognitive control in the service of conflict resolution (Kanske & Kotz, 2011a; Norman & Shallice, 1986).

At present, there is some ambiguity regarding the conditions under which emotion may facilitate versus impede processing under high cognitive conflict. There are considerable differences in tasks used across studies (Cohen & Henik, 2012), even when restricting the dependent variable to reaction times. These include modality (visual, auditory), task demands (flanker, Simon, Stroop), task parameters (timing, randomisation) and whether or not emotion is purely task irrelevant (although see Cromheeke and Mueller (2014) for an fMRI meta-analysis of emotion–cognition interaction tasks showing increased activation of the right dorsolateral prefrontal cortex and inferior parietal lobule when emotion was task-irrelevant relative to relevant, suggesting systematic differences merit further enquiry).

Additionally, it is important to rule out the possibility that perceptual load (rather than cognitive load) effects may be contributing in cases where reaction time interference is reduced in the presence of emotion under high load. In perceptual load tasks involving emotional distractors, i.e. tasks where load is manipulated by increasing the difficulty of a perceptual decision such as judging bar orientation, interference from emotion is usually reduced under high load (e.g. Erthal et al., 2005; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). The explanation typically given is that, under high load, insufficient attentional resources are available for processing task-irrelevant emotion, and therefore emotion is unable to break
through and detrimentally “capture” attention from the central task (Lavie, 2005; Pessoa et al., 2002). Since effects of perceptual load may look superficially similar to effects seen in the subset of cognitive conflict studies showing reduced emotional interference under high load, it is important to control as far as possible for potential differences in perceptual processing of task-irrelevant emotional information. Several previous well-designed studies have done so (e.g. Frühholz et al., 2009; Kanske & Kotz, 2011a, 2011b, 2011c; Zinchenko et al., 2015). In our previous study (Sebastian, McCrory, De Brito, & Viding, 2017), we used the same stimulus in the visual domain to convey both task-relevant information and task-irrelevant emotion, controlling as far as possible for differences in visual perception across conditions.

In this study, we described an emotional Simon (S-R compatibility) task which was designed to match perceptual processing of task-irrelevant emotional information across compatibility conditions in the visual modality. Participants were presented with pairs of male-female faces that were either emotional (fearful and angry) or calm in expression and were instructed to identify the target gender (e.g. male) and indicate whether it was tilted to the left or right (see Figure 1 and Task design and procedure for details). Task-relevant information (gender) and task-irrelevant emotion were co-localised to the same stimulus. In order to identify the target’s gender, the facial stimuli needed to be scanned to the same degree and in the same way on both compatible (e.g. target face on the left and tilting left (low conflict)) and incompatible (e.g. target face on the right and tilting left (high conflict)) trials. Mean reaction time effects showed reduced interference from fearful faces (vs. calm) under high (vs. low) cognitive conflict, but our task design ruled out a perceptual load based explanation.

One interpretation is in line with Kanske and Kotz (2011a) above, i.e. emotion triggered an adaptive executive attentional mechanism. Another (not necessarily mutually exclusive) possibility is that a top–down mechanism is involved whereby an “attentional set” or prediction is created as a result of the blocked nature of the design used in our above study, such that participants “expect” the same trial type (compatible or incompatible, and/or emotional or neutral) to be repeated (Cohen & Henik, 2012; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Theeuwes, Kramer, & Belopolsky, 2004). Using an emotional Stroop task, Etkin et al. (2006) found that the repetition of incompatible stimuli (e.g. a fearful face with the word “happy” superimposed), may have engaged an anticipatory top–down mechanism, leading to improved conflict resolution (reduced reaction time interference) on the next high load trial. While, the requirement to “switch” from one trial type to another was not controlled for in this study, meaning that conflict resolution may have been confounded by simultaneous switching, this was not a possibility in our previous study, since stimuli were blocked by emotion and condition. Thus, one interpretation is that reduced interference from fear in the high conflict condition could be driven by increased top–down control, applied prospectively across the block in response to high executive demand (Cohen & Henik, 2012).

The present study aimed to investigate the above hypothesis and shed light on prior inconsistent findings by studying the conditions under which the observed interaction effect holds. In Experiment 1 we used the same blocked design as Sebastian et al. (2017) to replicate this effect. In the following experiments, we systematically deconstructed aspects of the task’s structure which may facilitate performance.
in the emotional/high conflict condition. Experiment 2 fully randomised both emotion and compatibility trials, Experiment 3 randomised compatibility but kept emotion blocked, and Experiment 4 randomised emotion but blocked compatibility. We predicted that the design in Experiment 2 would abolish the interaction effect, i.e. we would not see reduced RT interference on emotion/high conflict trials. Further, if the interaction effect depends on anticipatory preparation for both compatibility and emotion, then the effect would also be obliterated in Experiments 3 and 4; alternatively, these experiments allowed us to investigate whether anticipation in only one domain is required.

**Experiment 1**

**Introduction**

As discussed above, in Experiment 1 we aimed to replicate the effects of reduced emotional interference under high cognitive conflict found by Sebastian et al. (2017), using the same task design, in which individual emotion conditions of high and low cognitive conflict were presented in separate blocks of trials.

