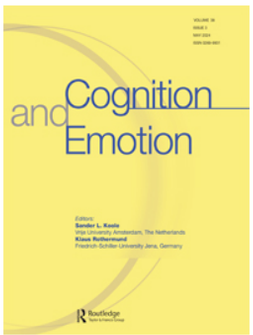

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# Sadness and fear, but not happiness, motivate inhibitory behaviour: the influence of discrete emotions on the executive function of inhibition

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**ABSTRACT**

Inhibition, an executive function, is critical for achieving goals that require suppressing unwanted behaviours, thoughts, or distractions. One hypothesis of the emotion and goal compatibility theory is that emotions of sadness and fear enhance inhibitory control. Across Experiments 1–4, we tested this hypothesis by inducing a happy, sad, fearful, and neutral emotional state prior to completing an inhibition task that indexed a specific facet of inhibition (oculomotor, resisting interference, behavioural, and cognitive). In Experiment 4, we included an anger induction to examine whether valence or motivational-orientation best-predicted performance. We found support that fear and sadness enhanced inhibition except when inhibition required resisting interference. We argue that sadness and fear enhance inhibitory control aiding the detection and analysis of problems (i.e. sadness) or threats (i.e. fear) within one's environment. In sum, this work highlights the importance of identifying how negative emotions can be beneficial for and interact with specific executive functions influencing down-stream processing including attention, cognition, and memory.

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Emotion; inhibition; executive function; motivation

The successful navigation of our environment and pursuit of goals relies on a collection of executive functions. Executive functions enable the focusing of attention, control of behaviour, flexible problem solving, and many other higher-level processes that are critical to everyday life (e.g. Banich, 2009; Inzlicht & Schmeichel, 2012). One important component of executive functioning is inhibition. Inhibition is necessary for achieving and coordinating goal-directed action that requires suppressing behaviours that are inappropriate, unsafe, or no longer required and preventing interference from non-goal relevant stimuli (Aron, 2011; Banich, 2009; Friedman & Miyake, 2004; Nigg, 2000). It is a key factor in everything from successful dieting and academic achievement to restricting the use of stereotypes and biases (e.g. Diamond, 2013; Muraven & Baumeister, 2000).

Emotions influence executive functions (e.g. Mitchell & Phillips, 2007; Storbeck & Maswood, 2016; Yang, Yang, & Isen, 2013) and promote goal-driven behaviour (Lang, 1995; Lench, 2018; Simon, 1967; Storbeck & Wylie, 2018). Interestingly, negative emotions are commonly thought to compete with executive processes for valuable psychological resources and often impair or have no impact on performance (e.g. Ellis & Ashbrook, 1988; Eysenck et al., 2007; Mitchell & Phillips, 2007; Pessoa, 2009). However, this account is incomplete. There are several studies that demonstrate sadness and fear benefit cognition that relies on executive functioning, such as reducing false memories (e.g. Forgas et al., 2005; Storbeck & Clore, 2005), aiding complex problem solving (see Andrews & Thomson, 2009), resisting the use of stereotypes (Bodenhausen,

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1993; Bodenhausen, Kramer, & Susser, 1994; Isbell, 2004), increasing healthier eating (Gerend & Maner, 2011), and facilitating learning (see McLaren & Mackintosh, 2000 and Olsson & Phelps, 2007). We argue that inhibition may be one factor that accounts for the benefit in performance across these tasks by reducing activation of potential memory intrusions and stereotypes, eliminating distractions to maintain focus on complex problems or appropriate behaviour, and limiting generalisation of associative learning. In the present research, we sought to directly examine a novel hypothesis that induced emotional states of sadness and fear *enhance* inhibition performance compared to happy and neutral-induced emotional states. We selected sadness and fear to test and examine whether shared valence (negative) and motivation orientation (withdrawal) would be a stronger predictor of behaviour compared to discrete or functionalist perspective of emotion.

## Inhibitory processes

While evidence suggests that inhibition consists of a network localised within the right inferior frontal and dorsomedial frontal cortex (pre-supplemental motor area) (Aron, 2011; Aron et al., 2004; Chikazoe et al., 2007), there is uncertainty around how the inhibition system is structured and organised (see Friedman & Miyake, 2004; Miyake & Friedman, 2012; Nigg, 2000, 2017; Schall, Palmeri, & Logan, 2017, for the various perspectives). Here, we adopted Nigg's framework, which proposes that there are four types of inhibition: (1) *interference control* (e.g. resisting interference from distracting, irrelevant information; example tasks include negative priming and Eriksen flanker); (2) *cognitive inhibition* (e.g. resisting intrusions from information that was previously relevant; example tasks include backward inhibition, Brown-Peterson variant, and cued recall); (3) *behavioural inhibition* (e.g. deliberate suppression of dominant or automatic motor responses; example tasks include stop-signal, Stroop, go/no-go); and (4) *oculomotor inhibition* (e.g. deliberate suppression of dominant or automatic visual responses; example task is anti-saccade). These four types of inhibition allow us to compare whether emotion has a unifying influence on inhibition (e.g. sadness influences all inhibition tasks) or has a selective influence on inhibition (e.g. sadness enhances cognitive inhibition, but not interference control). We do note that we selected this model due to its broad perspective of inhibition allowing us to begin to understand if emotion has a broad or narrow influence on inhibition. Newer research has not supported this framework (see Nigg, 2017), and there is still uncertainty as to whether inhibition is an independent executive function (Aron, 2011; Friedman & Miyake, 2017), an independent executive function with distinct subfactors (e.g. Nigg, 2017; Tiego et al., 2018), or not an independent function that instead is part of a common executive functioning (EF) factor (Friedman & Miyake, 2017).

## Emotion and inhibition

Existing theories and research generally observe that induced emotional states of happiness (as opposed to happiness-related targets or distracting stimuli) enhance executive functions (Ashby et al., 1999; Fredrickson, 2001; Gray, 2001; Mitchell & Phillips, 2007). In contrast, induced states of sadness and fear either have minimal (sadness) or an impairing (fear) influence on executive functions (Gray, 2001; Mitchell & Phillips, 2007; Pessoa, 2009). When it comes to specific executive functioning domains, happiness enhances shifting or cognitive flexibility, executive attention, and reactive control (Chiew & Braver, 2014; Dreisbach, 2006; Frober & Dreisbach, 2012; Gray, 2001; Kuhl & Kazen, 1999; Storbeck et al., 2015; Van Wouwe et al., 2011; Yang et al., 2013), but it impairs proactive control and resisting interference (Dreisbach, 2006; Frober & Dreisbach, 2012, 2014; Martin & Kerns, 2011; Phillips et al., 2002). Sadness enhances proactive control (Gray, 2001; Kuhbandner & Zehetleitner, 2011; Van Steenbergen et al., 2010) and attentional control (Jefferies et al., 2008), and often performs similarly to a neutral condition on cognitive flexibility, shifting, executive control, and reactive control (Dreisbach, 2006; Martin & Kerns, 2011; Mitchell & Phillips, 2007). This research suggests that affective states of positive and negative affect have varied effects on different aspects of executive functions, and few studies have directly examined how induced states of emotion or affect influence inhibition.

To our knowledge, there is currently no comprehensive framework for explaining how and which emotions interact with inhibition. Various theories, however, have touched upon inhibition indirectly. For instance, affective tuning-models, such as affect-as-information (see Clore et al., 2001; Clore & Huntsinger, 2007), propose that during task situations, positive affect serves as feedback to continue

engaging in the current or default processing style (e.g. relational processing); whereas negative affect serves as feedback to stop or inhibit the default processing style and engage in referential or item-specific processing. Similarly, Dreisbach and colleagues have proposed a flexibility-maintenance model of control with positive affect facilitating flexibility at the cost of maintenance capability relative to neutral and negative affective states (Dreisbach, 2006; Dreisbach & Goschke, 2004). This model emphasises how positive affect promotes greater flexibility with an underlying assumption that negative affect biases processing towards maintenance capability at the cost of flexibility. These theories indirectly implicate inhibition-like processes but do not identify a specific underlying mechanism. Moreover, these models focus on valence and often do not test whether other aspects of affect better predict behaviour (e.g. motivation, arousal). New evidence stemming from a functionalists' approach suggests that discrete emotions may better predict performance for specific cognitive and executive processes (see Storbeck & Wylie, 2018; and Lench, 2018).

The emotion and goal compatibility theory is one theory that aims to make specific predictions for how discrete emotions influence specific executive functions (Storbeck, 2012; Storbeck et al., 2015; Storbeck & Wylie, 2018). The emotion and goal compatibility model posits that emotions promote goal-driven behaviours guided by appraisals, which prioritise specific executive/cognitive processes over other processes to achieve the intended behaviour (Bargh et al., 2001; Kruglanski et al., 2002; Simon, 1967). Emotions consist of several response components including phenomenological, behavioural, and motivational (e.g. Ellsworth, 2013; Lazarus, 1991; Roseman, 2013), and often overlooked in these appraisal models are the underlying cognitions necessary to support subsequent behaviour. Simon (1967) postulated that situations that are appraised similarly over time should elicit the same emotion and corresponding behaviour (and cognitions). For instance, a dangerous environment may elicit fearfulness and freezing behaviour (e.g. Beck et al., 2005; Fanselow, 1994; Phelps & LeDoux, 2005), which we argue would require inhibition. Over time, the emotion, behaviour, and supporting cognitions become coupled together or integrated into a Hebbian-like fashion (Hebb, 1949). Given this integration of emotion and behaviour, we propose that emotions become embodied anticipation of the cognitive (and other) requirements of the situation. Goal integration has two implications, and it is the first implication we are testing in these experiments. First, when emotions correctly anticipate the cognitive requirements of situations (i.e. goal compatibility), performance is enhanced and psychological resources are conserved (e.g. Friston, 2010; Gray, 2004; Gray et al., 2002; Storbeck, 2012). Second, when emotion is integrated with cognition, it serves as a feedback-loop reinforcing their associations, such that fear prioritises inhibition and inhibition activates systems associated with fear.

There is support for the emotion and goal compatibility model for states of happiness and sadness. For instance, happiness fosters behaviours related to exploration, conceptual processing, play, and social connection (Ashby et al., 1999; Fredrickson, 2013; Storbeck & Wylie, 2018). To support such behaviours, happiness, we argue, prioritises executive functions of shifting over stability (Ashby et al., 1999; Dreisbach, 2006), verbal working memory over spatial working memory (Gray, 2001; Storbeck, 2012), semantic accessibility/retrieval (Storbeck & Clore, 2008; Storbeck & Clore, 2005), and executive control (Storbeck & Maswood, 2016; Yang et al., 2013). Sadness arises from a loss, elicits behaviour of inaction, and promotes cognitions focused on error analysis, referential or item-specific processing (Roseman, 2013; Storbeck, 2012). We argue that whereas inaction should elicit greater behavioural and oculomotor inhibition, error analysis should elicit greater cognitive inhibition because of an emphasis on referential and item-specific processes styles limiting conceptual activation. Some support for this claim has already been observed: Research suggests that states of sadness prioritise spatial working memory over verbal working memory (Gray, 2001; Storbeck, 2012), impair shifting of attention (Storbeck et al., 2019), and limit semantic accessibility/retrieval (Storbeck, 2008; Storbeck & Clore, 2005). In contrast, fear arises from threats and often invokes vigilance, threat detection, freezing (or running), narrowed attention, and item-specific processing (Roseman, 2013; Storbeck, 2012). We argue that fear should elicit behavioural and oculomotor inhibition similar to the influence of sadness, but its impact on cognitive and interference inhbition is less clear. Because of the item-specific and narrowed attention, we would predict that fear would enhance cognitive inhibition. We predicted that interference inhibition may be a place where the influence of fear and sadness diverge due to the increased

vigilance and narrow focus of attention of fear states (e.g. Fanselow, 1994; Öhman, 2009). Thus, our primary aim in the present research was to compare and contrast the influence of these two negative emotions on happiness and test whether fear and sadness specifically support the prioritisation of inhibitory functioning as stipulated by the emotion and goal compatibility theory (Storbeck, 2012; Storbeck & Wylie, 2018). Moreover, we selected four different styles of inhibition to further delineate whether sadness and fear elicit a more global inhibition or specific types of inhibition (e.g. oculomotor, behavioural, cognitive, and interference).

## Present research

The main goal of this paper was to examine how the three emotions of happiness, sadness, and fear influence four facets of inhibition across four experiments. A secondary goal, limited to Experiment 4, was to examine whether discrete emotions serve as a better predictor of behaviour than a valence or motivation dimension of emotion by including anger (an approach-oriented, negatively valenced emotion; see Carver & Harmon-Jones, 2009; Coan & Allen, 2003). Overall, we predicted that sadness and fear (compared to happiness, anger, and neutral emotions) would enhance inhibitory control for all four inhibition factors.

Experiments 1–4 had the same design, except that oculomotor (anti-saccade task), behavioural (go-no/go task), interference (negative priming task) and cognitive (backward task) inhibition facets were assessed independently, one in each experiment. Within each experiment, participants started by completing demographic information, then practiced the inhibition task and were then induced into a happy, sad, fearful, or neutral (or anger in Experiment 4) emotional state prior to completing the inhibition task and manipulation check assessment. Lastly, participants completed a variety of personality measures.

### *Experiment 1 – anti-saccade (oculomotor inhibition)*

A sudden onset of a stimulus typically invokes an automatic response to saccade to that stimulus. A saccade is a rapid, reflexive involuntary eye-movement (e.g. Hallett, 1978; Massen, 2004). The anti-saccade task requires participants to inhibit their automatic tendency to saccade to a rapid onset visual cue and instead saccade away from the visual cue to identify the correct orientation of a visual target. We predicted that sadness and fear, compared to happiness and neutral, conditions would enhance oculomotor inhibition (i.e. more accurate anti-saccade performance).

**Transparency and Openness.** We report in each section how we determined sample size, all data exclusions and how many people were excluded in each condition, all manipulations, and all measures in the study (see Footnote 1 for measures not included and why it was removed). Data was analysed as described in each section using SPSS 27.0 and 28.0. The design and analysis were not pre-registered. Additional, information for experimental procedures and data files can be found at the OSF site (https://osf.io/ubezt/).

**Participants**. One hundred forty-seven participants (females = 85, males = 62; $M_{age}$ = 20.65, $SD_{age}$ = 4.07) from Queens College participated for course credit. The City University of New York (CUNY) Institutional Review Board (IRB) approved the study, and all participants provided written consent. Based on our prior research examining emotion and executive functioning where we observed a medium to large effect size of approximately 0.30, we estimated a sample of about 130 participants (G*Power 3.1.9.7; ANOVA: fixed effects, omnibus, one-way with 4 groups; Faul et al., 2007) was required. We typically oversample given our high rate of participant removal due to the demographics of our college population. The sample analysed consisted of 141 participants initially as six individuals (Sad = 1; Neutral = 1; Fear = 4) were removed from the analysis because they either failed to complete the experiment ($n$ = 2) or scored lower than 60% on the anti-saccade task ($n$ = 3; mean accuracy on the task was 0.90, $SD$ = 0.07), or scored lower than 50% on block 2 of the anti-saccade task ($n$ = 1; we presume the participant reversed the keys as their accuracy was 0.37).

#### *Materials*

**Mood Induction.** Thirty-one images were selected for each emotion (sadness, fear, neutral, happiness), and all images were obtained from the International Affective Picture System (IAPS; Lang et al., 1999). For each emotion, images were selected to be thematically consistent with that specific emotion, while limiting the experience of other emotions (categorical ratings were obtained from: Barke et al., 2012; Libkuman et al., 2007). See Table 1 (note) for pictures selected for each emotion condition.