**Method**

**Participants**

Forty-two university students were recruited from Royal Holloway University of London and received course-credit or £3 for participation. This sample size was comparable to previous similar studies (38 participants in Sommer et al.’s (2008) study and 26 in Kanske and Kotz (2011b)) and double that of Sebastian et al.’s original study (20 participants), to maximise the chance of detecting the hypothesised effect if present (Simonsohn, 2015). Six participants were excluded due to error and missed trial rates that were greater than 2.5 standard deviations above the group mean. Data from a final sample of 36 participants (15 males, mean age 19.92, SD = 2.82, range = 18–30) were analysed. No participants overlapped across the four experiments. The study was approved by the Royal Holloway Department of Psychology ethics committee.

**Stimuli**

Stimuli consisted of 48 grey-scale faces of two male and two female identities each with different facial expressions depicting three emotions: fear, anger and calm. The expressions were chosen from the standardised NimStim face set (Tottenham et al., 2009). Positive emotional stimuli were not included in the task as previous studies using similar stimuli has found weaker or no effects with happy faces (e.g. Hodsoll, Viding, & Lavie, 2011; Sommer et al., 2008), most likely because such stimuli do not pose a threat (as do fear and anger) and so do not require processing resources to be diverted from the main task (Sun, Ren, & He, 2017). An oval cut-out was placed on each face to remove gender specific information, such as hair. Each face oval measured 6 × 4 cm. All faces were presented in male and female pairs with identical expressions and were tilted 35° to the left or 35° to the right (see Figure 1). There were eight possible pairs (each male with each female) for each facial expression at each level of cognitive conflict (high or low i.e. compatible or non-compatible), with 64 images in total. Face pairs were presented on a white background measuring 606 × 349 pixels.

**Task design and procedure**

These followed Sebastian et al. (2017). The task consisted of six blocks of trials, one block for each emotion (fear, anger, calm) × compatibility (compatible, incompatible) condition (8 trials per block). These six blocks (48 trials) were each presented three times in a pseudorandomised order (144 total trials). Randomisation was constrained so that no more than two of the same block type (e.g. fear/compatible) was presented sequentially. Within each block, randomisation was constrained so that all left (or right) response trials were not presented sequentially. Participants completed two runs of the task (288 trials in total).

Each trial was presented for 2000 ms, followed by a fixation cross presented for 500 ms. After every 48 trials a fixation cross was displayed for 10 s as a short break. Participants were given clear instructions beforehand to search for the target face (either male or female; counterbalanced across participants and stratified by participant gender) and indicate on the keyboard using their dominant hand whether the target face was tilting left or right. On compatible trials, the target face was located on the same side to which it was tilted (e.g. on the left and tilting left); while on incompatible trials the target face was on the opposite side (e.g. on the right and tilting left). This set up a spatial incompatibility between the required response and its location. Participants viewed the task on a monitor of 1920 × 1090 pixels.
The task was presented and responses were recorded using Cogent 2000 for Matlab (version R2015a).

**Additional measures**

Participants also completed questionnaire measures of aggression (The Buss-Perry Aggression Questionnaire (Buss & Perry, 1992); The Self-Report Psychopathy Scale-III Short Form (SRP-III-SF; Paulhus, Neumann, & Hare, 2016)) and anxiety (State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983)) to investigate the role of individual differences on the processing of emotion under differing cognitive conflict. However, these measures were not correlated with task performance and are therefore not discussed further.

**Data analysis**

Behavioural data were analysed using repeated measures ANOVAs on mean correct reaction times (RTs) after removing missed trials and extreme individual RTs (<200 ms or >1500 ms), and on error rates. Pairwise comparisons were Bonferroni corrected. Missed trials were low overall (0.49%) and were not analysed further. Error rates were also low across all four experiments (<5%), and thus error rate analyses were not informative. However, as a manipulation check, we checked whether error rates were higher for incompatible than compatible trials; indeed, this was the case for all experiments (p < .05).

**Results**

A 2 × 3 Compatibility (compatible, incompatible) × Emotion (fear, anger, calm) repeated measures ANOVA on mean correct RTs revealed a main effect of Compatibility: $F(1, 35) = 96.10, p < .001$, partial $\eta^2 = .73$, with RTs significantly faster on compatible ($M = 762$ ms, $SD = 112$) than incompatible ($M = 834$, $SD = 110$, $p < .001$) trials. The difference in RTs between incompatible and compatible trials was significant for all three emotion face types ($ps < .001$). There was also a significant main effect of Emotion: $F(2, 70) = 11.53, p < .001$, partial $\eta^2 = .25$, with RTs significantly slower for anger trials ($M = 816$, $SD = 113$) relative to calm ($M = 791$, $SD = 111$, $p < .001$) and fear ($M = 785$, $SD = 110$, $p = .001$), however there was no significant difference in RTs between fear and calm ($p > .99$).