**Table 1.** Mood manipulation check descriptive statistics.

| | Emotion Conditions | | | | |
|---|---|---|---|---|---|
| Variables | Happy | Sad | Fear | Neutral | Anger |
| **Anti-saccade (Exp. 1)** | | | | | |
| Arousal | 3.92 (1.59) | 2.65 (1.63) | 4.11 (1.25) | 3.00 (1.37) | |
| Happiness | 5.00 (0.88) | 1.97 (0.94) | 2.31 (0.83) | 4.06 (1.11) | |
| Sadness | 2.22 (1.06) | 4.50 (1.13) | 3.31 (0.87) | 2.34 (0.97) | |
| Fear | 1.92 (0.86) | 3.26 (1.05) | 4.29 (1.18) | 2.03 (0.89) | |
| Anti-Saccade RT | 521.6 (215.1) | 423.2 (97.3) | 434.4 (66.7) | 488.7 (131.1) | |
| **Negative Priming (Exp. 2)** | | | | | |
| Arousal | 3.13 (1.32) | 2.90 (1.33) | 3.42 (1.35) | 2.58 (1.48) | |
| Happiness | 4.66 (1.15) | 2.00 (0.79) | 2.21 (0.87) | 3.13 (0.94) | |
| Sadness | 1.39 (0.75) | 4.56 (0.99) | 3.66 (1.52) | 2.58 (1.28) | |
| Fear | 1.47 (1.08) | 3.49 (1.73) | 4.16 (1.56) | 2.45 (1.36) | |
| ACC Inhibit | .990 (.041) | .994 (.018) | .995 (.013) | .995 (.012) | |
| ACC Control | .996 (.008) | .995 (.014) | .991 (.021) | .997 (.007) | |
| **Backward Inhibition (Exp. 3)** | | | | | |
| Arousal | 3.14 (1.27) | 3.37 (1.24) | 3.78 (1.57) | 2.53 (1.41) | |
| Happiness | 4.27 (1.19) | 1.97 (0.82) | 2.08 (0.98) | 3.16 (0.82) | |
| Sadness | 1.78 (1.32) | 4.24 (1.44) | 3.16 (1.57) | 2.71 (1.37) | |
| Fear | 1.49 (0.93) | 3.00 (1.58) | 4.24 (1.72) | 2.58 (1.29) | |
| **Go-No/Go (Exp. 4)** | | | | | |
| Arousal | 3.47 (1.57) | 3.26 (1.77) | 3.55 (1.43) | 2.37 (1.30) | 3.77 (1.55) |
| Happiness | 4.72 (1.20) | 2.00 (0.77) | 1.90 (0.79) | 3.33 (0.71) | 1.53 (0.73) |
| Sadness | 1.66 (0.90) | 4.61 (0.84) | 3.71 (1.24) | 2.30 (1.29) | 3.83 (0.87) |
| Fear | 1.66 (1.10) | 3.26 (1.55) | 4.65 (1.20) | 2.53 (1.50) | 3.60 (1.57) |
| Anger | 1.19 (0.54) | 2.97 (1.53) | 3.23 (1.38) | 1.73 (0.98) | 4.73 (1.08) |
| Go Trials ACC | 0.94 (0.09) | 0.97 (0.03) | 0.97 (0.04) | 0.96 (0.06) | .94 (0.07) |
| Go-No/Go RT | 200.2 (29.5) | 211.7 (48.9) | 221.8 (54.0) | 206.2 (41.3) | 209.7 (37.8) |

**Manipulation Check.** The emotion check consisted of a single item asking how the images made them feel, repeated four times with different anchors (Rottenberg et al., 2007). The set of anchors were: not at all happy (1) to very happy (6); not at all sad to very sad; not at all fearful to very fearful; and not at all emotionally aroused to very emotionally aroused.

**Anti-Saccade Task**. This task was adapted from Friedman et al. (2008). Each trial started with a fixation cross in the centre of the screen, which remained on the screen at various durations between 1500 and 3500 msec to prevent anticipation effects. Upon termination of the fixation, a visual cue (a red square) appeared on one side of the screen for 150 msec; upon termination of the visual cue, the target stimulus was presented on the opposite side of the screen for 175 msec. The target stimulus was immediately replaced by a visual mask, which remained on the screen until a response was recorded. The target stimulus consisted of an arrow, pointing left, right, or up, within a white box with a black frame. Participants had to determine the direction of the arrow by pressing the corresponding arrow key on the keyboard. Participants sat approximately 55 cm away from the monitor. The square used for the visual cue and the arrow subtended 0.83 degrees horizontally and vertically. The centre of the square (visual cue/arrow) is subtended 8.63 degrees from the centre of the fixation point to one side of the screen. Accuracy served as the main dependent variable and participants were encouraged to respond correctly rather than respond quickly.

***Procedure***. Participants received an overview of the study followed by the consenting process. Once participants consented, they were randomly assigned to one of the four emotion inductions. Participants began by completing personality and demographic questionnaires. Participants then received instructions concerning the anti-saccade task and completed 20 practice trials. Practice trials were provided prior to the emotion induction to: (1) minimise practice effects on the initial trials, and (2) ensure maximum potency of the emotional induction for the experimental trials of the task. The emotion induction phase followed the practice trials for which participants viewed thirty images (each image presented for 5 sec) and were told to imagine how they would feel in the situation pictured. Following the mood induction, 160 experimental trials (2 blocks of 80 trials with a 10-sec break between blocks) of the

anti-saccade task were completed. The mood manipulation check was then completed. [1]

### Results

**Manipulation Check**. Four independent one-way ANOVAs were run for each emotion check item by emotion condition, and all variables were significant: arousal, $F(3, 137) = 8.105$, $p < 0.001$, $\eta_p^2 = 0.151$; happiness, $F(3, 137) = 82.239$, $p < 0.001$, $\eta_p^2 = 0.643$; sadness, $F(3, 137) = 38.140$, $p < 0.001$, $\eta_p^2 = 0.455$; and fear, $F(3, 137) = 44.40$, $p < 0.001$, $\eta_p^2 = 0.493$. Post-hoc analyses were conducted using Tukey. Each emotion condition reported the highest level of that given emotion (e.g. the happiness condition reported greater happiness than the other three conditions; all $p < .001$). For arousal, people in the sad condition reported lowers levels of arousal than the happy ($p = 0.002$) and fear ($p < 0.001$) conditions; the fear condition reported higher levels of arousal than the neutral condition ($p = 0.010$); and the happy condition reported higher levels of arousal than the neutral condition ($p = 0.044$). See Table 1 for descriptive statistics and see Supplemental Table 1 for post-hoc statistics.

**Anti-Saccade Task**. ***Accuracy.*** We collapsed across blocks (no effect of block, $ps > 0.200$) and ran a one-way ANOVA with emotion as the between-subjects factor assessing accuracy. The Levene's test revealed a significant difference for a lack of equality of error variances, $F(3,137) = 4.822$, $p = 0.003$. Therefore, we ran a Kruskal–Wallis nonparametric test, which yielded a significant effect, $H(3, 141) = 8.931$, $p = 0.030$, for emotion. Pairwise comparisons yielded significant effects in the predicted direction. The fear condition had higher levels of accuracy compared to the neutral, $p = 0.037$, and happy, $p = 0.032$, conditions, and the sad condition had higher levels of accuracy compared to the neutral, $p = 0.038$, and the happy, $p = 0.033$, conditions (see Figure 1 for a graphical representation of the means and see Supplemental Figure 1 for a graph of individual data points by condition).[2]

### Discussion

Individuals exposed to sad or fearful images were more successful at inhibiting automatic tendencies to saccade to a rapidly appearing stimulus than those exposed to happy or neutral pictures. These findings suggest that sadness and fear emotions enhanced the inhibition of oculomotor reflexes that redirect attention away from the intended goal. An induced state of happiness failed to either enhance or impair oculomotor inhibition relative to the neutral state. Thus, for oculomotor inhibition, our hypothesis was supported.

## Experiment 2 – negative priming (resisting interference)

Interference inhibition involves suppressing task-irrelevant stimuli and the negative priming task is commonly used to assess this construct (MacQueen et al., 2003; Tipper, 2001). The goal of the task is to identify the larger of two circles presented for each trial. Trials are paired such that the first of the pair is referred to as the prime (first trial) and the second of the pair is referred to as the probe (second trial). Negative priming results when the inhibited location (smaller circle) for the prime is in the same location as the larger circle for the probe, resulting in slower RT. Control pairs present the larger circle on probe trials in a location not occupied on the preceding prime trial. We predicted that sadness and fear conditions would demonstrate stronger negative priming effects than happiness and neutral conditions.

**Participants**. One hundred fifty-eight participants (females = 107, males = 48; $M_{age} = 20.77$, $SD_{age} = 4.612$) participated in the experiment. The CUNY IRB approved the study, and all participants provided written consent. We followed the same powering procedure as used in Experiment 1 and identified that a sample of 130 participants was required. The sample analysed consisted of 155 participants as three participants (happy = 1; sad = 1; fear = 1) were removed from the analysis due to poor performance on the negative priming task (accuracy < 60%). The mean average accuracy in the remaining sample was 0.993 (SD = 0.0153).

### Materials

The mood induction and manipulation check were identical to the materials used in Experiment 1.