There was also a significant interaction between Compatibility and Emotion: $F(2, 70) = 6.13, p = .004$, partial $\eta^2 = .15$ (Figure 2(a)). We ran post-hoc t-tests to further investigate the interaction effect by determining whether the difference in RTs between compatible and incompatible trials for fear (and anger) significantly differed from that of calm. Indeed, the difference in RTs between compatible and incompatible trials for calm ($M = 741$, $SD = 110$; calm incompatible: $M = 841$, $SD = 112$; difference: $M = 100$, $SD = 50$) was significantly greater than the equivalent difference for fear (fear compatible: $M = 754$, $SD = 116$; fear incompatible: $M = 816$, $SD = 103$; difference: $M = 61, SD = 68$; (t(35) = 3.28, $p = .007$) and anger (anger compatible: $M = 790$, $SD = 109$; anger incompatible: $M = 844$, $SD = 116$; difference: $M = 54$, $SD = 77$; (t(35) = 3.11, $p = .011$). There was no difference between anger and fear ($t(35) = .49, p > .99$) (see Figure 2(a)).

Pairwise comparisons of simple effects (see Figure 2(a)) further revealed that during the compatible blocks RTs for anger trials were significantly longer relative to fear trials ($p = .001$) and calm trials ($p < .001$), however fear trials were not significantly different from calm trials ($p = .44$). In contrast, during the incompatible block RTs for anger trials were not significantly different from fear ($p = .10$) or calm trials ($p > .99$), however fear trials were faster than calm trials ($p = .015$).

Given that there was a main effect of Emotion, we computed difference scores after z-standardization of the RTs in each Emotion condition in order to control for the main effects of emotion. This is based on findings showing that the magnitude of S-R congruency effects is affected by the mean reaction time (De Jong, Liang, & Lauber, 1994). Pairwise comparisons of the z-difference scores were performed revealing a significant difference between calm and fear ($p = .014$), and calm and anger ($p = .016$), but not fear and anger ($p > .99$).

To investigate the effects of participant gender, gender was included as a between-subjects factor in the main ANOVA. There was no significant main effect of participant gender ($p = .07$), or an interaction between gender and Emotion ($p = .38$) or gender and Compatibility ($p = .82$). The Gender × Emotion × Compatibility interaction was also not significant ($p = .98$). Thus, for the following experiments we used convenience samples which were predominantly female.

**Discussion**

As would be expected due to the relative difficulty of the task, RTs for incompatible trials were longer (and
error rates higher) compared to compatible trials. We also found a main effect of Emotion, driven by slower RTs to angry faces relative to both calm and fearful faces, with no difference between fear and calm trials. In line with Sebastian et al.'s (2017) study, the interaction between Compatibility and Emotion was significant; however, while the original study found the effect to be driven only by fear, here we found similar effects for both emotion conditions. For both fear and anger, RTs were disproportionately slow in the compatible relative to the incompatible condition, with a significantly larger RT difference seen between the two calm conditions. This suggests that emotion caused proportionately reduced interference on more demanding (incompatible) trials, replicating and extending (to anger) the original effect found by Sebastian et al. (2017).

However, some differences were also seen. For example, Sebastian et al. (2017) found no significant differences between RTs on fear, anger and calm conditions during the incompatible blocks (indicating that emotion did not cause interference under high cognitive conflict). However, while there was no difference between anger and calm incompatible trials in the present study, RTs to incompatible fear trials were significantly faster compared to incompatible calm trials, suggesting if anything a facilitation effect for this condition (in line with Kanske & Kotz, 2011a, 2011b). Some studies have shown that fearful expressions gain preferential access to awareness (Yang, Zald, & Blake, 2007), which may explain the faster RTs; albeit speculatively since this result was not in line with predictions. Regarding compatible trials, Sebastian et al. (2017) found slower RTs on fear compatible trials relative to calm compatible trials (another line of evidence suggesting emotional interference specifically on compatible, but not incompatible, trials), whereas the current study found this effect for anger but not fear. This could again be due to a general fear facilitation effect across compatibility conditions. Overall however, the evidence of a smaller

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**Figure 2.** Mean RTs (ms) for correct trials across all conditions when 2(a) emotion and compatibility were blocked, 2(b) emotion and compatibility were randomised, 2(c) compatibility was randomised and Emotion was blocked, 2(d) compatibility was blocked and emotion was randomised. Error bars represent standard error. For 2(a), the difference between compatibility conditions was significantly greater for calm than for fear or anger, as indicated by *p < .05. For 2b, c, d, brackets indicate main effects of Emotion, **p < .001. For every Emotion there was also a significant difference between compatibility conditions (p < .001).
difference between compatible and incompatible RTs for fear and anger relative to calm replicates and extends (to anger) the previous pattern of results.

These findings are in line with previous studies (e.g. Frühholz et al., 2009; Kanske & Kotz, 2011a, 2011b; Zinchenko et al., 2015) that have shown reduced RT interference from emotion during high cognitive conflict. Since perceptual inputs were matched across conditions, a “bottom-up” explanation, i.e. that perceptual inputs differ in some way, is unlikely (although without eye-tracking measures, this cannot be conclusively shown). Therefore, it might be hypothesised that a top-down mechanism is involved whereby an attentional set or prediction is created as a result of the blocked nature of the design (Etkin et al., 2006; Theeuwes et al., 2004). On incompatible (high conflict) conditions, processing resources may be “pre-allocated” to resolving the cognitive conflict, thereby reducing the capacity for processing the emotional information, or even actively suppressing this processing. However, during compatible (low conflict) trials, greater attentional capacity is available, leading to processing of the emotional information which then interferes with task performance relative to calm trials. In support of this explanation, Etkin et al. (2006) suggested that the repetition of incongruent stimuli in an emotional Stroop task engaged an anticipatory top-down mechanism likely implemented by the rostral anterior cingulate cortex, which facilitated performance.