**Negative Priming Task**. This paradigm consisted of four arrows with each arrow pointing out in one of the four cardinal directions (MacQueen et al., 2003). The arrows were 1.2 cm in length and from tip to tip was 3 cm. Three circle sizes were used as targets; .7 , .5 , and .3 cm, representing large, medium, and small, respectively. The large and medium circles were presented on prime slides, and the medium and small circles were presented on probe slides. The circles were presented at the tip of the arrow, and circles were always presented at

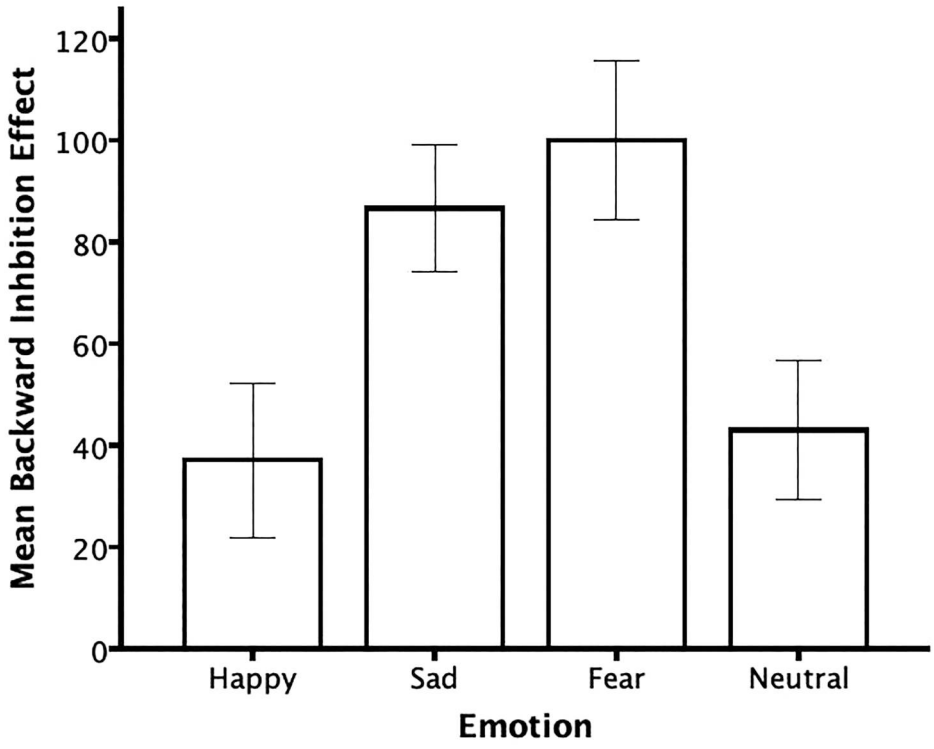


**Figure 1.** The mean percent accuracy is presented for the anti-saccade task across the emotion conditions. The bars represent 1 standard error of the mean.

adjacent arrows (e.g. north and east; east and south; south and west; west and north). Participants were seated 55 cm away from the monitor.

***Procedure***. Procedures were identical to those of Experiment 1 with the exception that participants completed the negative priming task. The goal of the negative priming task was to identify the larger of the two circles. Each trial consisted of a prime slide and a probe slide. There were two trial types; control and negative. Each trial type had the same timing procedure in which the first set of arrows was presented for 1500 msec, and then the two circles were presented (prime slide). After a response was recorded, the arrows were presented alone for 1500 msec followed by the presentation of two circles (probe slide). For the control trials, the two circles for the probe trial were presented in the two locations (e.g. north & east) that were not used in the prime trial (e.g. south & west). For the negative trials, the larger circle of the probe trial (the medium circle) was presented in the same location (e.g. east) as the smaller circle of the prime trial (the medium circle); whereas the smaller circle for the probe trial (e.g. south) was presented opposite to the larger circle presented on the prime trial (e.g. north). For the practice trials, participants completed a total of 18 trials with 12 control trials and 6 negative trials. For the experiment trials, participants completed a total of 120 trials with 80 control trials and 40 negative trials. Participants were told to respond as quickly as possible and, they pressed the arrow key that matched the direction of the arrow that was associated with the larger of the two circles.

## *Results*

**Manipulation Check**. The manipulation check for happiness yielded a significant effect, $F(3, 151) = 62.431$, $p < 0.001$, $\eta_p^2 = 0.554$; however the effect for arousal was not significant, $F(3, 151) = 2.655$, $p = 0.051$, $\eta_p^2 = 0.050$. Sadness (Levene's test: $F(3,151) = 6.028$, $p = 0.001$), and fear (Levene's test: $F(3,151) = 6.346$, $p < 0.001$) failed the assumption of the equality of variances; therefore, a Kruskal–Wallis test was run. Both, sadness, $H(3, 155) = 81.966$, $p < 0.001$, and fear, $H(3, 155) = 55.299$, $p < 0.001$, yielded significant effects as expected. For each emotion condition of

happiness, fear, and sadness those participants reported the highest level of that given emotion, *ps* < 0.040, suggesting the emotion manipulation was successful. See Table 1 for descriptive statistics and see Supplemental Table 2 for post-hoc statistics.

**Negative Priming Task**. The main dependent variable for the task was the negative priming score, which involves subtracting the inhibition probe from control probe RTs (see MacQueen et al., 2003). A one-way ANOVA revealed a significant main effect for emotion influencing the negative priming score, $F(3, 151) = 4.367$, $p = 0.006$, $\eta_p^2 = 0.080$.[3] Contrary to our hypothesis, post-hoc analyses revealed that sadness had a lower negative priming score than happiness, $p = 0.001$, fear, $p = 0.007$, and neutral, $p = 0.015$. No other post-hoc effects reached a level of significance (*ps* > 0.150). See Figure 2 for a graphical representation of the means and see Supplemental Figure 2 for a graph of individual data points by condition.

We assessed the errors to ensure there was no speed-accuracy trade-off, and we ran a repeated measures ANOVA with the trial type (inhibit probe, control probe) x emotion (sad, fear, happy, neutral) with trial type within-subjects and emotions between-subjects factor. There was a significant effect for trial type, with inhibition trials taking longer than control trials, $F(1, 151) = 25.313$, $p < 0.001$, $\eta_p^2 = 0.144$. There was no significant effect of emotion, $F(3, 151) = 0.171$, $p = 0.916$, $\eta_p^2 = 0.003$. There was a significant interaction of trial type and condition, $F(3, 151) = 4.367$, $p = 0.006$, $\eta_p^2 = 0.080$. Paired-samples t-test revealed that only the sad condition did not yield a difference in RT between the Inhibition Probes and the Control Probes, $t(38) = -.0546$, $p = 0.588$. For all other emotion conditions, Inhibition Probe trials took longer to complete than Control Probe trials (happy: $t(37) = 3.525$, $p = 0.001$; fear: $t(37) = 3.296$, $p = 0.002$; neutral: $t(39) = 3.638$, $p = 0.001$).

### *Discussion*

Contrary to prediction, happiness, fear, and neutral conditions all revealed similar levels of negative

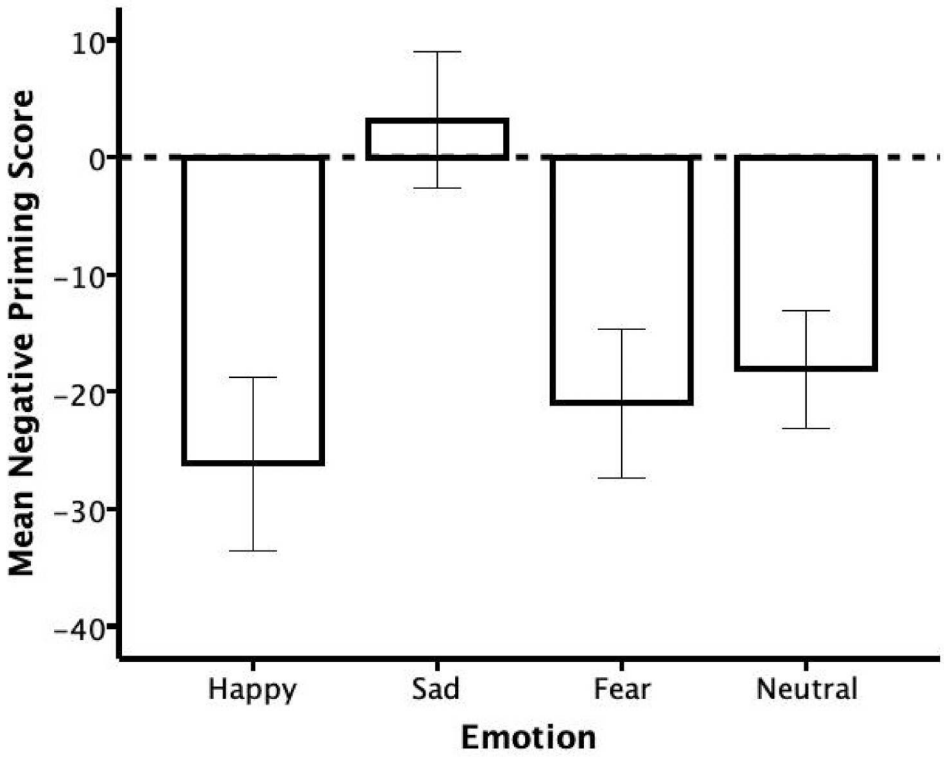


**Figure 2.** The mean negative priming effect in milliseconds is presented for the negative priming task across the emotion conditions. A score of zero (dashed horizontal line) signifies the absence of a negative priming effect and a score in the negative direction signifies negative priming. The bars represent 1 standard error of the mean.

priming compared to sadness. Moreover, sadness, which was expected to produce a robust negative priming effect, resulted in impaired interference resolution compared to all other conditions. One possibility is that sadness ignores the prime trial and treats the probe trial as a new set. Examining the reaction times, only the sadness condition showed no response differences between the prime and probe trials. Such findings have been observed before in that induced states of sadness reduced semantic priming effects, such that responding was not faster when a semantically related prime preceded the target (see Strobeck & Clore, 2008). This account would be consistent with theoretical interpretations that negative affect prioritises referential, local, or accommodative processing styles (e.g. Clore et al., 2001; Forgas et al., 2005; Schwarz, 2011), which suggests inhibiting non-relevant associative information.

## Experiment 3 – backward inhibition (Cognitive inhibition)

Cognitive inhibition involves the suppression of one goal set facilitating the transition to another goal set and backward inhibition is a commonly used task to index this construct (Houghton & Tipper, 1994; Mayr & Keele, 2000). For the backward inhibition task, the goal set was defined by a stimulus feature (shape, size, orientation), and the task was to find the deviant stimulus associated with the current goal set. Backward inhibition is revealed when people respond slower to goal set A (trial n) that was previously relevant (trial n – 2) but inhibited from responding to goal set B (trial n – 1) in a trial sequence such as ABA (and a control trial sequence would be ABC as C is not related to the inhibited goal set A). We predicted that the sadness and fear conditions would reveal stronger backward inhibition than happiness and neutral conditions.

**Participants**. One hundred sixty participants (52 males, 102 females, 1 gender non-defined; $M_{age}$ = 21.11, $SD_{age}$ = 5.53) participated in the study. *A priori* power was calculated following the same procedure from Experiment 1 and identified that a sample of 130 participants was required. The CUNY IRB approved the study, and all participants provided written consent. The sample analysed consisted of 150 participants as five participants (happy = 2; sad = 1; fear = 1; neutral = 1) were removed for poor performance (accuracy < 60%) on the backward inhibition task, and five participants did not finish the study. The mean accuracy for the remaining sample was $M = 0.955$ ($SD = 0.045$).

### Materials

The mood induction and manipulation check were identical to those materials used in Experiment 1.

**Backward Inhibition Task**. The stimuli consisted of three rectangles and one oval (deviant shape) all in blue against a white background. All stimuli were oriented vertically, except for the deviant stimulus, which was tilted 45°. The height for the stimuli was 2 cm except for the shape-deviant stimulus for which the small size was 1 cm and the large size was 3.8 cm. The presentation area consisted of an unseen grid with four quadrants, and a single object was located in the middle of each quadrant (upper left, upper right, lower left, lower right).

***Procedure***. The procedures were identical to those of Experiment 1 except with the backward inhibition task replacing the antisaccade task. The goal of the backward inhibition task was to identify the deviant stimulus, which was dependent on the goal set. Response options were 1 (bottom left), 2 (bottom right), 4 (top left), and 5 (top right) on the number keypad, with the numbers corresponding to the location of the deviant stimulus. Participants were instructed to place their dominant index finger in the middle of the four keys located on the number keypad. A single stimulus was presented in each of the four quadrants, and the location of the stimulus was randomly determined. Each trial started with a blank screen for 100 msec. Then the current goal set was presented by displaying one of the three words ORIENTATION, SHAPE, or SIZE in the middle of the screen for 100 msec. There were two trial types; control and backward. The control trial was a trial for which the trial two trials back were different. For instance, trial 1 had an ORIENTATION cue, trial 2 had a SIZE cue, and trial 3 had a SHAPE cue (trial 3 was different than trial 1). The backward trial was a trial in which the current trial set was the same as two trials back (e.g. trial sequence of ORIENTATION, SIZE, ORIENTATION). There were 50 practice trials and 150 experimental trials with half the trials consisting of control and the other half as backward trials. The goal sets were quasi-random to ensure an equal number of control and inhibition trials.

### Results

**Manipulation Check**. The emotion manipulation check items were all significant: arousal, $F(3, 146) = 5.464$, $p = 0.001$, $\eta_p^2 = 0.101$; happiness, $F(3, 146) = 46.225$, $p < 0.001$, $\eta_p^2 = 0.487$; sadness, $F(3, 146) = 19.102$, $p < 0.001$, $\eta_p^2 = 0.282$. The fear condition did not meet the assumption of the equality of variances (Levene's: $F(3, 146) = 7.291$, $p < 0.001$), and a Kruskal–Wallis nonparametric test was run and yielded a significant effect, $H(3,150) = 48.554$, $p < 0.001$. Each emotion condition reported the highest level of that given emotion; all $ps \leq 0.001$. For arousal, all conditions had similar levels of arousal, except that the neutral condition reported lower levels of arousal compared to the sad ($p = 0.042$) and fear ($p = 0.001$) conditions. See Table 1 for descriptive statistics and see Supplemental Table 3 for post-hoc statistics.

**Backward Inhibition Task**. Following the procedures of Mayr and Keele (2000), trials that exceeded 3000 msec (1.5%) and error trials (4.4%) were removed from the analysis. To assess performance on the backward inhibition task, we ran a 3 (Stimulus [size, orientation, shape]) x 2 (Trial [inhibit, control]) x 4 (Emotion [happiness, sadness, fear, neutral]) ANOVA with stimulus and trial as within-subjects factors and emotion as a between-subjects factor. Stimulus type produced a significant main effect, $F(2, 292) = 129.329$, $p < 0.001$, $\eta_p^2 = 0.470$, and post-hoc analyses confirmed that size was associated with the slowest RT, shape the next slowest RT, and orientation with the fastest RT, all $ps < 0.01$. Trial type also produced a significant main effect, $F(1, 146) = 98.248$, $p < 0.001$, $\eta_p^2 = 0.402$, revealing the typical backward inhibition effect with control trials being faster than inhibition trials. Critically, as predicted, the trial type by emotion interaction was significant, $F(3, 146) = 4.142$, $p = 0.008$, $\eta_p^2 = 0.078$. There was no effect of emotion, $F(3, 146) = 0.82$, $p = 0.482$, $\eta_p^2 = 0.017$. Stimulus by trial type, $F(2, 292) = 2.059$, $p = 0.129$, $\eta_p^2 = 0.014$, stimulus by emotion, $F(6, 292) = 0.665$, $p = 0.678$, $\eta_p^2 = 0.013$, and stimulus by trial type by emotion, $F(6, 292) = 0.817$, $p = 0.558$, $\eta_p^2 = 0.017$, interactions were all non-significant.

To examine the emotion by trial type interaction, we simplified the analysis by creating a single backward inhibition difference score by subtracting RTs on inhibition trials from control trials, with higher (positive) scores reflecting stronger backward inhibition (reflecting the metric and analysis used in Mayr & Keele, 2000). As expected, there was a significant effect of emotion, $F(3, 146) = 4.827$, $p = 0.003$, $\eta_p^2 = 0.090$.[4] Post-hoc comparisons revealed that fear produced stronger backward inhibition scores than happiness, $p = 0.002$, and neutral, $p = 0.005$. Sadness also produced stronger backward inhibition scores than happiness, $p = 0.015$, and neutral, $p = 0.031$. See Figure 3 for a graphical representation of the means and see Supplemental Figure 3 for a graph of individual data points by condition.

### Discussion

The sadness and fear conditions revealed stronger backward inhibition, which was consistent with our hypothesis that sadness and fear enhance inhibition. Cognitive inhibition is important for facilitating changing cognitive sets and it appears sadness and fear may enhance this process.

## Experiment 4 – go/no-go (behavioural inhibition)

Behavioural inhibition is defined as suppressing automatic or dominant responses and is commonly measured with a go/no-go task (e.g. Friedman & Miyake, 2004; Nigg, 2000). Participants are encouraged to respond rapidly to a single stimulus (A) and refrain from responding to another stimulus (L). The go response becomes the dominant response by forcing participants to respond quickly to a greater number of "go" than "no-go" trials (75% to 25% of trials, respectively). We also included the emotion anger to assess whether valence (positive versus negative emotions) or motivation (approach versus withdrawal emotions) serves as the better predictor for behavioural inhibition (Carver & Harmon-Jones, 2009). It was predicted that withdrawal-oriented emotional states (i.e. sadness and fear) would be more accurate on the task (in particular, inhibiting no-go trials) compared to the approach-oriented (i.e. happy and angry) and neutral conditions.