It might therefore be predicted that, in the current task, removing the blocked structure would eliminate the interaction effect found, since a top-down strategy would no longer be possible. This is addressed in Experiment 2 where all trials (compatible/incompatible, fear/anger/calm) are intermixed and randomised. In order to systematically investigate the conditions under which the interaction effect of interest is found, in Experiment 3 emotion is blocked while compatibility is randomised, and in Experiment 4 compatibility is blocked while emotion is randomised. This will allow us to uncover whether anticipation of compatibility, emotion, or both are required in order to see reduced interference from emotion under high (vs. low) cognitive conflict. As discussed above, it is possible that this emotion × compatibility interaction effect arises from participants’ ability to prepare for emotion/high conflict trials in a fully blocked design. Although in the in the domain of perceptual load rather than cognitive conflict, Theeuwes et al. (2004) found that increased distractor interference under low (relative to high) load during a visual search task was abolished when high and low load trials were intermixed. Instead, interference was seen across both load conditions. Further, trial-by-trial data showed reduced emotional interference only in high-load trials preceded by a high load trial. These findings suggest that, when high and low load trials are randomised, expectancies must be generated on a trial-by-trial basis, making it difficult to impose a top-down attentional set that could be applied to several trials of the same type (unless such trials occur consecutively by chance). Further, Etkin et al. (2006) found similar effects in an emotional conflict resolution task. Participants were faster to judge whether a face was fearful or happy in a high conflict trial (fearful face overlaid with the word “happy” and vice versa) when that trial was preceded by another high conflict trial. This suggests that an anticipatory mechanism engages in a similar way for conflict resolution in the cognitive domain as for high perceptual load. However, the Etkin et al. (2006) study did not specifically examine an emotion × conflict interaction as a neutral control condition was not included; additionally, emotion was task-relevant, in contrast to the present study. In Experiment 2 we fully randomise trial presentation across both Compatibility and Emotion, while keeping constant all other aspects of task design. If such an anticipatory mechanism explains the effects obtained in Experiment 1, we would predict randomising trial order to lead to interference from emotion in both high and low conflict trials.

**Method**

**Participants**

A total of 41 (3 males, mean age = 18.68, SD = 1.46, range = 18–27) participants were recruited in the same manner as for Experiment 1 and data for all participants were analysed.

**Stimuli and procedure**

The stimuli, design, and procedure were exactly the same as in Experiment 1. However, the presentation
of the six different trial types (fear compatible, fear incompatible, anger compatible, anger incompatible, calm compatible and calm incompatible) was randomised. Randomisation was constrained so that no more than two of the same trial types were presented sequentially.

**Results**

In line with Experiment 1, there was a significant main effect of compatibility ($F(1, 40) = 98.32, p < .001, \eta^2 = .71$) with RTs significantly faster for compatible trials ($M = 803, SD = 115$), compared to incompatible trials ($M = 868, SD = 119; p < .001$). There was also a significant main effect of Emotion ($F(2, 80) = 18.61, p < .001$, partial $\eta^2 = .32$) with RTs significantly slower for anger trials ($M = 853, SD = 116$) relative to calm ($M = 828, SD = 118, p < .001$) and fear ($M = 827, SD = 118, p < .001$); however, there was no significant difference in RTs between fear and calm ($p > .99$).

There was, however, no significant interaction between Compatibility and Emotion ($F(2, 80) = 1.36, p = .26$, partial $\eta^2 = .03$). As with Experiment 1, we ran post-hoc tests and found that there were no significant differences in the RT difference between compatible and incompatible trials for calm (calm compatible: $M = 791, SD = 118$; calm incompatible: $M = 864, SD = 117$; difference: $M = 73, SD = 50$) and fear (fear compatible: $M = 798 ms, SD = 118$; fear incompatible: $M = 856, SD = 118$; difference: $M = 58, SD = 57$; $t(40) = 1.56, p = .38$) or calm and anger (anger compatible: $M = 822, SD = 109$; anger incompatible: $M = 884, SD = 123$; difference: $M = 62, SD = 54$; $t(40) = 1.08, p = .38$), in contrast to the findings of Experiment 1. There was also no difference between fear and anger difference RTs ($t(40) = −.48, p > .99$) (Figure 2(b)).

To control for the main effect of emotion we conducted the same analysis on the z-difference scores as in Experiment 1 and did not find any significant differences between the emotion conditions ($ps > .39$), in contrast to Experiment 1.