### Method

**Participants**. One-hundred sixty participants (111 females, 52 males, 3 unreported; $M_{age} = 22.13$, $SD = 6.84$) from Queens College participated for course credit and provided informed consent. Again, we determined this number *a priori* following the same powering procedure from Experiment 1; however, with the additional *anger* condition, we needed a total sample of 140 participants. The CUNY IRB

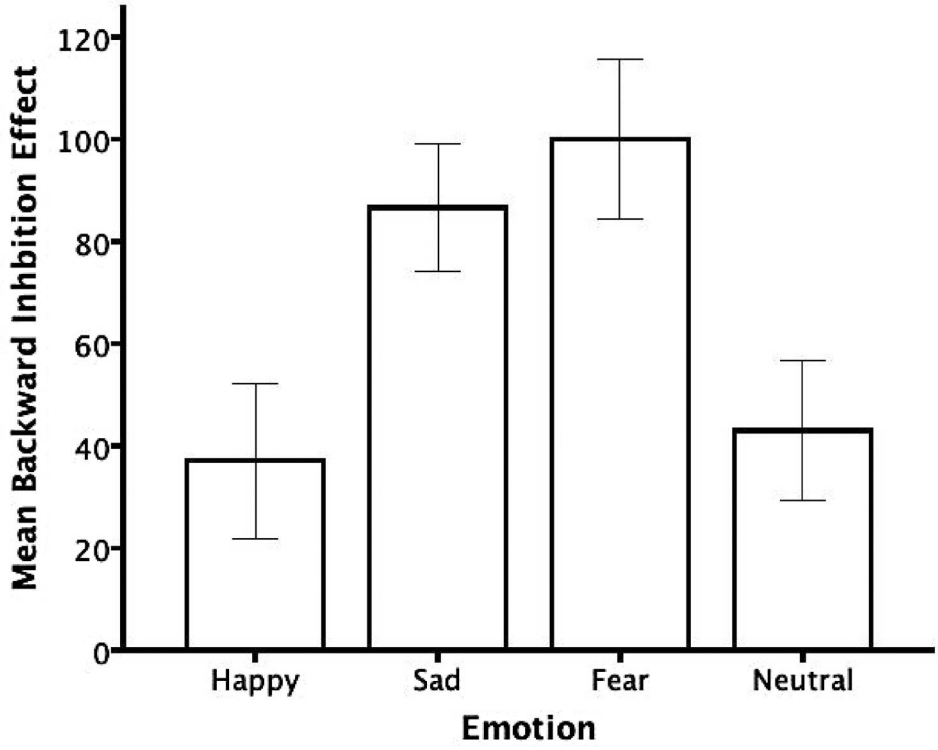


**Figure 3.** The mean backward inhibition effect in milliseconds is presented for the backward inhibition task across the emotion conditions. A score of zero signifies the absence of a backward inhibition effect and a score in the positive direction signifies backward inhibition. The bars represent 1 standard error of the mean.

approved the study, and all participants provided written consent. The sample analysed consisted of 154 participants as six participants (happy = 1; sad = 2; anger = 1; neutral = 2) were removed due to poor performance on the go/no-go task (accuracy < 60%). The mean accuracy on this task was 0.9333 (SD = 0.0599)

### *Materials*

The mood induction and manipulation check were identical to materials used in Experiment 1 with the two following exceptions. Thirty-one angry images were selected from the IAPS to induce an angry emotional state, and an additional item was added to the manipulation check to assess feelings of anger (not at all angry (1) to very angry (7)).

**Go/No-Go Task**. Each trial of the go/no-go task started with the presentation of a fixation for 500 msec followed by the letter "L" or "A" in the middle of the screen (adopted from Falkenstein et al., 1999). The letters cued the participant to either respond by pressing the corresponding key or to withhold from responding. The letter remained on the screen for 200 msec and a blank white screen was displayed. For go trials, there was a 500 msec response window to encourage quick responding, and for no-go trials if a response was not made the trial timed out after 1500 msec. There was a 1000 msec delay between trials.

***Procedure***. Participants completed 20 practice trials and 200 experimental trials of the go/no-go task. For both the practice and experimental trials there were two blocks of 100 trials each (10 trials per block for practice). One block had the A as the go-response, and the other block had the L as the go-response (blocks were randomised). Seventy-five percent of the trials within each block were associated with a go response.

### *Results*

**Manipulation Check**. All one-way ANOVAs for the emotion check items were significant: arousal, $F(4, 149) = 3.781$, $p = 0.006$, $\eta^2 = 0.092$., and anger, $F(4, 149) = 44.107$, $p < 0.001$, $\eta^2 = 0.542$. For happiness

(Levene's $F(4, 149) = 3.562$, $p = 0.008$, $\eta^2 = 0.660$), sadness (Levene's $F(4, 149) = 3.201$, $p = 0.015$, $\eta^2 = 0.530$), fear (Levene's $F(4, 149) = 3.145$, $p = 0.016$, $\eta^2 = 0.350$), and anger (Levene's $F(4, 149) = 9.752$, $p < 0.001$, all groups failed Levene's equality of variances. The Kruskal–Wallis nonparametric test was run for happiness, $H(4,154) = 96.066$, $p < 0.001$, sadness, $H(4, 154) = 79.728$, $p < 0.001$, fear, $H(4, 149) = 54.289$, $p < 0.001$, and anger, $H(4, 154) = 84.567$, $p < 0.001$), and all checks yielded significant main effects. Each emotion condition reported the highest level of that given emotion; all $ps < 0.034$. As for arousal, only the neutral condition was found to be less arousing than every other condition, $ps < 0.029$. All other conditions were similar in arousal ratings. See Table 1 for descriptive statistics and see Supplemental Table 4 for post-hoc statistics.

**Go/No-Go Task**. ***Accuracy.*** We first assessed whether block interacted with emotion, and the interaction was not significant, $F(4, 149) = 1.148$, $p = 0.336$, $\eta^2 = 0.030$, therefore, we collapsed across the blocks. A one-way between-subjects ANOVA (with five levels: happiness, sadness, fear, anger and neutral) was run to assess whether emotion influenced accuracy on the go/no-go task. As predicted, a main effect was observed, $F(4, 149) = 2.732$, $p = 0.031$, $\eta^2 = 0.068$. Post-hoc analyses confirmed that the sadness condition was more accurate than the anger, $p = 0.033$, and happiness, $p = 0.020$, conditions. Moreover, the fear condition was more accurate than the anger, $p = 0.023$, and the happiness, $p = 0.014$, conditions. No other conditions were different from one another, including the neutral condition, $ps > 0.160$. See Figure 4 for a graphical representation of the means and see Supplemental Figure 4 for a graph of individual data points by condition.

We also examined accuracy independently for go and no-go trials. The design had a high percent (75) of go responses, which makes withholding a response during no-go trials more challenging (i.e. more errors on no-go trials). Thus, it is predicted the emotion should have a stronger influence on the NoGo accuracy. Performance on the no-go trials was influenced by emotion, $F(1, 149) = 3.591$, $p = 0.008$, $\eta^2 = 0.088$. Post-hoc analyses confirmed that the sadness condition had greater success inhibiting during no-go trials compared to the anger (marginal), $p = 0.056$, neutral, $p = 0.043$, and happiness, $p = 0.006$, conditions. Moreover, the fear condition had greater success inhibiting no-go trials compared to the anger, $p = 0.035$, neutral, $p = 0.026$, and happiness, $p = 0.003$, conditions. No other comparisons were significant, $p > 0.400$. Accuracy on the go trials was not influenced by emotion, $F(1, 149) = 1.877$, $p = 0.117$, $\eta^2 = 0.048$. See Table 1 for the descriptive statistics for the go trials.

***RT.*** We ran an analysis to determine whether reaction time was influenced by block and emotion conditions. The effect of block, $F(1, 149) = 1.399$, $p = 0.239$, $\eta^2 = 0.009$, emotion, $F(4, 149) = 1.074$, $p = 0.371$, $\eta^2 = 0.028$, and the interaction term, $F(4, 149) = 0.604$, $p = 0.661$, $\eta^2 = 0.016$, were all non-significant.

### *Discussion*

Sadness and fear conditions were more accurate when asked to withhold from responding only on *no-go trials* compared to happiness and neutral conditions. The fear condition also revealed higher levels of accuracy only for *no-go trials* when compared to anger. Critically, the anger condition performed similarly to the happiness condition, which suggests that motivation (approach vs. withdrawal), compared to valence, may be a more important factor for predicting how emotion influences behaviour.