**Discussion**

Similar to the findings of Experiment 1, RTs for incompatible trials were longer compared to compatible trials, and RTs to angry faces were longer relative to calm and fearful faces. The interaction between Compatibility and Emotion, however, was not significant. Therefore, despite individual trials being identical to those in Experiment 1, we did not see reduced interference from emotion on incompatible trials when presentation of all trial types was randomised. If cognitive conflict had been the only factor determining the extent to which emotion interfered with task performance, the effects of Compatibility should have been the same in the two experiments. It is likely that in randomising stimulus presentation, participants were unable to engage differential anticipatory top–down cognitive control processes for high vs. low conflict trials (in line with Etkin et al., 2006; Theeuwes et al., 2004), leading to similar interference effects on both low and high conflict trials.

Some previous studies which have used randomised or pseudorandomised trial presentation and manipulated cognitive task difficulty have found similar behavioural effects as the present experiment. For example, Mitchell et al. (2007) asked participants to indicate the gender of an emotionally valenced face (defined as low cognitive load), or judge superimposed words based on case (mid load) or judge words based on syllable number (high load). While they found that RTs were slower with increasing load, there was no significant interaction between emotion and cognitive load (although an interaction was seen in amygdala response). Thus, it could be that manipulating cognitive load on a trial-by-trial basis is not always sufficient to elicit an interaction effect in the RT data, albeit using a different cognitive task that did not involve a classic conflict resolution element. Kanske & Kotz (2011a, 2011b), on the other hand, did find an interaction effect with pseudorandomised trial presentation. However significant task differences relative to our emotional Simon task (emotional flanker and auditory Simon tasks, significantly longer trials), and a difference in the shape of the interaction (driven by increased RTs on the neutral/incongruent condition, as opposed to increased RTs on emotional/compatible trials), makes direct comparison difficult.

Looking at the results of Experiment 1 and 2, our findings suggest that the opportunity for participants to engage a top–down anticipatory mechanism across the block is an important factor underpinning the elicitation of an emotion × compatibility interaction. The cognitive conflict manipulation alone (as implemented in the present task) does not seem to elicit this effect on a trial by trial basis. However, it is unclear which aspects of block structure are most important. In Experiment 2, two aspects of the task were varied relative to Experiment 1: randomised compatibility, and randomised emotion. Therefore, in the following studies we systematically investigate
whether it is the compatibility randomisation that is the key factor in eliminating the interaction effect, or whether predictability of the emotion is also important.

**Experiment 3**

**Introduction**

As demonstrated in Experiment 2, when trial types are intermixed expectancies need to be generated on a trial-by-trial basis, making it difficult to anticipate and prepare for demanding emotion/high conflict trials (which may explain paradoxically reduced RT interference on such trials in Experiment 1). However, it is unclear whether both compatibility and emotion need to be unpredictable in order to abolish the interaction seen in Experiment 1, or whether randomisation in just one domain is required. Prior studies have shown that repetition/predictability trials (which may explain paradoxically reduced RT faster for compatible trials ($M = 758$ SD = 85), compared to incompatible ($M = 821$, SD = 87) trials ($p < .001$). There was also a significant main effect of Emotion ($F(2, 74) = 37.40$, $p < .001$, partial $\eta^2 = .50$) with RTs significantly slower for anger trials ($M = 817$, SD = 90) relative to calm ($M = 781$, SD = 81, $p < .001$) and fear ($M = 770$, SD = 88, $p < .001$), however there was no significant difference in RTs between fear and calm ($p = .092$).

As with Experiment 2, there was no significant interaction between Compatibility and Emotion: $F(2, 74) = 2.27$, $p = .11$, partial $\eta^2 = .06$ and the post-hoc tests showed no significant differences in RT differences between compatible and incompatible trials when comparing calm (calm compatible: $M = 748$, SD = 81; calm incompatible: $M = 815$, SD = 80; difference: $M = 67$, SD = 43) and fear (fear compatible: $M = 744$, SD = 88; fear incompatible: $M = 797$, SD = 87; difference: $M = 53$, SD = 44; $t(37) = 2.17$, $p = .11$) and calm and anger (anger compatible: $M = 783$, SD = 85; anger incompatible: $M = 850$, SD = 94; difference: $M = 67$, SD = 45; $t(37) = .077$, $p > .99$) in line with the findings of Experiment 2. There was no difference between fear and anger ($t(37) = −1.60$, $p = .36$) (Figure 2(c)).

However, the $z$-difference score analysis to control for the main effect of Emotion (as in Experiment 1 and 2) revealed a significant interaction between Emotion and Compatibility ($F(2,74) = 3.62$, $p = .032$, partial $\eta^2 = .089$), driven by a significant difference between calm (incompatible – compatible) and fear (incompatible – compatible) ($p = .014$, driven by a greater difference between compatibility conditions for calm than fear, as in Experiment 1). There were no differences between calm and anger ($p = .48$), or fear and anger ($p = .83$).