## General discussion

The overall goal was to examine how induced states of happiness, fear, and sadness influenced various facets of inhibition. In general, fear and sadness improved oculomotor (anti-saccade task), behavioural (go/no-go task; no-go trials), and cognitive (backward inhibition task) inhibition compared to happiness and neutral conditions. Sadness was associated with impaired interference inhibition, whereas happiness, fear, and neutral had similar levels of interference inhibition (negative priming task). Moreover, in Experiment 4 (go/no-go task; no-go trials), an induced state of anger impaired behavioural inhibition compared to fear and sadness (marginally), suggesting that valence may not be the best predictor of inhibition performance *per se*. In sum, the evidence suggests that fear and sadness enhanced oculomotor, behavioural, and cognition inhibition, whereas happiness failed to enhance or impair all types of inhibition processes.

The emotion and goal compatibility theory was partially supported in that the negative emotions of fear and sadness enhanced various facets of inhibition. The initial model of the emotion and goal compatibility theory was agnostic with respect to specifying which emotions should benefit which

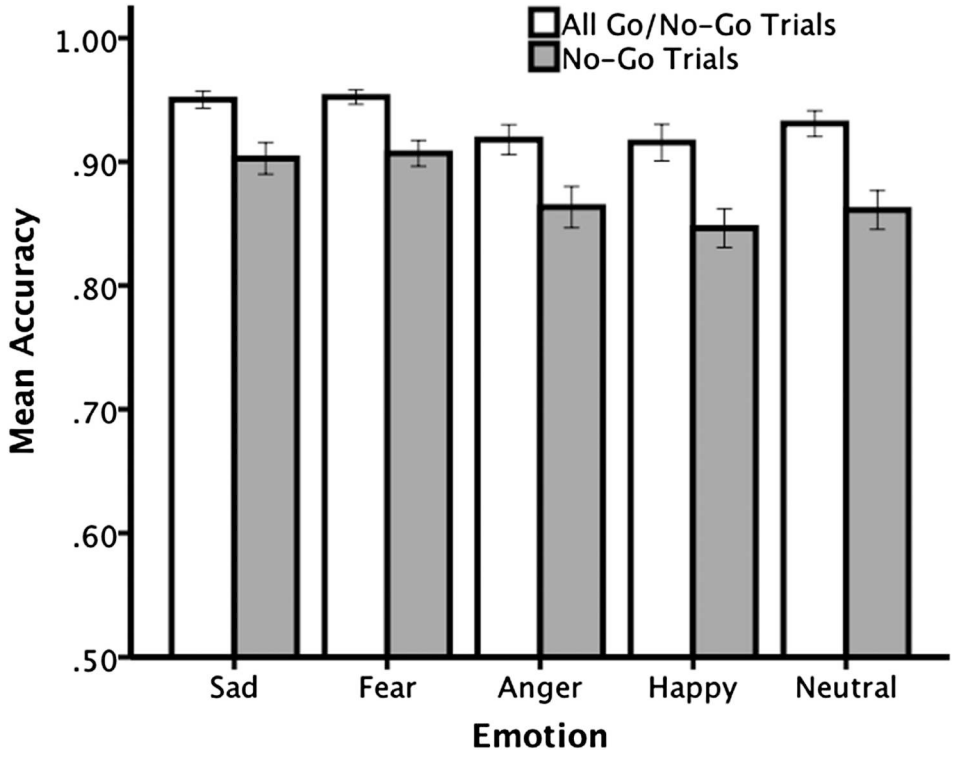


**Figure 4.** The mean percent accuracy is presented for the go/no-go task (white bars) and the no-go trials (grey bars) across the emotion conditions. The bars represent 1 standard error of the mean.

executive functions (Storbeck, 2012; Storbeck et al., 2015; Storbeck & Watson, 2014); rather, the model broadly suggested that approach-motivated emotions would prioritise and benefit executive functions of verbal working memory, shifting (cognitive flexibility), planning, and executive control, whereas withdrawal-motivated emotions would prioritise and benefit the executive functions of spatial working memory, inhibition, and monitoring. The present study provided support that fear and sadness, both withdrawal-motivated emotions, prioritised and benefited inhibition. These benefits were demonstrated when compared to happiness (approach-oriented) and neutral emotional states and to an anger emotional state (approach-oriented) in the behavioural inhibition experiment.

The other theories mentioned in the introduction lack a specific prediction for inhibition. With that said, the neuropsychological theory of positive affect (Ashby et al., 1999), and the broaden-and-build theory (Fredrickson, 2001) emphasise how positive affect enhances cognitive flexibility (shifting), working memory, or executive control albeit due to different mechanisms. Even considering that positive affect enhances working memory capacity (e.g. Yang et al., 2012) and resilience (e.g. Fredrickson, 2001), neither of these processes facilitated inhibition performance when people were induced into a happiness state. Similarly, the flexibility-stability theory suggests a continuum of flexibility-stability, with a positive affect enhancing flexibility at the expense of stability (Dreisbach, 2006; Dreisbach & Goschke, 2004). If one assumes stability incorporates aspects of inhibition than this theory was supported. Specifically, positive affect shifted processing towards flexibility and away from stability and reduced the capacity to successfully inhibit performance compared to the sad and fear conditions. Theories associated with cognitive tuning (e.g. affect-as-information, affect-as-input, mood-as-input, etc.; Bless, 2001; Clore & Huntsinger, 2007; Martin, 2001; Schwarz, 2011) may also have been supported by the findings. Such tuning models articulate the negative affect serves as a cue signalling to invalidate (or stop) current thoughts and inclinations, and instead promote systematic or item-specific processing. Although such

terminology does not refer to inhibition directly, there appears to be an underlying inhibition-like mechanism at work to *stop* the default processing.

### Implications for inhibition and emotion

The overall results suggest that inhibition or inhibitory control may be too broad of a construct and poorly defined to be conceptualised as a singular construct. The present studies would support such a notion in that the effects of emotion were varied across the studies. Interestingly, the fact that sadness and fear had similar effects across three different tasks does suggest there could be a core inhibition factor. Early models by Nigg (2000) suggested a singular inhibition component with four subprocesses, which we tested in this paper. Conversely, Miyake and colleagues (Friedman & Miyake, 2004, 2017) had participants perform a variety of tasks, including inhibition, shifting, and updating, and their model suggested inhibition was fully encapsulated within executive control with shifting and updating making independent contributions. Our findings are not compatible with this theory as it would have suggested that similar findings would have been observed across the four studies. Newer work by various groups has proposed a middle ground with the hierarchical model (e.g. hierarchical model of inhibitory control, Tiego et al., 2018; see also Kane et al., 2016; Kane & Engle, 2002; Stahl et al., 2014). The hierarchical model proposes that executive control is the governing factor and under its umbrella of control are two independent inhibition factors, response inhibition and attentional inhibition. Response inhibition "refers to the process of countermanding a prepotent motor response", which is tested using non-selective stopping tasks (e.g. antisaccade, go/no-go); and attentional inhibition "refers to the ability to resist interference from stimuli in the external environment", which is tested using interference-based tasks (e.g. the Flanker task, negative priming, backward inhibition) (Tiego et al., 2018, p. 2). Under this hierarchical model, our data would support the response inhibition component as sadness and fear demonstrated the same influence on response inhibition tasks (i.e. go/no-go and anti-saccade). However, sadness and fear did not demonstrate the same performance for the two tasks that fall under the attentional inhibition tasks (i.e. negative priming and backward inhibition).

Why then were there differences in attentional inhibition? We suggest there are two scenarios that could provide insight into the differences. First, executive control is more associated with attentional inhibition than response inhibition (Tiego et al., 2018). Specific to the negative priming task, researchers have observed that negative priming effects become stronger for individuals with greater working memory capacity (Conway et al., 1999; Rothermund et al., 2005). Furthermore, models created to account for negative priming effects are rooted in a dual-process approach with inhibition being one factor and the other proposed factor including working memory (Chung et al., 2013; Diamond, 2013), working memory capacity (Conway et al., 1999; de Fockert et al., 2010), or memory retrieval (Frings et al., 2007; MacLeod & MacDonald, 2000). Therefore, if there is a requirement for inhibition and executive control, then negative priming may be facilitated with a positive affective state as positive, compared to negative, states have been shown to increase working memory capacity (Storbeck & Maswood, 2015; Yang et al., 2013). Consistent with this interpretation, the happiness condition did demonstrate the strongest negative priming effect albeit not significantly different from fear or the neutral conditions. Therefore, it is quite possible that our negative priming task required both inhibition and executive control limiting performance for those in a sad mood state.