A three-way Emotion (fear, anger, calm) $\times$ Current Trial Type (compatible, incompatible) $\times$ Preceding Trial Type (compatible, incompatible) repeated
measures ANOVA was conducted to investigate sequential trial effects (Gratton effect). However, the crucial three-way interaction was not significant (F(2, 74) = .14, p = .87, partial η² = .004), neither was the Emotion × Current Trial Type interaction (F(2, 74) = 1.79, p = .17, partial η² = .046), nor the Emotion × Preceding Trial Type interaction (F(2, 74) = .86, p = .43, partial η² = .023). There was a main effect of Emotion (F(2, 74) = 32.4, p < .001, partial η² = .47), in line with the findings of the previous Experiments. There was also a main effect of Current Trial Type (F(1, 37) = 102.23, p < .001, partial η² = .73), Preceding Trial Type (F(1, 37) = 12.31, p = .001, partial η² = .25) and an interaction between the two (F(1, 37) = 12.41, p = .001, partial η² = .25).

Discussion

Similar to the findings of Experiment 1 and 2, RTs for incompatible trials were longer compared to compatible trials and RTs to angry faces were longer relative to calm faces and fearful faces, but there were no differences in RTs between fear and calm trials. As with Experiment 2 the interaction between Compatibility and Emotion was not significant (although controlling for the main effect of emotion, a small effect was seen in the fear condition, relative to calm), and similar patterns were observed across both compatible and incompatible trials. This supports the findings of Experiment 2 and previous studies (e.g. Etkin et al., 2006), suggesting that when high and low conflict trials are intermixed, similar emotional interference effects (in this case limited to anger) occur on both low and high conflict trials. Experiment 3 also extends findings from Experiment 2 to show that removing compatibility predictability is sufficient to attenuate (if not completely abolish) the interaction effect seen in Experiment 1. Even if we take the results of the subsidiary analysis in which an interaction was seen for fear, the mean RT difference (calm/incompatible-calm/compatible)–(fear/incompatible-fear/compatible) was only 14 ms (relative to 39 ms in Experiment 1).

The additional sequential trial effects analysis failed to yield a significant interaction with Emotion, perhaps due to limited power; however this would have strengthened the argument of top–down expectancies playing a role in the interaction effect in Experiment 1.

The results of Experiment 3 would be predicted on the basis of previous studies that have looked at the importance of load predictability (e.g. Theeuwes et al., 2004). In the final experiment, we randomise emotion but block high and low conflict trials in order to investigate whether removing predictability of emotion alone would be sufficient to abolish the interaction effect.

Experiment 4

Introduction

So far, we show that when both compatibility and emotion are blocked, emotional interference is reduced on incompatible trials but when compatibility and emotion, or compatibility alone, is randomised, the Compatibility × Emotion interaction disappears. In this final experiment, compatibility was blocked but emotion was randomised. In theory this blocked design would still enable anticipatory cognitive mechanisms to differentiate between high and low conflict blocks, and therefore we might expect to see the same results as Experiment 1, regardless of emotion. Although the task differed, utilising perceptual load rather than cognitive conflict, Erthal et al. (2005) found reduced emotional interference (from unpleasant photos) during a difficult bar orientation task relative to an easy one, where perceptual load was blocked but emotion randomised. However, it could be that for the current cognitive conflict task, both compatibility and emotion need to be predictable in order to see the pattern of results in Experiment 1, in which case in the present iteration we would expect results more in line with Experiments 2 and 3.

Method

Participants

A total of 40 participants were recruited in the same manner as for Experiment 1, 2 and 3. One participant was excluded due to error rates 2.5 standard deviations above the group mean. Data from a final sample of 39 participants (6 males, mean age 18.97, SD = 1.37, range = 18-26) were analysed.

Stimuli and procedure

The stimuli, design, and procedure were the same as in Experiments 1, 2 and 3. However the presentation of the stimuli was blocked by Compatibility while Emotion was randomised. Within each block, randomisation was constrained so that no more than three of the same emotion types were presented in
the same block. For example, a compatible block consisting of 8 compatible trials could consist of 3 fear trials, 3 calm trials and 2 anger trials, all of which were randomised within that block.

**Results**

Replicating the results of Experiment 1, 2 and 3, there was a significant main effect of Compatibility ($F(1, 38) = 135.7, p < .001, \eta^2 = .78$) with RTs significantly faster for compatible trials ($M = 729, SD = 120$), compared to incompatible trials ($M = 801, SD = 120; p < .001$). There was also a significant main effect of Emotion ($F(2,76) = 18.69, p < .001$, partial $\eta^2 = .33$) with RTs significantly slower for anger trials ($M = 784, SD = 121$) relative to calm ($M = 758, SD = 120, p < .001$) and fear ($M = 754, SD = 118, p < .001$), however there was no significant difference in RTs between fear and calm ($p > .99$).

As in Experiment 2 and 3, the interaction between Compatibibility and Emotion was non-significant ($F(2, 76) = 1.90, p = .16$, partial $\eta^2 = .05$). Similarly, the post-hoc tests showed no significant difference in the difference in RTs between compatible and incompatible trials when comparing calm (calm compatible: $M = 717, SD = 116$; calm incompatible: $M = 798, SD = 125$; difference: $M = 82, SD = 52$) and fear (fear compatible: $M = 720 ms, SD = 122$; fear incompatible: $M = 787, SD = 114$; difference: $M = 67, SD = 48$; t(38) = 1.58, $p = .37$) and calm and anger (anger compatible: $M = 750, SD = 123$; anger incompatible: $M = 818, SD = 120$; difference: $M = 67, SD = 48$; t(38) = 1.59; $p = .36$) in line with the findings of Experiments 2 and 3. There was also no difference between fear and anger ($t(38) = -.06, p > .99$) (Figure 2(d)).

The z-difference score analysis to control for the main effect of Emotion (as in Experiment 1, 2 and 3) also revealed no significant differences between the emotion conditions ($ps > .29$).

**Discussion**

As with the previous experiments, RTs for incompatible trials were longer compared to compatible trials and RTs to angry faces were longer relative to calm faces and fearful faces, but there were no differences in RT between fear and calm trials. As with Experiments 2 and 3 the interaction between Compatibility and Emotion was not significant and similar patterns were observed across both compatible and incompatible trials, despite load being blocked and thus predictable.

The findings suggest that the interaction effect found in Experiment 1 was not solely due to conflict predictability. The lack of an interaction effect in the present experiment is in line with the behavioural findings of Pessoa, Padmala, and Morland (2005), where facial expression (fearful and neutral) was also randomised within each block of high, medium and low perceptual load trials, and no RT effect was found (though the predicted pattern was seen in amygdala response). Therefore, it appears that trials within a block need to be predictable in both compatibility and emotion domains in the present task in order to obtain the compatibility × emotion effect, presumably via an anticipatory top–down load- and emotion-specific mechanism, implemented when task demands are high. If there is a single change, e.g. an emotional face being followed by a non-emotional face, it may be that this breaks the continuous “expectancy set”.

**General discussion**

In the current study four experiments were conducted to investigate the conditions under which interference from emotional distractors can either be elicited or eliminated. In Experiment 1 we found that while RTs were disproportionately slowed by the presence of angry and fearful faces in the compatible condition, we did not see the same effect in the incompatible condition. There was no difference between anger and calm, and a facilitation effect for fear, with RTs faster for fear than calm, a pattern also seen by Kanske & Kotz (2011a, 2011b). Our task design meant that this somewhat counterintuitive finding could not be explained by perceptual load effects, since perceptual demands were held constant across conflict conditions. However, the blocked task structure employed raised the possibility that participants were engaging in a top–down anticipatory strategy (Cohen & Henik, 2012) enabling them to pre-emptively compensate on the most demanding emotion/high conflict trials (in line with Etkin et al., 2006). We addressed this possibility in a series of three experiments.

In Experiment 2 all trials were randomised, and as predicted we found no disproportionate effect of emotion on low conflict trials, although main effects of both compatibility and emotion were still seen. For the following experiments we systematically investigated whether randomising compatibility (Experiment 3) or emotion (Experiment 4) alone
would be sufficient to abolish the interaction effect. The main analyses in each experiment suggested that randomising either was sufficient to do so, although a subsidiary analysis in Experiment 3, controlling for the main effect of emotion, showed a small interaction effect driven by the fear condition, albeit attenuated relative to Experiment 1. Findings suggest that predictability of both compatibility and emotion is required in order to engage preparatory strategies uniquely tailored to emotion/high conflict task demands within a conflict resolution setting.

We concluded that trials within a block need to be blocked by compatibility and emotion for top–down control to be imposed in a prospective manner and thus for a compatibility × emotion interaction effect to be robustly elicited, at least when perceptual inputs are also closely matched as in the present task. This is perhaps because a single difference from one trial to the next means that it is impossible to prospectively engage the relevant top–down control process specifically aimed at resolving emotional conflict under high cognitive conflict. Indeed, conflict resolution was most difficult when all trials were randomised (and therefore most unpredictable, increasing cognitive load), as evidenced by an increase in RTs of ~50–70 ms for all conditions of Experiment 2 relative to the other three experiments. This is in line with previous studies which have shown that the conflict generated by a preceding incongruent trial activates an anticipatory mechanism, which leads to improved conflict resolution on the next trial (through activation of an inhibitory top–down pathway from the rostral cingulate to the amygdala) (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Etkin et al., 2006). Furthermore, by including a neutral control condition, the results of Sebastian et al. (2017) and the present study suggest that participants may engage an emotion-specific anticipatory control mechanism when there is a response incompatibility.

Taken together, the experiments in the present study demonstrate that top–down anticipatory control mechanisms are an important factor in the extent to which task-irrelevant emotional information influences processing of cognitive conflict. Findings also suggest that when perceptual inputs are matched, cognitive conflict per se may not always influence the extent to which emotion causes interference on a trial by trial basis. This potentially helps to resolve inconsistencies in previous studies. Several previous studies have found increased RT interference by emotion under high cognitive conflict (e.g. Hart et al., 2010; Sommer et al., 2008), and some, including our own work have found decreased interference (e.g. Frühholz et al., 2009; Sebastian et al., 2017; Zinchenko et al., 2015). Our previous finding (Sebastian et al., 2017) represented a puzzle, in that a task manipulating cognitive conflict while closely matching perceptual inputs yielded a pattern of results resembling a perceptual load effect (e.g. similar to Erthal et al., 2005). The results from the current study show that there may be more than one pathway to the observed pattern of results. On perceptual load tasks, perceptual load theory may best explain results, i.e. reduced attentional capacity for processing emotional distractors under high load (Lavie, 2005; Murphy et al., 2016). However, on cognitive conflict tasks, the opportunity to engage control mechanisms prospectively may underpin a superficially similar interaction.