The second scenario for the divergence in results could be due to attention. This negative priming task in part requires encoding the location of both the larger and smaller circle as a unit with a "tag" to respond to the large circle and a "tag" to inhibit the smaller circle (see Milliken et al., 1994 and Mayr & Buchner, 2007). Such a global encoding of the two stimuli requires inhibition, but if encoded at the local level (only attending to a larger circle) inhibition may not be required, as there is no need to suppress the irrelevant stimulus (see Poirel et al., 2014). When the reaction time was examined between the control and inhibition trials only the sadness condition had similar performance supporting such a local processing style. Conversely, the other emotion conditions revealed the typical pattern of slower responding in inhibition trials. Such findings would be consistent with negative affect or sadness fostering local processing (see Clore & Huntsinger, 2007 for a review). Under this scenario, sadness could have encoded the stimuli as entirely separate stimuli, thereby reducing the need to "inhibit the irrelevant location". Moreover, a recent paper by Storbeck

and colleagues (2019) examined the splitting of attention, and they found that happiness and fear were better at splitting foci of attention, whereas sadness impaired the splitting of attention. This finding, although rare that happiness and fear had the same influence on attention, may suggest attention may have influenced the findings as both happiness and fear had similar effects on negative priming. In sum, we cannot clearly articulate why sadness did not demonstrate negative priming, but we do suggest there could be two factors underlying performance differences among the emotional states and future research could try to further understand how emotions influence inhibition tasks that require attentional control.

### *Further considerations*

Overall, the findings suggest that the strongest predictor of inhibition performance was negative, withdrawal-orientated emotions with the exception of interference inhibition. We did further test the motivational account in Experiment 4 by including an angry state, which demonstrated worse inhibition performance compared to both the sad and fear emotional states. When a negative emotion was associated with an approach orientation, inhibition was impaired, suggesting that negative emotions with a withdrawal-orientation are more likely to facilitate inhibition, though not a guarantee given our pattern of findings. It would be important to test other emotions like disgust, which shares valence and motivational qualities with fear but differs in functionality. Likewise, as only one of our experiments included a negative emotion condition with an approach-orientation (anger), additional research is warranted to directly compare approach – and withdrawal-oriented negative emotions across types of inhibition to solidify this assertion. Moreover, it would be important to test anger when it is a withdrawal-oriented emotion or to test whether motivational intensity influences inhibition performance (see Harmon-Jones et al., 2012; Harmon-Jones et al., 2013; Harmon-Jones et al., 2013). A functionalist approach to emotions would suggest that disgust given its different appraisal compared to fear and sadness (see Susskind et al., 2008) may result in different behaviour than a fear or sadness state. Ultimately, we do believe a functionalist approach would be more predictive and informative compared to valence, arousal and motivational orientation or intensity. In consideration of the functionalist approach, it might then better account for the divergent findings of the negative priming task with regard to fear and sadness.

The negative priming task was utilised because it is thought to reflect interference inhibition via negative priming and because no study to date has examined how emotion influences such a task. However, as discussed above, the negative priming task has been highly debated about the executive factors that contribute to performance (see Chung et al., 2013; Tiego et al., 2018; Tipper, 2001). Therefore, future studies could manipulate task demands within a negative priming paradigm (e.g. Chung et al., 2013) to better understand how and when specific emotions would benefit or not task performance. Alternatively, attentional inhibition and response inhibition tasks could be selected to reduce task impurities as such task impurities can reduce internal validity (Tiego et al., 2018). The ideal situation would be to consider running a large sample study that includes a variety of tasks that assess response inhibition, attentional inhibition, and related factors like executive control (measured via working memory capacity) to better understand the relationship among emotion, inhibition, and executive control. The current study could have benefitted from controlling for individual differences in working memory capacity, which may have yielded more pure effects of emotion on inhibition task performance.

### *Summary*

The negatively valenced, withdrawal-related emotions of sadness and fear benefited the inhibition, specifically response inhibition and cognitive inhibition. However, the effect of sadness and fear improving inhibition was not universal across inhibition sub-processes and may suggest that inhibition itself is not a singular factor. Interference inhibition was impaired by sadness and unaffected by happiness and fear. Moreover, we did demonstrate the possibility of a reciprocal relationship between negative affect and inhibition. By identifying such a reciprocal relationship, it may further extend a functionalist approach to emotions suggesting there could be specific relationships between a specific emotion, appraisals, supporting cognitions, and behaviours. If so, this opens the door to better understanding of how emotional disorders like anxiety and depression may result in prolonged states of anxiety and depression if there are reciprocal and reinforcing

links among emotions, cognitions, and behaviours. In sum, we argue and found support that the specific emotions of sadness and fear facilitate various facets of inhibition and engaging in inhibition behaviour may activate negative feelings and cognitions.

### *Context Paragraph*

This manuscript grew out of three independent lines of research, and these lines of research inspired the development of the emotion and goal compatibility theory (Storbeck, 2012; Storbeck & Wylie, 2018). First, the affect-as-information approach suggests that negative affect serves as a stop cue signalling that something is wrong in one's environment. One of our seminal studies found that a simple state of sadness could reduce the robust DRM false memory effect (Storbeck & Clore, 2005), which prompted an exploration that inhibition could be the underlying mechanism associated with sadness. Second, motivation and frontal asymmetries (e.g. approach motivation and left PFC; Coan & Allen, 2003) research observed that motivation frontal asymmetries and specific executive functions reveal shared hemisphere symmetries. Specifically, verbal working memory and approach motivation elicit left frontal activity, whereas spatial working memory and withdrawal motivation elicit right frontal activity. These emotion and EF hemisphere alignments suggest a potential integration of specific motivations and EFs. Third, work by Hebb (1949), Simon (1967), and Friston (2010) shaped our thinking that appraisals elicit emotional states and these states could serve as cues to meet situational demands. Overtime if situations elicit similar appraisals (emotions) and behaviour (e.g. fear and freezing), then overtime a Hebbian network may develop fostering integration among situations, emotions, and behaviour (e.g. fear → inhibition → freezing). The emotion and goal compatibility theory developed from this work, and it currently drives our present work providing testable predictions for which emotions are integrated with specific executive functions. We have revised the model emphasising discrete emotions (functionalist approach) over motivational orientations.

## Notes

1. Experiments 1–4 also included a Stroop task to measure psychological depletion. However, given the issues surrounding the measurement of psychological depletion and replicability, we felt it appropriate to remove this aspect of the study. The Stroop task was completed after the mood manipulation check. Task information and data can be obtained by emailing the corresponding author.
2. Although reaction time (RT) is not the dependent variable of interest, we ran the same analysis as accuracy but with RT. Levine's test revealed a significant effect, $F(3, 137) = 6.027$, $p = 0.001$. The Kruskal-Wallis test yielded a significant effect for emotin, $H(3, 141) = 9.344$, $p = 0.025$. Pairwise comparisons revealed that the sadness condition responded faster than the happy ($p = 0.017$) and neutral ($p = 0.016$) conditions. No other effects were observed ($p$'s > 0.060). Thus, there was no speed-accuracy trade-off, but rather the opposite, sadness was more accurate and produced faster responses.
3. Analysis was also conducted using a repeated measures ANOVA with the Control vs. Inhibition trials entered as within factors and emotion as the between factors. The interaction was significant, $F(3, 151) = 4.367$, $p = 0.006$, $\eta_p^2 = 0.080$. No effect of emotion was observed, $F(3, 151) = 0.326$, $p = 0.807$, $\eta_p^2 = 0.006$. Control trials were faster than inhibition trials, $F(1, 151) = 25.313$, $p < 0.001$, $\eta_p^2 = 0.144$.
4. An additional analysis was conducted using a repeated measures ANOVA with trial type (control vs. inhibition) as the within-subjects variable and emotion condition as the between-subjects variable. The trial type main effect was significant with control trials being faster than inhibition trials, $F(1,146) = 87.934$, $p < 0.001$, $\eta_p^2 = 0.376$. There was a significant emotion by trial type interaction, $F(3, 146) = 4.827$, $p = 0.003$, $\eta_p^2 = 0.090$.

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## Public significance statement

Our work demonstrated that the emotions of sadness and fear, compared to happiness, are beneficial to inhibiting behaviour, and the importance of using different tasks to assess inhibition. States of sadness and fear due to enhanced inhibition may help to reduce distraction of non-goal relevant information, freeze in the presence of danger, and reduce unwanted behaviours. The larger significance of this work suggests that everyday emotions can have powerful influences on our thoughts and behaviour.

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