Understanding this may help to impose greater clarity on the existing literature, in which perceptual and cognitive load terms are often used interchangeably (Carretië, 2014); in which little differentiation is made between different types of cognitive load (e.g. cognitive conflict, working memory load); in which cognitive load stimuli include perceptual confounds (see review paper by Benoni & Tsal, 2013; Mitchell et al., 2007), and task stimuli differ unsystematically across studies in terms of task demands and stimulus randomisation. Outcome measures also often differ considerably but are interpreted interchangeably, for example some studies find an interaction effect in amygdala response but not reaction times (or vice versa) (e.g. Lim, Padmala, & Pessoa, 2008; Mitchell et al., 2007), but the relationship between these measures is unclear. Based on our findings, we would predict that for cognitive conflict specifically, when perceptual load is kept constant, and trial order is randomised across emotion, cognitive conflict, or both, then we should not see reduced emotional interference under high load. Rather this effect should be abolished, or even reversed.

A question remains, however, as to why we did not in fact see a reversed interaction effect, in line with some previous studies (e.g. Hart et al., 2010; Sommer et al., 2008) and Desimone and Duncan’s (1995) biased competition model of selective attention, which would suggest that the resource-competing nature of processing negative emotion should drive increased interference under high cognitive conflict. One possibility is that our task was too easy. Error rates and missed trials were low, and so it is possible
that the combined emotion/high conflict condition did not sufficiently tax resources to manifest in increased RTs in these conditions, even in Experiment 2, which was the most demanding task iteration as evidenced by slower RTs overall (although main effects of both emotion and compatibility were seen).

A further outstanding question concerns a minority of papers that have shown decreased interference under emotion/high conflict while pseudorandomising stimuli (Kanske & Kotz, 2011a, 2011b). However, it is worth noting that the shape of the interaction in these papers did not directly mirror those seen in Sebastian et al. (2017) and Experiment 1. Effects were driven by increased RT interference in the neutral/high conflict condition relative to emotion/high load, rather than a relative reduction in RT interference under emotion/high conflict relative to emotion/low conflict. The tasks used were also very different (verbal emotional flanker and auditory Simon task vs. emotional face Simon task; very different timing parameters). Given these differences it is difficult to draw strong conclusions. It may be that the explanation given by the authors (i.e. adaptive triggering of executive attention by salient emotional stimuli to improve conflict resolution) represents a further plausible mechanism underpinning reduced emotional interference under high conflict.

However, the results of the present study cannot tease apart the effects of emotional valence on conflict resolution as only negative emotional stimuli were presented. Findings from previous research have been mixed, with some studies showing that positive targets speed up cognitive conflict processing (Kanske & Kotz, 2011c; Xue et al., 2013), positive non-targets impede conflict processing (Blair et al., 2007; Dreisbach, 2006) or that positive emotions have no influence on this process (Martin & Kerns, 2011; Zinchenko, Obermeier, Kanske, Schröger, & Kotz, 2017a). The inclusion of positive emotional stimuli, alongside negative emotional stimuli, in future studies should help to identify whether all types of emotional stimuli trigger executive attention thereby improving conflict resolution.

Interpersonal characteristics can also modulate the role of emotions on conflict processing (Zinchenko et al., 2017b). For example, using Flanker and Simon tasks, Kanske and Kotz (2012) found that participants high in depression and anxiety showed reduced enhancement of conflict processing in negative emotional stimuli. Therefore, future studies should also consider interpersonal characteristics, such as age and affective symptoms, when examining emotion–cognition interactions. Furthermore, future studies should systematically vary additional factors such as timing parameters (e.g. the timing of emotion presentation and the response-time window), the nature of the emotional stimuli (e.g. real faces, words, sounds, pictures are thought to differ in their emotional value (Okon-Singer, Lichtenstein-Vidne, & Cohen, 2013)) and whether or not emotion is purely task irrelevant, to further elucidate the mechanisms interacting to yield differing patterns of results.

Conclusions

The present study clarifies the circumstances under which emotion interferes with cognitive conflict resolution. Using a blocked design, Experiment 1 found reduced RT interference from emotion under high cognitive conflict. The randomised design in Experiment 2, however, abolished this interaction effect, suggesting that top–down expectancies were generated in Experiment 1 across Emotion/Compatibility. The interaction effect was attenuated in Experiment 3 (randomised compatibility, blocked emotion) and abolished Experiment 4 (randomised emotion, blocked compatibility), demonstrating that top–down anticipation in both domains is required (i.e. blocked compatibility and blocked emotion) in order to engage preparatory strategies, and thus for cognitive conflict to modulate the effects of emotion on task performance. The results of all four experiments therefore suggest that the opportunity to engage top–down control prospectively may underpin reduced interference to emotion under high cognitive conflict.

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Data availability
Data has been made available on the Open Science Framework (https://osf.io/4yp7u/).

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